Project acronym: PROTEIN2FOOD

Project no.: 635727

H2020-SFS-2014-2015/H2020-SFS-2014-2

Start date of project: March 2015

Duration: 5 years

Deliverable 5.2

Report on the methodology applied in this project for Life Cycle and Socio-Economic Assessment

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Date: 16 March 2018

Project co-funded by the European Commission within the Horizon 2020 Program		
Dissemination Level		
PU	Public	X
PP	Restricted to other program participants (including the Commission Services)	
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 635727.

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1. Introduction

Work Package 5 aims to better understand environmental and socio-economic-advantages and disadvantages of plant-based protein-rich food prototypes (innovative food) developed in work package 1-3 of PROTEIN2FOOD (P2F). The potential contribution of those newly developed protein-rich food products to improved sustainability will be examined by a sustainability assessment.

For this purpose, environmental impact profiles of innovative food prototypes covering the whole food supply chain will be generated. These impact profiles will be based on Life Cycle Assessment (LCA) and give - wherever possible - quantitative information on areas for improvement of the innovative food prototypes as well as on the environmental advantages or disadvantages compared to alternative products already existing on the market. Similarly, information on socio-economic aspects will be obtained by the Socio-Economic Assessment (SEA). These two lines of work combined will form the core elements of the sustainability assessment.

In D5.1 terminology was defined to help be clear when talking about food products in the context of the sustainability assessment. The main terms relevant also for D5.2 are shortly repeated here:

The term "**innovative food products**" refer to the protein-rich P2F food prototypes to be developed in this project. In P2F prototype development is carried-out for the following product lines:

- Meat alternatives: spread-like meat and meat analogue (fibre-like meat)
- Bakery products: bread and biscuits (optional)
- Pasta
- Breakfast cereals
- Beverages: vegetable milk and smoothies (optional)
- Infant foods (powder infant formulas)

Among those selected product lines are going to be compared against traditional food product counterparts. The term **"traditional food products"** refers to animal based (meat, sausages, etc.) or plant-based food products (conventional bread, wheat pasta, etc.) which are wide-spread and form part of the traditional (European) diet.

Project partners during the 1st annual meeting in Poland expressed interest that P2F prototypes should also be compared to some of the existing modern food products. The term **"modern food products"** refers to plant-based food products mainly made from soy but also from legumes, buckwheat and amaranth which are already available in many retail outlets but not necessarily "high protein" content products.

This second deliverable presented here describes the specific methodology and assumptions to be applied in the LCA (section 2) and the SEA (section 4) in the context of the P2F project.

Both, LCA and SEA are going to be applied to what was referred to in deliverable 5.1 as technical scenarios which describe defined process chains underlying selected innovative, modern or traditional food products and which are modelled based on product- and process-specific data.

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2. LCA Methodology to be applied in the P2F project

2.1. General Aspects

As a baseline, this LCA takes into consideration ISO 14040/14044, ISO TS 14067, ILCD (EU JRC 2011) and World Food LCA Database as guidelines.

This section and the following ones address the methodological assumptions which are particularly relevant for the product systems examined in the P2F project.

P2F innovative products are developed in laboratories and pilot plants of the project partners. Data needed for LCA calculations are made available by partners based on the processes developed and operated by them. On the other hand, P2F prototypes are to be compared against products already existing on the EU markets. Traditional products like meat or pasta are usually produced under industrial scale conditions which from our experience do not differ too much between the EU countries. Modern (usually soy-based) products are also produced at a commercial scale although potentially not as far developed and high scale as the traditional products. For the purpose of the LCA, it is intended to research and apply data which reasonably reflects these production conditions.

For a fair comparison of P2F prototypes assumptions are applied in order to upscale the laboratory and pilot scale data such that they reflect production conditions at a commercial scale. The approach chosen for this purpose is described in section 2.5.2.3. Conditions at a commercial scale are defined on a case-by-case basis and agreed with respective partners. Details on the application of the upscaling approach described in section 2.5.2.3 will be part of the product and process-specific documentation in the next deliverable D 5.3.

The agricultural production of protein-rich crops as well as feed crops (required for traditional, animal-based reference food products) takes place at many different locations varying for each crop. For this reason, the aim is to model a typical production situation for each crop considering a major geographic region with high production volumes.

A further methodological aspect to consider is the fact that agricultural production and processing of agricultural products usually not only provide one main product but also up to several co-products or by-products. The approach how to handle this multi-functionality of agriculture-based food product systems for LCA purposes needs to be decided upon. This LCA follows the approach described in the World Food LCA Database. "*In WFLDB 'physical causality' is used to define allocation criteria, when a utilization pathway of a product and co-products from a production system is known and clearly defined. If several potential uses exist, it is not possible to define one 'physical causality' that fits for all potential applications and consequently, economic allocation criteria are applied in these cases. Such an approach is consistent with ISO 14044.*" As each food product has specific further products as well as by-products throughout the value chain, a specific documentation related to this aspect will be included in deliverable 5.3.

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2.2. System Boundaries

The study is designed as a ‘cradle-to-gate’ LCA, in other words it includes the cultivation of crops, the extraction and production of raw materials, processing steps from crop processing up to the finished food product at the factory gate, all transports up to the delivery of ingredients and other inputs to the food factory. All energy and raw material pre-chains are included.

Figure 1 and figure 2 provide a schematic flow chart illustrating the system boundaries and the main supply chain steps contained.

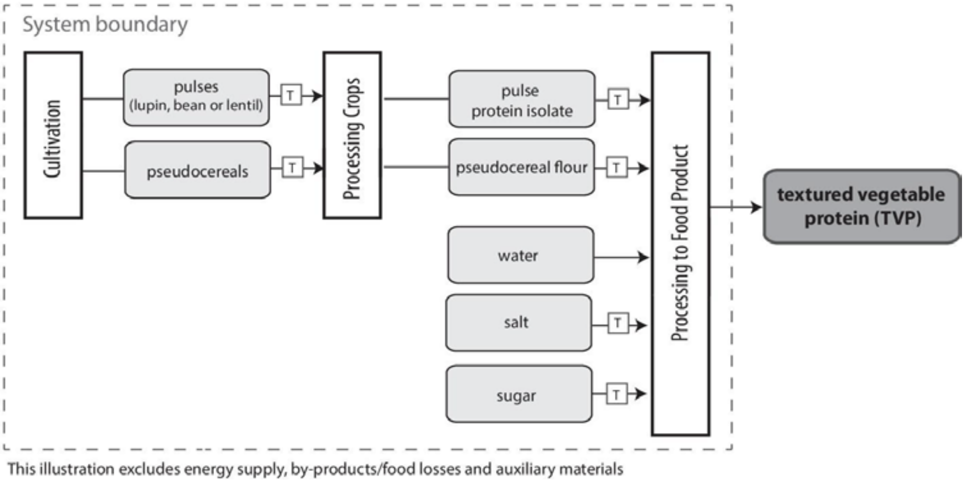

Figure 1: Process flow chart of P2F meat substitute prototype

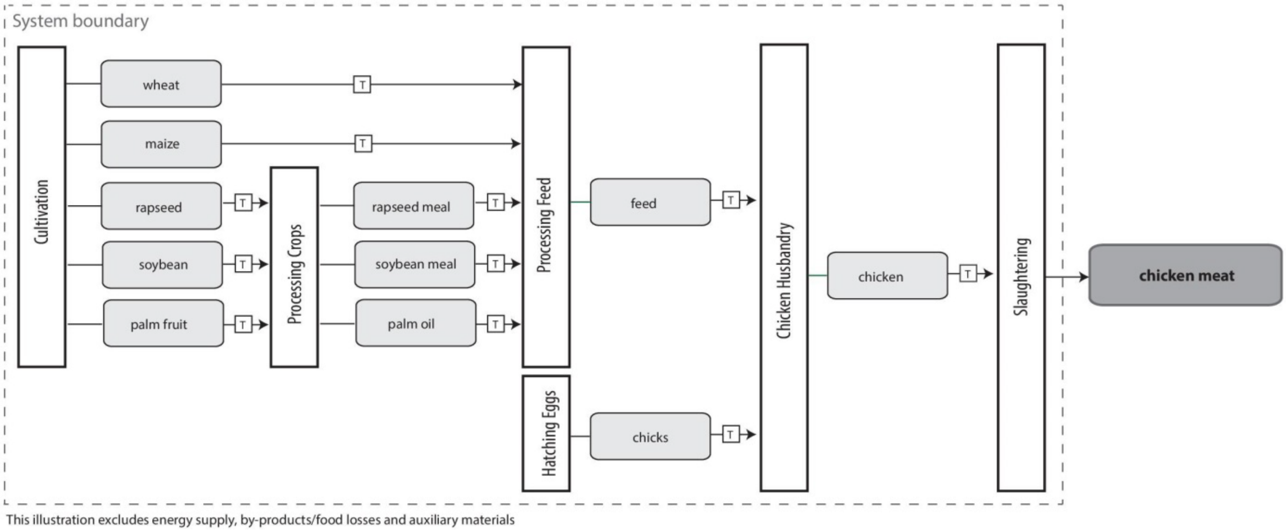

Figure 2: Process flow chart of a traditional fibre meat (chicken) product

The system models will include the processes of all raw material production and processing, energy generation and transportation required throughout the supply chain of each food product

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examined. In the case that no specific data are available, a cut-off will be accepted as long as it can reasonably be assumed that it will contribute to less than 1% of the environmental impact of the product system. For this purpose, a maximum potential environmental impact will be calculated based on best-available knowledge regarding the respective data gap, e.g. based on other processes with similar technology etc. Otherwise proxy data will be used or generated which help to comply with this cut-off criterion.

2.3. Product function and functional unit

The functional unit (FU) is a key element of an LCA. It enables comparison between environmental performances of different systems or options (here: food products) on an equal basis[1] (function). It is therefore crucial to identify an FU appropriate for the comparison of food products[2] developed in the P2F project. The following characteristics can be pointed out for those products:

A. Origin of the products: Innovative and modern food products are solely plant-based, whereas traditional food products can be both: animal- (meat, spread, milk, infant food, egg pasta) as well as plant-based (bread, egg-free pasta, breakfast cereals, biscuits)

B. Innovative and modern plant-based food products, as well as traditional animal-based food products are all protein-rich products

C. Traditional plant-based food products like bread and pasta are particularly rich in carbohydrates

A functional unit referring to the protein or energy content of the food products would be plausible. From a consumer perspective a further aspect comes into consideration. A consumer often simply buys a portioned food item offered on the shelf or purchases a defined amount at the shop counter, which would suggest a comparison of food products based on mass or volume.

Consequently, three distinct functional units are going to be looked at more closely within the LCA.

<u>Protein-based functional unit</u>

A functional unit based on protein content also addresses a fundamental function of food as proteins are the major structural component of muscles and other tissues in the body. In addition, they are used to produce hormones, enzymes and haemoglobin (Hoffman and Falvo 2004). Furthermore, there is a correlation between an adequate protein supply and the intake of other micronutrients and minerals (van Dooren et al. 2017). Yet, a focus on protein content still needs to build on the assumption that the remaining nutritional requirements are satisfied within the overall diet (Kendall and Brodt 2014; Sonesson et al. 2016).

The issue of selecting a functional unit was discussed with the P2F consortium at the annual meeting in Caserta during late May 2017. It was agreed that a protein-based functional unit would

[1] This equal basis is commonly referred to as “function” in LCA language
[2] As stated in deliverable 5.1, environmental impact profiles will be generated for protein-rich food products. Their ingredients are the respective main products of the protein crop processing chain. Consequently, the selection of suitable functional units also refers to those protein-rich (main) food products under examination.

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be the most adequate choice for an LCA of P2F prototype as the focus of prototype development is on protein-rich food products. In addition, supplying the consumer with proteins is the most recognized function of animal-based products (Smetana et al. 2016). The substitution of animal-based food products by innovative food products developed within P2F is one of the major impacts pursued by the P2F project.

Because of the importance of proteins in a human diet they are often used as a proxy for food security. Additionally, proteins are a key factor in food production systems, as they can be produced in very different ways (plant-based and terrestrial or marine animal-based) with different environmental impacts and resource uses. Food security must be achieved with as little environmental impact and resource use as possible. So having tools to measure environmental impact in relation to protein supply should be valuable (Sonesson et al. 2016).

Energy-based functional unit

A functional unit based on the calorific value of a food item address the probably most fundamental function of food which is the supply of energy to maintain the organism functioning, sustain its metabolism and movements. Food energy is an integrated value of products, which is derived from carbohydrates, fats and proteins.

Energy content is an aggregated value it does not reflect the full spectrum of nutritional values (Smetana et al. 2016). Thus, it works for individual food items if assumed that all nutritional requirements are satisfied within the overall diet (Kendall and Brodt 2014; Sonesson et al. 2016).

Mass-based functional unit

This gives a good approximation of how much of a given product a person chooses to eat in a given setting, as it is often the basis for judging a portion size (Quantis 2013). However, it does not reflect specific nutritional aspects of the food.

The mass-based functional unit works well when a whole diet is analysed, given that the nutritional value of compared diets are similar. While this argument does not apply to single food items (as part of an overall diet), as those assessed in the P2F project, it could be assumed that nutritional requirements are satisfied within the overall diet (Kendall and Brodt 2014; Sonesson et al. 2016).

Mass is the most common FU in LCAs of food products (Kendall and Brodt 2014; Sonesson et al. 2016; Smetana et al. 2016). Choosing a mass-based FU provides the possibility to compare LCA results with those available in literature. Additionally, mass-based FUs are sufficient for many research aims such as identifying system hotspots (Heller et al. 2013)

Table 1 and table 2 show the three functional units exemplarily applied to two P2F prototypes[3]:

[3] The application of the three functional units is shown here exemplarily in order to illustrate the methodology. All product-specific characteristics of the application of the functional units to all of the food products assessed by means of LCA will be documented in the deliverable D5.3

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Case 1 (see table 1) is a fibre-like vegetable meat alternative (VMA-fibre) which is compared to chicken meat and an already existing soy-based (textured soy protein: TSP) alternative. In the mass-based approach the three food products are compared for 100 g weight each.

The comparative numbers for the energy content are derived by taking the energy content of 100g of VMA-FIBRE as a starting point. In addition, the energy content of each of the three food products is required (see numbers in brackets). From there, the amount (mass) need of chicken meat and TSP respectively to obtain the same amount of energy is calculated. More meat and less TSP is needed to achieve the same energy supply as for VMA-FIBRE.

The same procedure applies for protein content. Here more meat and as well as more TSP is needed to achieve the same protein supply as for VMA-FIBRE.

Table 1: Comparison of a variety of FUs, example: substituting animal-based food products

Reference flow of food product / Functional Units	Innovative: VMA-FIBRE[4]	Traditional: Chicken meat	Modern: TSP[5] (Soy chunk)
Energy content (136 kcal) *	100 g (~1360) kcal/kg)	114.3 g (~1190) kcal/kg)	75.1 g (~1810) kcal/kg)
Protein content (30 g) *	100 g (~300 g protein/kg)	140.2 g (~214 g protein/kg)	176.5 g (~170 g protein/kg)
Mass (100g)	100 g	100 g	100 g

Case 2 (see table 2) is that of a protein-rich bread compared to a traditional bread. Here only the comparison based on proteins leads to major differences in the overall mass of product compared. It depends e.g. on the type of diet (animal-based, vegetarian or vegan) up to which point the protein-content actually reflects the functionality of both of the products.

Table 2: Comparison of a variety of FUs, example: substituting plant-based food products

Reference flow of food product / Functional Units	Innovative: protein-rich bread	Traditional: stone baked bread[6]
Energy content (224.4 kcal) *	100 g (~2244 kcal/kg)	102 g (~2200 kcal/kg)
Protein content (11.3 g) *	100 g (~113 g protein/kg)	159.2 g (~71 g protein/kg)
Mass (100g)	100 g	100 g

[4] VMA-FIBRE = vegetable meat alternative, fibre-like
[5] TSP = textured soy protein
[6] 1688 Steinofenbrot, Harry Brot; see Deliverable 5.1
* On the basis of the P2F food product

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Thus, protein content will serve as a base case for the functional unit in order to avoid any bias by this choice, while mass and calorific value will be applied for sensitivity analysis[7] as a supplement.

[7] In LCA studies, sensitivity analysis is applied in order to check the relevance of e.g. key methodological choices to be made within a given LCA study. Such a key methodological choice is the selection of a suitable functional unit. For example, key focus of comparison will be the LCA results based on the function of protein supply, but the relevance of the selection of the protein basis for overall findings will be checked by means of sensitivity analysis based on energy and mass.

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2.4. Environmental Impact Assessment

A set of environmental categories with related category indicators and characterisation models is used to assess the environmental performance of the food product system examined. In the present study, the set of the environmental categories should reflect the environmental issues associated with the production of food products for the European market. Therefore, the selection of relevant environmental impact categories has been made based on the areas of environmental concern of the European agriculture and food sectors.

A. Climate change is causing a wide range of impacts on society and the environment all over Europe. The prevention is a key priority for the European Union. To reduce greenhouse gas emissions, the European Commission launched the first European Climate Change Programme (ECCP) in June 2000 and a second Programme (ECCP II) in October 2005. According to research by EU's Environmental Impact of Products, production of food accounts for close to 30% of the EU total greenhouse gas emissions (European Commission 2006). Meat and derived products have the largest carbon footprint accounting for 70% of total food production (Steinfels et al. 2006), followed by milk products such as butter and cheese (Lee 2013).

B. Biodiversity and ecosystem services are likewise important, as around 30% of the total human-induced global biodiversity loss among flora and fauna is related to livestock production (Westhoek 2011) and maintaining biodiversity provides the basis for all agricultural services (EC 2010). Agriculture is the main driver of biodiversity loss in Europe and will be so for years to come[8]. In the common agricultural policy of the EU, the issue of biodiversity is addressed, for example, by the concept of High Nature Value Farmlands (HNV) (EC 2006).

C. The impact on human health due to air pollutants is also an important issue when looking at agriculture. The air quality in Europe – 2016 report (EEA 2016) says, that "agriculture is the main emitter sector in which emissions of air pollutants have decreased least." This refers to NH_3, CH_4, NMVOC and PM_{10} emissions with following contributions of the agricultural sector in the EU-28 in 2014 (EEA 2016):
   - 52 % of total CH_4 emissions
   - 94 % of total NH_3 emissions
   - 17 % of total PM_{10} emissions (third most important source of PM10 primary emissions in the EU-28)
   - 11 % of total NMVOC emissions

Due to the numerous negative impacts of an intensive livestock production system on the planet's resources and ecosystems, promotion of a more resource-efficient diet in the EU is an urgent priority (Vanham and Bidoglio 2013). Especially, the following resources are important when looking at a sustainable food production:

D. The conservation and management of water resources is an important matter of food production, since the animal products represent more than 50 % of the total EU water footprint (Vanham and Bidoglio 2013).

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[8] http://eeb.org/eu-not-on-track-to-halt-biodiversity-loss/)

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E. The scarcities related to the natural resources fertile land area, energy, phosphorus and nitrogen has been identified by the European Commission as one of the most critical issues for the agricultural production in a 30-40 years perspective (SCAR 2011).

Based on that, for the purpose of this study, the following environmental categories are selected for the environmental assessment in the P2F project:

Emission-related categories

- climate change
- acidification
- terrestrial eutrophication
- aquatic eutrophication
- ozone depletion
- photochemical ozone formation
- particulate matter

Resource-related categories

- water use
- land use
- primary energy consumption
- use of phosphorus

Biodiversity as an overarching area of environmental concern, which is influenced by a lot of emission and resource-related categories factors, will be assessed qualitative as separate category.

A more comprehensive explanation of the impact and inventory categories with their unit of measure and elementary flows is given in section 2.6.

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2.5. Modelling of Life Cycle Inventories

2.5.1. Crop Cultivation

2.5.1.1. General aspects

For the crop cultivation phase, the following sub-processes and key parameters are important:

- Seed demand
- Field work carried out by machinery (tractors etc.)
- Application of fertilizers and their respective production
- Irrigation in case of irrigated crops
- Application of pesticides and other substances and their respective production
- Yield

An overview of the individual sub-models developed in order to build-up the crop cultivation model is given in Figure 3. This figure also exemplarily illustrates the inputs to (e.g. Area, Water) and the outputs from the field (e.g. emissions to air and water) as well as the related elementary flows are taken into consideration.

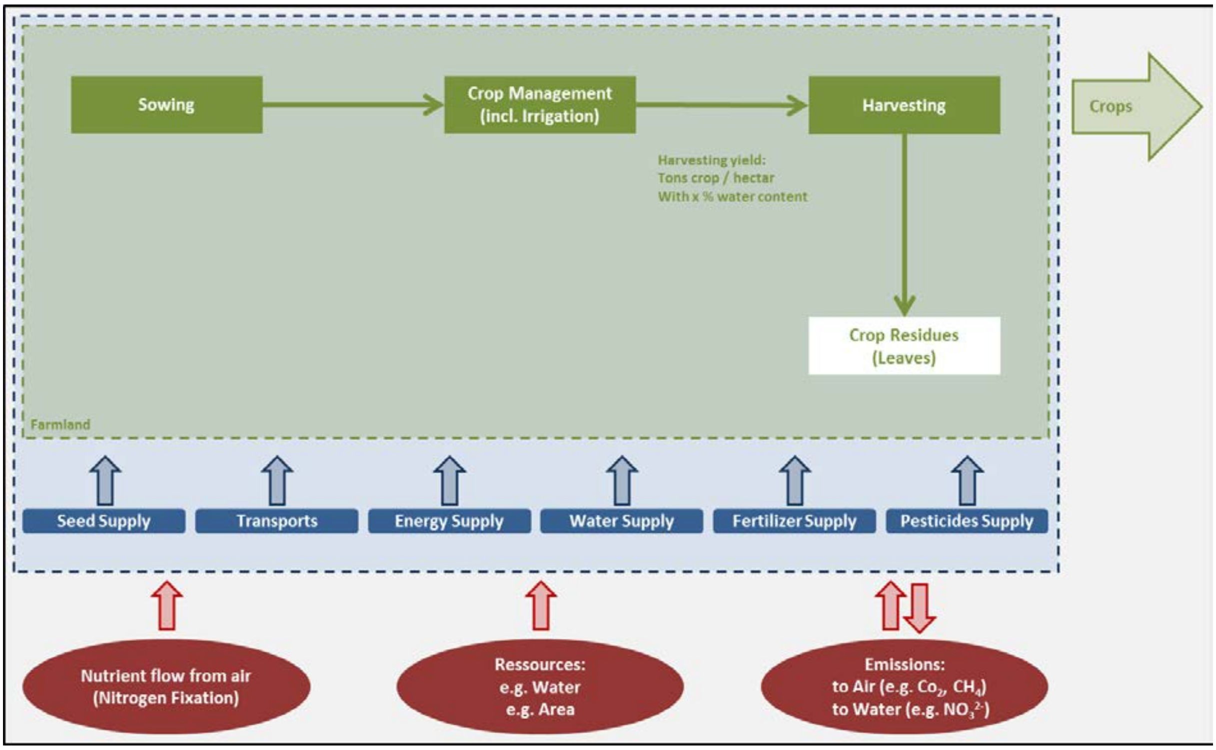

Figure 3: Crop cultivation model

All inputs of those individual sub-models are traced back to their origin, i.e. up to their resources taken from the environment. Residue fractions of the crops (e.g. stems, leaves, pods) on the other hand are assumed to remain on the field. Consequently, all environmental burdens and benefits of the field are assigned to the crops harvested.

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The crop cultivation model is developed under an EU perspective. This means that for crops already under commercial agricultural production within the EU, the aim of the models is to reflect conditions of typical growing regions of a specific crop within Europe. Typical here is to be understood as e.g. the European production country with the largest annual production of the respective crop out of European countries. For more “innovative” crops, the aim is to reflect conditions and regions where those crops are going to grow once established as commodity crops.

Many of the inputs and outputs taken into consideration for the crop production show a variation on the field depending on site-specific characteristics & conditions. An example here would be nitrate leaching from the field into water bodies, which is influenced e.g. by rainfall and/or the time of nitrogen fertilizer application. However, for the purpose of an overall environmental assessment of the cultivation of examined crops in Europe, generic direct field emission models are developed. Related assumptions that form the basis of those generic models are addressed in the following sections from 2.5.1.2 on.

Crop cultivation models developed aim to represent the most probable cultivation variants to be found once the crops are established as commodity crops. For the crops modelled in the P2F project, the most probable cultivation variant is single crop cultivation as this is also the cultivation type predominantly found in crop species currently cultivated as commodity crops in Europe.

As a general rule, all cultivation models assume agricultural good practice, e.g. farming management operations that minimize nitrate losses and maximize nitrogen fixation from air. All yields applied in the crop production models are net yields.

2.5.1.2. Nutrient Cycles

Legumes, which are the key crop class examined in the present project, show some interesting characteristics relative to other crops. More specifically, legumes show several advantages in terms of nutrient cycles on the field. One of the many advantages is, for example, the nitrogen fixation from air, which serves, on the one hand, to cover the nitrogen requirement for plant growth. On the other hand, a part of that nitrogen fixed from air may serve to increase the soil nitrogen pool. In this case, potential follow-up crops (further along the crop rotation schemes) may also show a benefit from the increased nitrogen availability. Other characteristic aspects include the phosphorus mobilization potential of e.g. lupin plants. The latter is related to the deep-growth root system of lupin plants.

Out of these nutrient-related advantages, there are certain aspects that can be quantified and others are more of a qualitative nature.

Figure 4 gives an overview on typical nitrogen flows on the field, using the lupin case as an example.

Nitrogen-related advantages of legumes are implemented in in the crop cultivation models as follows:

The nitrogen fixation from air by legumes can be quantified. A part of the nitrogen fixed remains in the soil pool and is thus available for uptake by follow-up crops. In order to also reflect this benefit of legume crops in a crop rotation in the crop cultivation models, it is assumed that the need for nitrogen fertilizer in the follow-up crops is reduced accordingly. This reduction is

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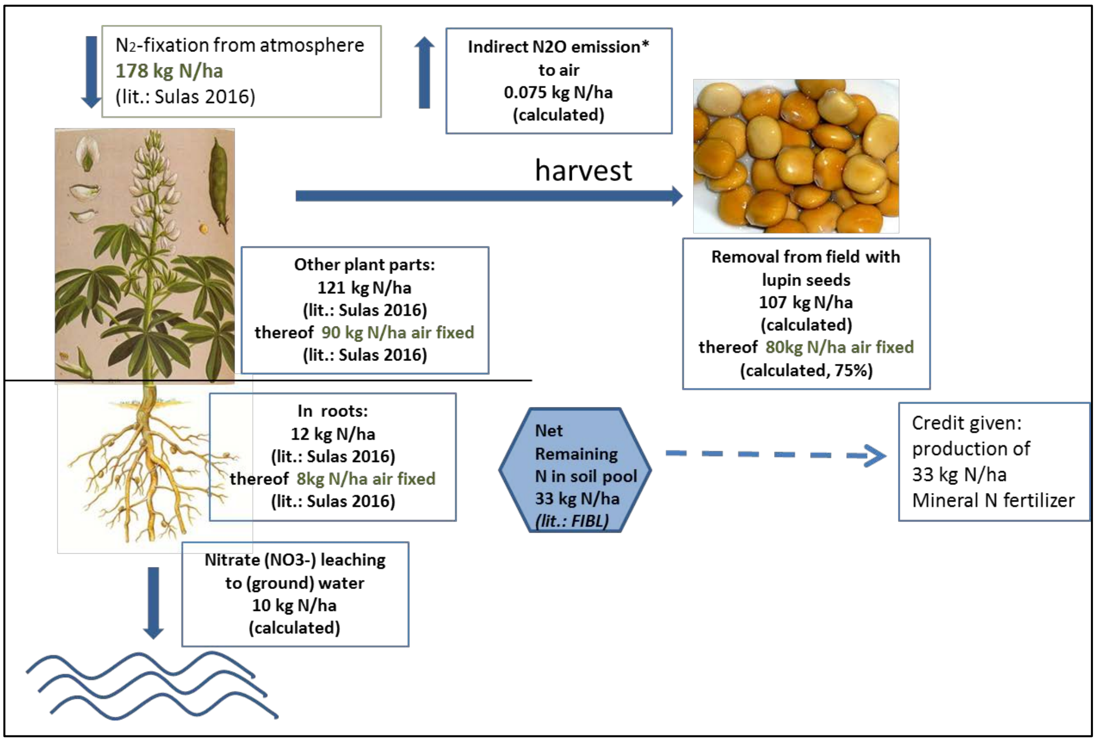
represented in the LCA models by means of a mineral N fertilizer credit given. This is based on the assumption that legumes are cultivated after and before crops with high nitrogen demand like corn which would also be in accordance with agricultural production guidelines developd by WP1 and documented in deliverable D1.X currently under submission. , .



*indirect N2O emission from nitrate leaching

Figure 4: Nitrogen-Cycle of the legume Lupin *L. albus*

2.5.1.3. Direct Field Emissions

Direct field emissions are emissions released directly from the field (e.g. to air and water). Those emissions will vary depending on site-specific characteristics and management types.

Direct field emissions taken into account for the developed crop cultivation models are:

- NH_3 to air
- N_2O to air
- NO_x to air
- CO_2 (from urea fertilization and liming) to air
- NO_3- to water
- PO_4^{3-} to water

2.5.1.4. Handling of Multi-Functionality

The agricultural production on the field is composed of various biomass fractions:

1. The crop cultivation product itself (i.e. the harvested seeds)
2. Further aboveground biomass (i.e. stems, leaves, pods…)

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3. Belowground biomass (roots)

For the crop cultivation models of the present project, the harvested seeds are classified as main product. All further aboveground and belowground biomass parts are classified as residues. It is assumed that all residues remain on the field, thus all burdens related to cultivation are assigned to the harvested seeds.

The field as such is typically cultivated in form of a crop rotation principle. For the purpose of the present study, only the inputs and outputs of one year are taken into account, as those directly refer to the examined crop. However, crop rotation aspects are taken into account in form of air nitrogen fixed by legumes. This nitrogen partly remains in the soil and is thus available for subsequent crops in the crop rotation (see also section 2.5.1.2 nutrient cycles).

2.5.1.5. Land Use Change

Direct land use change is addressed in the crop cultivation models, if deforestation or transformation from secondary forest or grassland into arable land takes place. These are for example important feed crops for animal feed, such as soybean from Brazil.

Due to uncertainties in input parameters for the land use change calculation, the contribution of the environmental impacts related to land use change will be shown separately.

2.5.1.6. Data Gathering and Data Quality

Data collection for the crop cultivation stage is carried out according to the following procedure, with the aim, to collect suitable primary data for crops to be used for innovative food products. Data collection is initiated by the development of data questionnaires.

Data questionnaires developed are illustrated in table 3. Those questionnaires are filled with data points collected by the P2F partners based on their respective field trials and expert judgement. Remaining data gaps are completed by a collection of secondary (literature) data, such as for example the nitrogen remaining in soil after harvesting the legumes.

Further crop cultivation datasets required as raw materials for modern soy products (soybean cultivation in Europe) as well as cultivation of animal feed crops (e.g. soybean cultivation in Brazil) are collected from secondary data sources (scientific literature, LCA databases, other databases)

As a second step, all datasets collected are intensively internally reviewed and relevant plausibility checks are carried out (such as mass flow / nutrient flow checks). As a result, a consolidated set of inventory parameters is achieved for each of the crops examined in the life cycle assessment.

In a third step, the consolidated set of inventory parameters is assessed according to data quality criteria based on requirements according to ISO 14040/14044 series.

Table 4 summarizes the individual data quality aspects for all three groups of crop cultivation datasets. A crop-specific documentation will be part of deliverable 5.3.

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Table 3: Data questionnaires developed for data collection of the crop cultivation stage

1.1 Geographical representativeness (aim for P2F project)	**Unit**
Reference year(s) of data collected or estimated for	
Data representativeness	
Crop management practices	
Soil type	
1.2 Irrigation	
Amount of irrigation water used	m^3 / ha
1.3. Crop management (sowing, fertilizing, weed removal…all operations up to harvesting)	
Diesel from sowing up to harvest (including harvesting)	L / ha
1.4 Cultivation	
Nitrogen fertilizer (total mineral fertilizer as N - or otherwise please specify)	kg N/ ha
Share of Urea-N in above fertilizer-N	%
Potassium fertilizer (as K2O - or otherwise please specify)	kg K2O / ha
Magnesium fertilizer (as MgO - or otherwise please specify)	kg MgO / ha
Phosphorus fertilizer (as P2O5 - or otherwise please specify)	kg P2O5 / ha
Seeds	kg/ha
Pesticides	kg active ingredient / ha
1.5. Harvest	
Crop yield (refers to water content of crop after drying)	kg / ha
Water content of crop at harvest	%
Is the crop dried after harvest (for storage)?	
If yes: water content of crop after drying	%
1.6. Nutrient flows	
Nitrogen fixation from air during plant growth	kg N / ha
Residual nitrogen in soil after harvest	kg N / ha
ADDITIONAL QUESTIONS	
2 Data for nutrient balance calculation	
Clay content of soil	%
Rooting depth of crop	m

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Table 4: Summary of data quality aspects for all three groups of crop cultivation datasets

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	Crops for innovative food prototypes	Crops for modern reference products (soy for human consumption)	Feed crops for animal-based traditional food products
Temporal coverage	2010 – 2016, primary data as up-to-date as possible (predominantly 2015-2016)	2010 – 2014, foreground data as up-to-date as possible	2010 - 2014, foreground data as up-to-date as possible
Geographical coverage	Shall represent typical European conditions (typical yields, average precipitation etc.). Typical is here understood to refer to the regions expected to be most relevant areas of cultivation within the EU. Typical conditions assumed here are agreed with WP1 partners. For means of LCA, simplification is necessary at this point relative to the overall P2F project, where eventually a more comprehensive set of production guidelines on different European countries (e.g. North/South representatives) is to be generated.	Shall represent typical European conditions (typical yields, average precipitation etc.). Typical is here understood to refer to selected regions with the most relevant annual crop production within the EU	Feed crops except soy and palm oil: Shall represent typical European conditions (typical yields, average precipitation etc.). Typical is here understood to refer to selected regions with the most relevant annual crop production within the EU Soy: shall represent typical Brazilian conditions (commercial soy production) as representative for imported feed soy Palm oil: shall represent typical Malaysian conditions (commercial crop production) as representative for imported palm oil
Technological coverage	Shall represent typical European scale cultivation, conventional agriculture, typical use of machinery, general good farming practice	Shall represent typical European scale cultivation, conventional agriculture, general good farming practice, typical use of machinery	Large scale cultivation for imported commodity feed crops (soy and oil palm), as those are very established crops. Typically intensive use of field machinery. Typical European scale for cultivation in case of other feed crops. Conventional agriculture
Precision	Foreground data are a mix of primary data based on P2F partner trials, supplemented with data from crop-specific literature. Relevant assumptions will be assessed by means of sensitivity analysis.	Foreground data: crop-specific literature data	

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Completeness	Aim to have the same completeness for all crop systems, i.e. crop-specific data gaps are closed with proxy data etc. in order to assure completeness All relevant inputs and outputs shall be considered
Representativeness	Shall represent European Commercial crop production
Consistency	Consistent use of related background data, all crops modelled based on the same set of parameters

2.5.2. Crop Processing

2.5.2.1. General aspects

The crop processing phase in this project is understood as the sum of all processing steps required starting from the seeds as harvested from the field until their processed status when they serve as an ingredient for food (e.g. protein isolate) or animal feed (e.g. soy meal), respectively.

Generally, the crop processing stage includes the following sub-processes:

- Cleaning & Sorting of harvested seeds
- Drying of seeds up to a water content suitable for storage
- Drying of seeds up to a water content suitable for wet or dry processing
- Dry processing (e.g. flours)
- Wet processing (e.g. protein isolates)
- Crop crushing (e.g. for oil/meal)
- Feed mixing (e.g. for animal feed)
- Drying of obtained food ingredients if applicable (e.g. protein isolate)
- Transport processes to/in-between above listed processing steps

Figure 5 illustrate the sub-processes implemented in the crop processing model for protein isolate & flour production (for innovative food prototypes), animal feed, and other plant-based raw ingredients (e.g. defatted soy flour for textured soy products).

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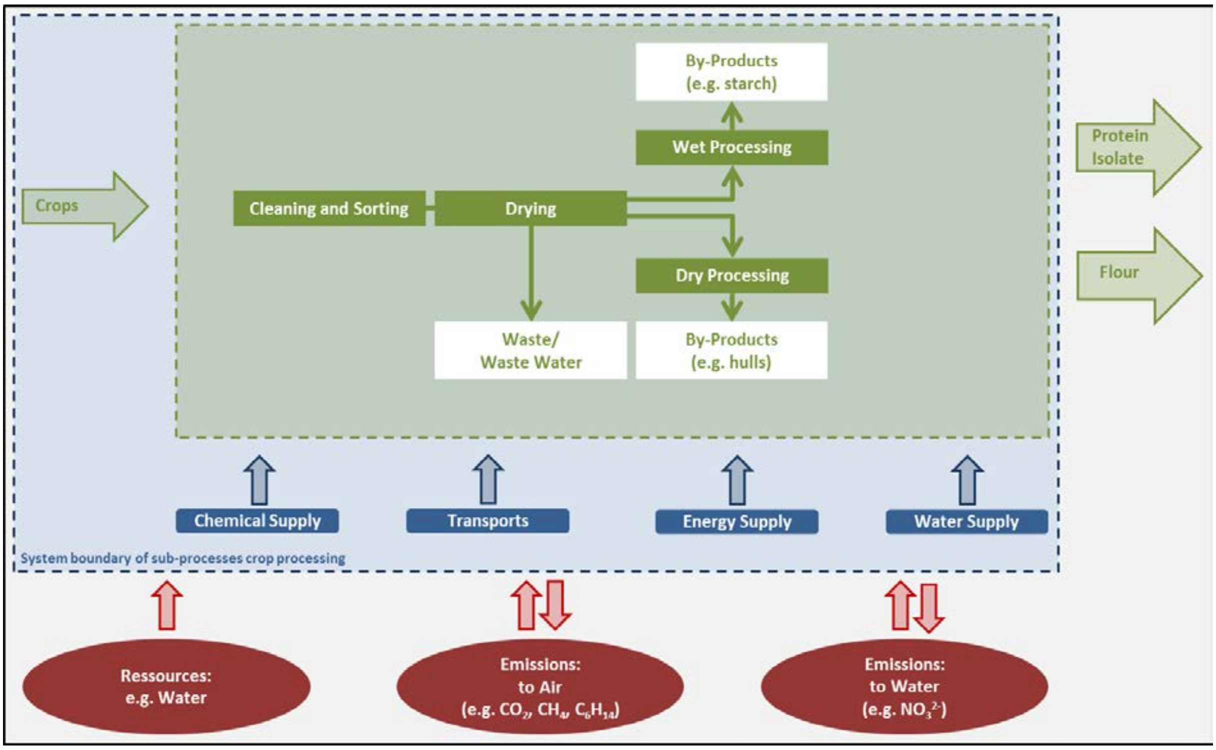

Figure 5: Crop processing model for protein isolate and flour production as ingredients for innovative food products

Wet processing for the production of protein isolate include, e.g. for lupin seeds, following processing steps:

- Dehulling
- Flaking/Milling
- De-Oiling
- Acid extraction
- Protein extraction
- Protein precipitation
- Drying of protein isolate

Dry processing for production of protein-rich flours include, e.g. for amaranth seeds, following two steps:

- Milling
- Sieve classification

2.5.2.2. Handling of Multifunctionality

Crop wet and dry processing steps typically generate not only the desired valuable product, but often also one or more other products with further potential uses. Desired valuable products are in the following referred to as main products, whereas the other valuable products are referred to as by-products. Those by-products may be used in other food products, or processed into other products such as animal feed etc. For an assessment of the environmental impacts of an innovative food product, it is therefore necessary to determine the share of environmental burdens of the

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complete process that should be assigned to the main product as well as the share that should be assigned to by-products.

The general approach followed here is allocation (see also section 2.6). The allocation procedure carried out for the crop processing in the present study can be structured into the following two individual steps:

1. **Classification** into the categories: Main Products, Further products, By-products, Waste

2. **Definition and Application** of allocation criteria for all inputs and outputs of respective processing steps

Figure 6 illustrates, exemplarily for quinoa wet processing, the result of the classification into the main products, by-products and waste.

For the crop processing, economic allocation criteria are applied, as this option well reflects the intended aim to assess an industrial production scale. In case of established processing steps (e.g. oilseed crushing for animal feed), market price average data is collected, and by the combination of mass flow outputs with their respective prices, the allocation factors for the main and by-products are derived. Market price averages are preferred over several years (e.g. 5 years), in order to even out very short-term price change effects.

In case of the innovative crop processing steps, the approach cannot be implemented as easily as for the established processes, as information on potential value and use of further products and by-products due to the novel character of those products is very limited (e.g. starch fractions from protein extraction processes). More research is needed regarding, which products the innovative by-products could be used for and which prices would be possible to be achieved. As a result, currently there are no prices available for those by-products. However, a classification process into “higher-value” further products, “lower-value” further products, as well as “by-products” has been carried out within a working group composed of IVV, UCPH-Food, UCC as well as IFEU. The result of this classification process will serve as the main reference for comparative LCA results. Final confirmation and agreement on the result of this classification process between WP2, WP3 and WP5 is aimed to be achieved at the annual meeting 2018. In order to properly consider this uncertainty in the environmental assessment, variants[9] are furthermore calculated in the LCA models. Those variants cover the full possible range of economic values that by-products may achieve: Their value is assumed to change from 0% of the value of the main product (which corresponds to a classification as waste material) up to 100% of the value of the main product. The latter option means that both the main and by-product are assumed to be products with the same value. Furthermore, this option mathematically corresponds to a mass-based allocation criterion, and the main product would equally share the burdens (e.g. energy consumption, emissions) with the by-products.

[9] Those variants are in LCA language typically referred to as „sensitivity analyses“

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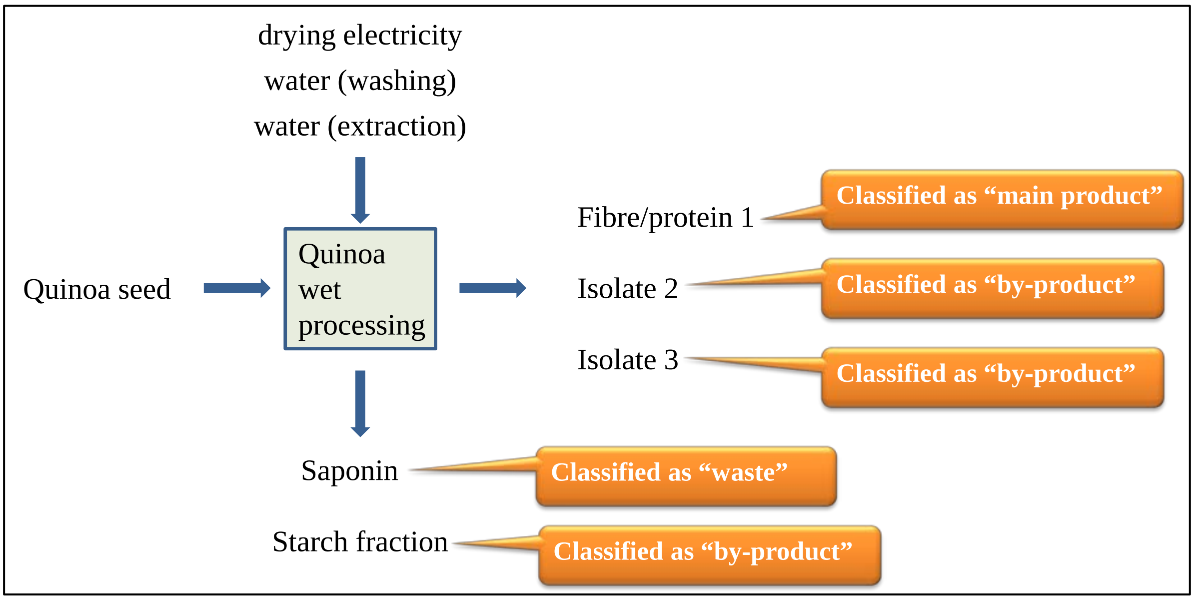

Figure 6: Allocation of crop processing: classification into Main Products, By-products and Waste – example quinoa wet processing

2.5.2.3. Data Gathering and Data Quality

Data collection for the crop processing stage can be classified into two groups, depending on the data requirements for the respective type of food products:

A. For **innovative crop** and **food processing,** unit process data are not available from LCA databases/literature as these products are mostly currently under development by the P2F partners. Consequently, a primary data collection with the help of the project partners procedure carried out.

B. For **modern** and **traditional plant-based food processing** as well as **feed processing** as an upstream process for animal-based food, data is in principle available through collection of specific literature data and/or collection from LCA databases depending on data availability and suitability (e.g. in terms of data quality criteria). Therefore, a secondary data collection procedure is carried out for this group of process data.

A. <u>Primary data collection from P2F partners:</u>

For purpose of the primary data collection, two different questionnaires were developed as a first step:

- **crop processing questionnaire:** collection of unit process data for the individual process steps.
  For the dry processing of quinoa, the process steps de-hulling, milling and classification are comprised.
- **food product processing questionnaire:** collection of unit process data comprising the sum of the processing steps.
  Example: for bread the individual processes of weighing, mixing, forming and baking are comprised.

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The questionnaires developed in order to collect primary data at unit process level are illustrated in Table 5 and Table 6.

Table 5: Extract of the questionnaire developed by ifeu for purpose of the P2Fproject to gather specific information on unit process data. This table contains the input data.

General	Unit	Lab scale	Scale up industrial
Reference year for data collected			
Production capacity of considered facility	kg/year		
Equipment			
Laboratory scale?			
Equipment			
Nominal machine power	kW		
Machine runtime	h/year		
INPUT	**Unit**	**mass flow**	**mass flow**
Raw Material Input			
Washed Amaranth:	kg		
% of water	%		
% of proteins	%		
% of fat	%		
% of starch	%		
Carbon content	%		
Energy/Water input	**Unit**	**mass flow**	**mass flow**
Electric energy	kWh		
Thermal energy	MJ		
Source of thermal energy (natural gas, light fuel oil, …)	-		
Compressed air	Nm^3		
Fresh water use (process water)	L		
Fresh water use (cooling water)	L		
Processing chemicals	**Unit**	**mass flow**	**mass flow**
	kg		

The questionnaires request data on raw material inputs, energy & water inputs, as well as other inputs from technosphere (e.g. processing chemicals if applicable). On the output side, all output mass flows are requested along with some key properties (such as e.g. protein, water content). All data points collected are classified regarding the scale they refer to: lab scale, pilot scale or industrial. Furthermore (and being aware of the limited availability of market prices), prices or estimated values of the main and by-products are asked for from the project partners. They shall help make adequate assumptions in the allocation procedure (see chapter 2.8.2.2. Handling of Multifunctionality)

As a second step, collected datasets are checked by mass balance checks (inputs/outputs balance for overall dry and wet mass flows as well as for key components, such as protein flows) as a plausibility and consistency check.

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In addition, data are cross-checked with literature data related to corresponding or similar processes. Data gaps are then filled with proxy data, literature data, as well as calculations based on machine specifications, etc. The criterion applied here is the best-available dataset in terms of specificity for examined processing step, its geographical coverage and if it is sufficiently up-to-date.

As a third step, a classification of various output streams into "valuable by-products" or "waste fraction" (see section 2.8.2.2) takes place.

Table 6: Extract of the questionnaire developed by ifeu for purpose of the P2F project to gather specific information on unit process data. This table contains the output data.

OUTPUT	Unit	mass flow	mass flow	Price/t
1. Profitable products				
a) Full fat Amaranth flour:	kg			
% of water	%			
% of proteins	%			
% of fat	%			
% of starch	%			
Carbon content	%			
2. By-products				
a)	kg			
b)	kg			
3. Residues (waste)				
a)	kg			
Waste water (process)	L			
Waste water (cooling)	L			

As a result, a consolidated set of calculation parameters is obtained for each of the processing steps. This set has been shared with the partners in order to agree data (including derivations, assumptions, etc.) with the project consortium.

B. Secondary data collection:

The secondary data collection procedure is carried out for modern and traditional plant-based food products and feed crops.

Collection of secondary data is carried out for the individual process steps of crop processing (up to food ingredient or feed). Among the data sources for food processing are databases such as Ecoinvent Version 3.2. and Agrifootprint 2.0. Further data sources are public industry-wide datasets (e.g. unit process data on oil mills commissioned by FEDIOL, the European association of vegetable oil and meal producers). IFEU-internal/in-house datasets were also used to supplement data gaps where the in-house data is more suitable or public literature data missing. An exemplary overview of secondary data collected for feed crop processing is given in the following Table 7.

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Collected secondary datasets are also checked for mass balance and plausibility in order to form a consolidated set of calculation parameters.

Table 7: Example of secondary data collection for feed crop processing data

Feed crop processing	Sources
Feed Composition	Agrifootprint 2.0 (2015)
Feed Amount	Ecoinvent 3.3 (2016)
Oil mills	Based on FEDIOL study (2013)
Feed mixing plants	IFEU-internal/in-house dataset
Price averages in order to derive economic allocation factors	soybean oil and –meal: CBOT[10] rapeseed oil and –meal: MATIF[11] crude palmoil and -kernel: MPOC[12]

[10] Chicago Board of Trade [http://www.indexmundi.com/commodities/?commodity=soybean-meal&currency=brl **and** http://www.indexmundi.com/commodities/?commodity=soybean-oil&currency=brl] last accessed 04/08/2017

[11] Marché à Terme International de France [http://www.indexmundi.com/commodities/?commodity=rapeseed-oil&currency=brl **and** http://www.proplanta.de/Markt-und-Preis/MATIF-Rapsschrot/] last accessed 04/08/2017] last accessed 04/08/2017

[12] Malaysian Palm Oil Council [http://www.mpoc.org.my/Market_Statistics_And_Prices.aspx] last accessed 04/08/2017

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C. Upscaling procedure for primary data calculation parameter sets:

Primary data collected from P2F partners typically refers to pilot (or lab) scale. However, the aim for the environmental assessment is to reflect a situation under small/medium industrial conditions. This shall serve as the main basis of comparison for the technical scenarios. Consequently, a procedure is required in order to derive a small/medium industrial scale dataset using the collected primary data representing the pilot scale as a starting point. The following procedure has been developed as part of the P2F project.

As a first step, the available data collected at pilot (lab) scale is intensively reviewed and analyzed in terms of its main/key contributing parameters. Parameters related to overall mass flows (e.g. energy for dehulling of grains) as well as specific mass flows (eg. energy for drying of protein fractions) are identified as relevant key characteristics with a significant influence on the overall environmental performance. Furthermore, energy efficiency aspects are also key contributing parameters. Based on those observations, the following key system parameters are selected in a second step to be adjusted in order to reflect the small/medium industrial scale[13]

- Decrease of protein loss to hull fractions for de-hulled crops (e.g. lupin)
- Decrease of protein loss to by-product fractions (e.g. % protein in starch by-product fractions, e.g. quinoa)
- Increase of protein drying yields (ex. lupin)
- Increase of energy efficiency (ex. de-oiling)

As a result of the upscaling procedure, a dataset reflecting small/medium industrial scale is generated. This will serve as reference for the technical scenarios, which is compared to the modern and traditional reference products.

In a third step, the consolidated set of inventory parameters, aimed to reflect small/medium industrial scale, is assessed according to data quality criteria based on requirements according to ISO 14040/14044 series.

The following table 8 summarizes the individual data quality aspects for all three groups of crop processing datasets.

[13] Note: the list named here is of preliminary nature and may be revised / extended in further course of the P2F project

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Table 8: Requirements on data quality for plant-based processing

Parameter	Innovative	Traditional/Modern	Animal feed
Temporal coverage	Primary data developed in context of P2F project (predominantly developed in 2015-2017)	Data used shall be as new as possible (2010 – 2016).	
Geographical coverage	Preferably data representing typical European conditions shall be used. Background data (e.g. electricity prechains) shall refer to Europe (EU)		
	Typical European data shall be applied regarding provision of process stream and power grid, as well as upstream chains from auxiliary material input		Soy mills: predominantly Europe, with some share of Brazilian soy mills Palm oil mills: Malaysia Background data (e.g. electricity supply adjusted to specific countries (Brazil, Malaysia etc.)

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Technological coverage	Lab/pilot scale; derived small/medium scale industrial	Medium/Large-scale industrial	Large-scale industrial (e.g. oil mills FEDIOL)
Precision	Foreground: primary data sources Assumptions regarding data will be assessed within a sensitivity analyses (allocation variants based on prices for byproducts, …)	Best-available secondary data, mostly from peer-reviewed literature	
Completeness	Processing data gaps where primary data is missing, will be filled with secondary data sources Data shall be checked with P2F partners for correctness and completeness	All relevant upstream processes/inputs and direct emissions shall be considered.	
Representativeness	Europe		Europe + imported soybeans/soybean meal (Brazil) + imported palm oil (Malaysia)
Consistency	aim for primary data: input/output balance checks regarding dry and wet mass flows, as well as consistent specific nutrient flows (fat, protein, starch etc.) , then in the LCA model supplemented by the respective background datasets in order to assure consistent LCA models.	“unit process data” taken from databases and literature, then in the LCA model supplemented by the respective background datasets in order to assure consistent LCA models.	

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2.5.3. Animal Husbandry

2.5.3.1. General aspects

Animal husbandry is a relevant life cycle step when assessing the environmental performance of animal-based reference products, such as meat and milk. This section provides a documentation of the general LCA methodology related to animal husbandry as applied in this study. The methodology is illustrated with chicken husbandry as an example. The general approach is accordingly valid for pig and cow husbandry. Additional methodological aspects which are very specific for the individual animal classes examined in this study (besides chicken those are pigs and cows[14]) will be documented in the life cycle inventory part of deliverable D5.3 along with the LCA results.

Generally the animal husbandry stage includes the following sub-processes:

- Transports of feed components to feed mill,
- Feed mill,
- Energy for stables,
- Manure storage,
- Manure application,
- Chick hatching including animal husbandry for broiler parents (including their complete feed prechains etc.) (applicable for chicken)
- Parent animals husbandry (applicable for cows, pigs) & related complete feed prechains
- Slaughterhouse (slaughter line + cooling only)

Figure 7 illustrates the sub-processes implemented in the animal husbandry model, exemplarily for chicken in this case.

[14] Chicken husbandry and meat is included for comparison of the fibre-like meat P2F prototype, and pig husbandry and meat with respect to the spread-like P2F prototype. Milk cow husbandry is included for comparison with P2F prototypes sought to substitute cow milk.

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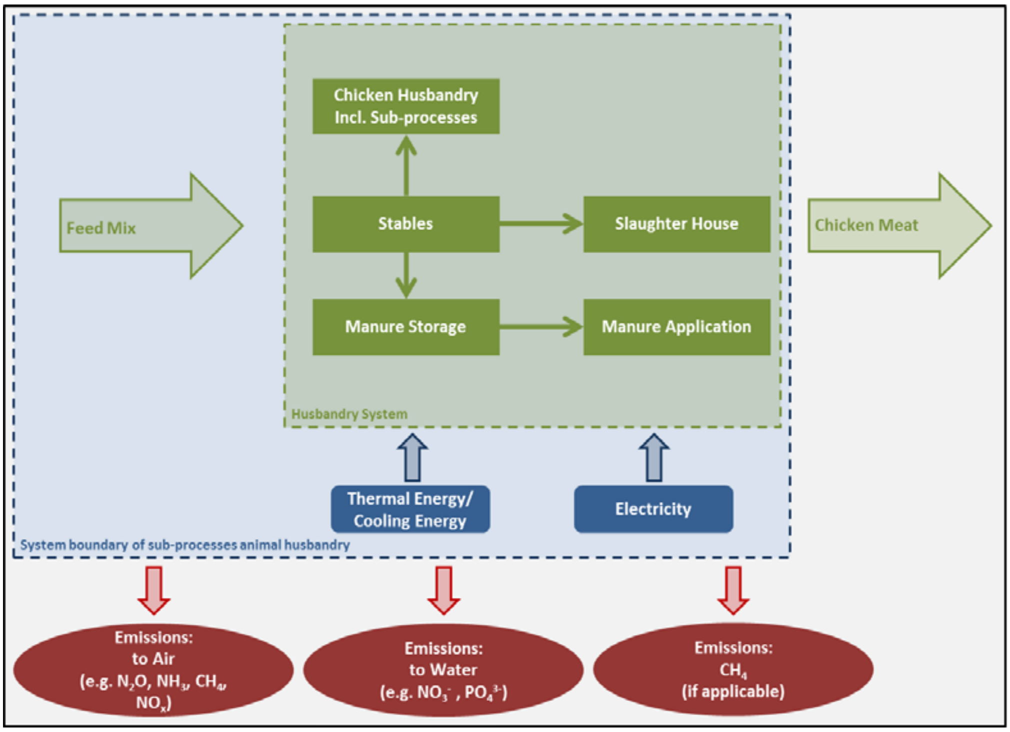

Figure 7: Animal husbandry model exemplarily for chicken

2.5.3.2. Feed Modelling

Feed upstream processing is an important element for the environmental assessment of an animal-based reference food product, such as meat and milk.

The following table 9 provides an overview on the feed mix as assumed for chicken husbandry (broiler feed). Adequate feed mixes and amounts are applied in the animal husbandry models while differentiating between the individual needs of chicken, pigs and milk cows. Feed mix and amounts are such to reflect industrial meat and milk production based on intensive animal husbandry prevalent within the EU by market share.

Table 9: Feed mix as applied for chicken husbandry

Feed component	% share in feed mix	Origin crop	Processing region
Soy meal	29.18%	Brazil	26.1% Brazil 73.9% Europe
Rapeseed meal	12.82%	Europe	Europe
Palm oil	11.16%	Malaysia	Malaysia
Wheat	21.95%	Europe	Europe
Corn	24.88%	Europe	Europe

As animal feed raw materials are typically globally traded goods, a typical upstream supply chain is implemented in the LCA model. For the chicken example, this is represented by the assumption

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that soy-based feed components typically originate from Brazil. Furthermore it is assumed for the LCA model that palm oil as feed ingredient originates from Malaysia.

Oil milling for the feed ingredients is assumed to take place partly in the country of origin (e.g. for soy feed products partly in Brazil). In case of palm oil, it is assumed that it is fully produced in the country of origin (Malaysia).

2.5.3.3. Emissions

Direct emissions from animal husbandry are released directly from the stables and related manure management. Those emissions will vary depending on site-specific characteristics and management options. For purpose of the animal models in the current project, typical conditions for intensive animal husbandry in Europe are assumed. The following emissions are considered (if applicable):

- On pasture (if applicable)
- In stables
- Manure management
- CH_4 from enteric fermentation if applicable
- Direct Air emissions: NH_3, N_2O, CH_4,
- Direct Emissions to water: NO_3, PO_4
- NH_3 losses from manure storage
- From manure application: N_2O, NO_x, NH_3

2.5.3.4. Handling of Multi-Functionality

In the following, chicken meat is used as example to describe handling of multi-functionality.

The animal husbandry stage leads to several by-products in the slaughterhouse. Besides the fresh chicken meat (= main product), typical by-products are:

- Food-grade by-products
- Feed-grade by-products
- Other by-products

Consequently, the environmental burdens need to be assigned between the main product chicken meat and the respective by-products. This is carried out by application of economic allocation factors, as this is clearly the main key driver for the operation of slaughterhouse. Therefore, the authors of the present study assess the economic allocation method as the most suitable one. Specific allocation factors will be part of the documentation in D5.3.

The application of animal manure on the agricultural fields leads to a nutrient input on the field as well as application-related emissions. As the manure can support the nutrient demand of a crop being grown on that field, the LCA model takes into account a credit for saved nitrogen fertilizer.

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2.5.3.5. Land Use Change (LUC)

Land use change effects are relevant for feed crop cultivation. For more information, please refer to section 2.8.1.5 in the chapter “Crop cultivation”.

2.5.3.6. Data Gathering and Data Quality

Required unit process data for the animal husbandry stage is in principle available through collection of specific literature and/or data collection from LCA databases depending on data availability and suitability (e.g. in terms of data quality criteria).

For this reason, a secondary data collection procedure is carried out.

Among the data sources for the animal husbandry stage and processing to food product for traditional animal-based reference products (meat, spread, and milk), databases such as Ecoinvent 3.2 and Agrifootprint 2.2 as well as ifeu-internal/in-house datasets are used.

An additional literature research for validating, updating and adjusting the data was also carried out. For this purpose, peer-reviewed journal articles are predominantly referred to as data sources. Journal articles are also used to close specific gaps on individual data points that could not be covered by unit process datasets taken from databases. For example, the mortality during transportation of broilers to slaughterhouse is not specified by unit process datasets. It is, therefore, taken from two articles Mitchell et al. (2009) and Vecerek et al. (2016).

An exemplary overview on secondary data collected for chicken meat is given in the following table 10.

Table 10: Example of secondary data collection for chicken husbandry

Processing of chicken meat	Sources
Egg Hatchery	Agrifootprint: Broiler parents <20 weeks, breeding, at farm, NL Broiler parents <20 weeks, for slaughter, at farm, NL One-day-chickens, at hatchery, NL
Chicken Broiler Husbandry	Ecoinvent Chicken Production (2012), GLO[15]
Credit from Manure Manure Storage and Application	ifeu-internal/in-house dataset
Slaughterhouse	Agrifootprint Chicken Meat in Slaughterhouse, NL (only slaughter line, without packaging)

[15] Obtained from international literature sources on raising of poultry from 1994-2008.

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The collected unit process datasets for the animal husbandry stage are assessed according to data quality criteria based on requirements according to ISO 14040/14044 series.

The following Table 11 summarizes the individual data quality aspects for animal husbandry using chicken as an example.

Table 11: Requirements on data quality for animal-based food products

Parameter	Animal husbandry - Example: Chicken
Temporal coverage	Data shall be as new as possible (preferably referring to a 2010 – 2016 period).
Geographical coverage	Preferably data representing a typical intensive animal husbandry within Europe. If not possible, global or national (only European countries) process data shall be used.
Technological coverage	Large scale industrial chicken production and slaughtering
Precision	Best-available data, mostly from peer-reviewed literature or established databases
Completeness	All relevant processes shall be considered.
Representativeness	Data shall comply with the temporal, geographical and technological coverage. The study shall be representative for European chicken production and slaughtering
Consistency?	"unit process data" level taken from databases and literature, then in the LCA model supplemented by the respective background datasets in order to assure consistent LCA models

2.5.4. Background Processes

Data on the upstream processes of ancillary products (e.g. fertiliser, tractor fuel, pesticides etc.), data on transport and waste processes as well as data on provision and use of electricity and fossil energy carriers are mostly taken from IFEU's internal database (ifeu 2017). These data are continuously updated and have been compiled and validated by ifeu throughout numerous studies. Besides, the datasets have been applied throughout many studies which were conducted in accordance with ISO 14040/44 and accompanied by a critical review process.

Where necessary, these data are supplemented by data from external databases such as ecoinvent V2.2 or V3.2.

The selection of background processes follows the following requirements:

- the used data shall be as up-to-date as possible
- the used data shall meet the geographic scope of the studied product routes
- the process technology underlying the datasets used in the study shall reflect process configurations as well as technical and environmental levels which are adequate for the systems studied and goals of the study

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Where no specific data regarding time period, geography or technology are available in the named databases, datasets are adapted to the specific conditions. In case of necessity, the most suitable available process data is chosen.

In the following, some important aspects of the background process data are addressed:

- **Energy generation – process heat**
  The dataset for process heat provision describes the production of thermal energy in a natural gas boiler with a thermal capacity of 10 MW including the pre-chains of energy sources and auxiliary materials (GEMIS 2001). This boiler represents an average industrial boiler for the supply of process and district heat with a thermal efficiency of 90 %.

- **Energy generation – electricity supply**
  Electric power supply is modelled using either country specific grid electricity mixes or the European electricity mix, since the environmental burdens of power production varies strongly depending on the electricity generation technology. Electric power supply within Europe refers to the European electricity mix. Electricity generation required for oil processing in Brazil and Malaysia is based on the Brazilian or Malaysian supply mix.

  The electricity mixes are obtained from a master network for grid power modelling maintained and annually updated at ifeu as described in (ifeu 2016). It is based on national electricity mix data for the reference year 2012 published by (IEA 2014).

- **Transport**
  <u>Truck:</u> The dataset used is based on standard emission data that were collected, validated, extrapolated and evaluated for the German, Austrian and Swiss Environment Agencies (UBA Berlin, UBA Vienna and BUWAL Bern) in the ‘Handbook of emission factors’ [INFRAS 2010]. The ‘Handbook’ is a database application referring to the year 2009 and giving as a result the transport distance related fuel consumption and the emissions differentiated into lorry size classes and road categories. The emission factors used in this study refer to the year 2008.

  <u>Overseas container ship:</u> The data used for the present study represent freight transport with an overseas container ship (10.5 t/TEU) and a utilisation of capacity by 55 %. Energy use is based on an average fleet composition of this ship category with data taken from (EcoTransIT World 2011). Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on EcoTransIT World (2011). For the consideration of well-to-tank emissions data were taken from IFEU’s internal database.

  <u>Field work machine:</u>
  The data used represent an average European field work machine. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on Borken et al. (1999). For the consideration of well-to-tank emissions data were taken from IFEU’s internal database.

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- **Waste disposal**
  Technologies related to waste disposal are intended to be representative for the current European situation. The share between incineration with/without energy recovery and landfill for the European market is based on the recent data published by Eurostat (2016). Eurostat collects and publishes data on municipal waste generation and treatment in different European countries every year.
  Process data for landfill are based on recent data published in the National Inventories Reports (NIR 2016) and efficiencies of European municipal solid waste incineration plants are based on the European average supported by a report of the European Waste Incineration Plant Operators (CEWEP 2006).

- **Fertilizer and pesticide production**

  Production of fertilizers and pesticides are taken from the Ecoinvent database Version 2.2. The data sets cover the process chain from the raw material extraction and transportation to the production of the respective products.

2.6. Selected Environmental Categories and Indicators

A description of the environmental impact and inventory categories analysed in this study can be found below. The selection of the impact indicators and characterisation models is based on their relevance for the agriculture and food sector. The indicator models are based on current practice in LCA and their applicability with regard to the completeness and availability of the underlying inventory data.

The description of the different categories and their indicators is based on the terminology used by ISO 14044 as well as by the ILCD handbook (EU JRC 2011). Table 12 gives one example on how the terms are used in this study. The results for the impact categories are expressed by category indicators, which represent potential environmental impacts.

Table 12: Applied terms of ISO 14044 for the environmental impact assessment using the impact category stratospheric ozone depletion as an example

Term	Example
Impact category	Stratospheric ozone depletion
LCI results	Amount of ozone depleting gases per functional unit
Characterisation model	Recent semi empirical steady-state model by the World Meteorological Organisation (WMO).
Category indicator	Ozone depletion potential (ODP)
Characterisation factor	Ozone depletion potential ODP_i [kg CFC-11eq. / kg emission i]
Category indicator result	Kilograms of CFC-11-equivalents per functional unit

Table 13 includes an overview of the selected impact and inventory categories, elementary flows per category, unit per functional unit and the characterisation model applied.

As can be seen, the resource-related categories are taken into account as inventory parameters which are not further characterised. The reason for this is that i) the available characterization models are still under methodological development, ii) the inventory data to assess these categories are often missing or not sufficiently differentiated and iii) there may be data asymmetries between data sets. For example, the categories ‘water use’ and ’land use’ do strongly relate to local conditions. The characterization models are still under development and the data available do not include local information or precise enough differentiation between different water types or land use types.

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Table 13: Selected categories and inventory parameters and their assignment to the inventory data calculated in this study

	Elementary flow (examples)	Unit	Characterisation model
Emission-related categories			
Climate change	to air: CO_2*, CH_4**, N_2O, $C_2F_2H_4$, CF_4, CCl_4, C_2F_6, R22	kg CO_2-e/fu	IPCC (2013)
Stratospheric ozone depletion	to air: CFC-11, N_2O, HBFC-123, HCFC-22, Halon-1211, Methyl Bromide, Methyl Chloride, Tetrachloromethane	kg CFC-11-e/fu	WMO (2010)
Photo-oxidant formation	to air: CH_4, NMVOC, Benzene, Formaldehyde, Ethyl acetate, VOC, TOC, Ethanol	kg O_3-e/fu	Carter (2010)
Acidification	to air/water/soil: NOx, NH_3, SO_2, TRS***, HCl, H_2S, HF	kg SO_2-e/fu	Heijungs et al. (1992)
Terrestrial eutrophication	to air/soil: NOx, NH_3, Sox	kg PO_4-e/fu	Heijungs et al. (1992)
Aquatic eutrophication	to water: COD, N, NH_4+, NO_3-, NO_2-, P	kg PO_4-e/fu	Heijungs et al. (1992)
Particulate matter	to air: PM2.5, SO_2, NOX, NH_3, NMVOC	kg PM2,5-e/fu	De Leeuw (2002)
Resource-related categories at inventory level			
Land footprint	use of agricultural area	m^2*a/fu	-
Water footprint	blue and green water use	m^3/fu	-
Cumulated energy demand (CED, total)	hard coal, brown coal, crude oil, natural gas, uranium ore, hydro energy, solar energy, wind energy, biomass	MJ/fu	-
Cumulated energy demand (CED, non-renewable)	hard coal, brown coal, crude oil, natural gas, uranium ore	MJ/fu	-
Cumulated energy demand (CED, renewable)	hydro energy, solar energy, wind energy, biomass	MJ/fu	-
Use of phosphorus	Phosphorus crude ore	kg/fu	-
* CO_2 fossil und biogenic / ** CH_4 fossil und CH_4 biogenic / *** Total Reduced Sulphur			

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2.6.1. Emission related categories

The selected impact categories related to emissions to be assessed in this study are listed and briefly addressed below.

Climate change

Climate change addresses the impact of anthropogenic emissions on the radiative forcing of the atmosphere. Greenhouse gas emissions enhance the radiative forcing, resulting in an increase of the earth's temperature. The characterisation factors applied here are based on the category indicator Global Warming Potential (GWP) for a 100-year time horizon (IPCC 2013). The category indicator results, i.e. GWP results, are expressed as kg CO_2-e per functional unit.

Note on dLUC: Changes of the carbon balance in context of direct land use change (dLUC) can have an impact on the GWP as well. Within this study, a negative CO_2 value for dLUC is accounted for crops where deforestation or transformation from secondary forest or grassland into arable land takes place. This includes for example important feed crops for animal feed, such as soybean from Brazil. Due to uncertainties in input parameters for the land use change calculation, the contribution of the environmental impacts related to land use change will be shown separately

Acidification

Acidification affects aquatic and terrestrial ecosystems by changing the acid-base-equilibrium through the input of acidifying substances. The acidification potential expressed as SO_2-equivalents according to Heijungs et al. (1992) is applied here as category indicator. The unit for the Acidification potential is kg SO_2-e per functional unit.

Eutrophication and oxygen-depletion

Eutrophication describes the excessive supply of nutrients (inorganic phosphorus (P) and nitrogen (N) compounds - hereafter referred to as P and N) to surface waters and soils. Increased levels of nutrients primarily stimulate the growth of biomass, which may lead to excess production and thus disrupt the food web with consequences for plant and animal species and the functioning of the entire ecosystem. Both aquatic and terrestrial ecosystems are affected by the supply of nutrients, but in different ways. An increased biomass production in terrestrial ecosystems could have a lasting effect on the sufficient availability of water and other nutrients than nitrogen and could result in potential displacement of species that are adapted to nutrient-poor conditions. Most aquatic ecosystems are primarily affected by excessive production of primary biomass (algae growth), which could lead to secondary effects like oxygen depletion. The Chemical Oxygen Demand (COD) is used as a measure of the possible perturbation of the oxygen levels in surface waters.

The terrestrial eutrophication potential and the aquatic eutrophication potential expressed as kg PO_4-e/functional unit according to Heijungs et al. (1992) are applied as category indicators.

For simplification purposes, the potential impacts of atmospheric nitrogen deposition on oligotrophic waters are included in the impact category terrestrial eutrophication.

Stratospheric ozone depletion (hereafter called ozone depletion)

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Stratospheric ozone depletion (ODP) addresses the anthropogenic impact on the Earth's atmosphere, which leads to the decomposition of naturally present ozone molecules, thus disturbing the molecular equilibrium in the stratosphere. In consequence, increased levels of UV-B radiation reach the Earth's surface, thus causing damage to certain natural resources or human health. In this study, the ozone depletion potential (ODP) compiled by the World Meteorological Organisation (WMO) in 2011 (WMO 2011) is used as category indicator. The unit for Ozone Depletion Potential is kg CFC-11-e/functional unit.

Photochemical-ozone formation

Photochemical-ozone formation also known as summer smog or Los Angeles smog is the photochemical creation of reactive substances (mainly ozone), which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides (NOx) and volatile organic compounds (VOC) in the presence of sunlight.

In this study, 'Maximum Incremental Reactivity' (MIR) developed in the US by William P. L. Carter is applied as the category indicator for the impact category Photo-Oxidant Formation. MIRs expressed as [kg O_3-e / emission $_i$] are used in several reactivity-based VOC regulations by the California Air Resources Board (CARB 1993, 2000). The recent approach of William P. L. Carter includes characterisation factors for individual VOC, unspecified VOC and NOx. The MIRs are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The recent factors applied in this study were published by (Carter 2010). The results reflect the potential where VOC reductions are the most effective for reducing ozone.

Particulate matter

The category covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly (primary particles) or formed from precursors as NO_x and SO_2 (secondary particles). Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Following an approach of De Leeuw (2002), the category indicator aerosol formation potential (AFP) is applied. Within the characterisation model, secondary fine particulates are quantified and aggregated with primary fine particulates as PM2.5 equivalents. This approach addresses the potential impacts on human health and nature independent of the population density.

2.6.2. Resource related categories

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Water footprint

The water footprint is an instrument to analyse the water use and consumption. In this study, the water footprint is measured by accounting for blue water used along the life cycle of the food products examined. Blue water is water withdrawn from rivers, lakes or groundwater. Within this project, ifeu intends to apply the concept of virtual water. For blue water, a differentiation between type (process water and cooling water) and source (surface water, ground water, etc.) is made. The unit is m^3 of water used.

Land footprint

Land use has large impacts on the natural environment, such as decrease in biodiversity due to direct loss of natural area or indirect impacts like area fragmentation, and impacts on the life support function of the biosphere, such as raw materials providing or climate regulation.

For the purpose of this study, only the occupation of agricultural area is considered. The results of this category show the cumulated amount of agricultural area per year (m^2 * a) needed for the production of the food products.

Primary Energy (Cumulative Energy Demand)

The *total primary energy demand (CED total),* the *non-renewable primary energy demand (CED non-renewable)* and *renewable primary energy demand (CED non-renewable)* serve primarily as a source of information regarding the energy intensity of a system.

- *Total primary energy (Cumulative Energy Demand, total)*

  The Total Cumulative Energy Demand is a parameter to quantify the primary energy consumption of a system. It is calculated by adding the energy content of all used fossil fuels, nuclear and renewable energy (including biomass). This category is described in VDI (1997) and has not been changed considerably since then. It is a measure for the overall energy efficiency of a system, regardless the type of energy resource used. The calculation of the energy content of biomass, e.g. wood, is based on the lower heating value of the dry mass. The unit for Total Primary Energy is MJ per functional unit.

- *Non-renewable primary energy (Cumulative Energy Demand, non-renewable)*

  The category non-renewable primary energy (CED non-renewable) considers the primary energy consumption based on non-renewable sources, i.e. fossil and nuclear energy sources. The unit for Non-renewable Primary Energy is MJ per functional unit.

- *Renewable primary energy (Cumulative Energy Demand, renewable)*

  The category renewable primary energy (CED renewable) considers the primary energy consumption based on renewable energy sources, i.e. solar energy, wind energy, biomass and hydropower. The unit for renewable primary energy is MJ per functional unit.

Use of phosphorus

The cumulated material demand (CRD) for phosphorus fertilizers are of a particular interest when assessing the raw material demand of agricultural systems. The CRD for phosphorus depicts the

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total of all mineral material resources introduced into a system expressed in units of weight and takes the phosphorus in crude ore into account rather than just the amount of phosphorus.

2.6.3. Biodiversity assessment

In 2016, the FAO published a review of indicators and methods to assess biodiversity for livestock production at a global scale, in which the pressure-state-response indicator framework and the life cycle framework is analysed and compared regarding the assessment of biodiversity (FAO 2016).

Methodology approaches for the life cycle assessment of the impact of land use on biodiversity, e.g. Chaudhary et al. (2015) recommended by UNEP-SETAC, do differentiate only between land use types like forest and agricultural land. Crop specific differences are not represented by these methods. The LCA framework includes other midpoint categories linked to biodiversity, e.g. Acidification or Eutrophication, which address crop specific aspects like nutrient leaching to ground water (FAO 2016).

However, for a comprehensive picture of impacts on biodiversity from livestock production, further cultivation specific factors have to be considered, which are not yet covered in standard LCA studies. Therefore, the investigations on biodiversity are supplemented by elements borrowed from other tools. The difficulty here is that the assessment is performed at generic - rather than site-specific – level and should highlight differences in crop species.

In this context, Agri-Environmental Schemes targeting the improvement of benefits and mitigation of agricultural pressure on biodiversity (FAO 2016) and the assessment of pressures per bioenergy crop developed by the European Environment Agency (EEA 2006) are useful methodologies. The latter is based on a qualitative analysis of pressures exerted on the environment by different crops and builds on an ecological prioritisation study of energy crops for German conditions (Reinhardt and Scheurlen, 2004). Methodological variants of the environmental impact assessment (EIA) approach have been applied in several European Union funded projects (BIOCORE[16] and SUPRABIO[17]).

Building on this, the influencing factors listed in Table 14 below have been identified as appropriate to make qualitative assessments based on the available data in the present project. The biodiversity assessment will be performed as qualitative assessment based on the comparison of the different crops.

Table 14: Factors targeting the improvement of benefits and mitigation of agricultural pressures on biodiversity based on Agri-Environment Schemes compiled by FAO (2016)

Pressure category	Influencing factor
Nutrient pollution	- Reduction of nitrogen input - Partial replacement of fertilizer input by including legumes in crop rotation

[16] http://www.biocore-europe.org/
[17] http://www.suprabio.eu/

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	- Nutrient leaching to ground and surface water (Aquatic Eutrophication and Acidification)
Pesticides and other pollution	- Reduction of pesticide treatments - Reduction of stratospheric ozone depletion - Reduction of photochemical ozone formation
Water balance	- Reduction of water demand
Soil degradation	- Reduced soil compaction due to mechanical field work - Increase of soil organic matter
Landscape structure	- Diversifying crop rotations

3. Methodology of Socio-Economic Assessment to be applied in P2F

3.1. Methodology of Socio-Economic Assessment to be applied in PROTEIN2FOOD

This section describes the methodology developed and design choices made to perform the Socio-Economic Assessment (SEA) of plant-based protein-rich food prototypes in the context of PROTEIN2FOOD (P2F). In a future stage (D5.3), SEA will be used to analyze the socio-economic impacts (positive and negative) of selected food products under different technical scenarios defined in D5.1. SEA will also be used in combination to LCA to carry out an Integrated Sustainability Assessment (D5.4) and to support the development and implementation of the WP4 multi-criteria assessment toolkit (D4.3).

First, this section reviews socio-economic assessment methodologies commonly used to identify and evaluate socio-economic impacts, and explains why the S-LCA was identified as the most suitable tool for developing the socio-economic assessment. Second, this section describes the S-LCA methodology and gives details about how it could be applied for the assessment of protein products within PROTEIN2FOOD.

3.1.1. Revision and Selection of different Methods for Socio-economic Assessment

The objective of a socio-economic impact assessment is to provide a set of quantitative and qualitative decision variables that will help to guide a decision-making process. Therefore, the ultimate goal of a socio-economic analysis is to analyze the positive and negative socio-economic impacts associated to a given development, policy or product (Tamborra M. , 2002).

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Since there are many different socio-economic methodologies, the first task required for the development of Task 5.2 was to revise the most common methodologies for analyzing socio-economic impacts. The aim was to identify the most suitable methodology for the task, and this suitability relied on their adequacy for analyzing social impacts along the life cycle of agri-food products and their complementarity with Environmental Life Cycle Analyses.

This review included the following methodologies: Input-output analysis, Cost-effectiveness Analysis, Cost-benefit analysis, Life-cycle Costing, Fiscal Analysis, Socio-economic Impact Assessment (Mackenzie), Product Social Impact Assessment, and Socio-economic Life Cycle Assessment (S-LCA). Table 1 displays these reviewed methodologies, indicating several of the advantages and disadvantages that were detected in the process.

Table 15:**.** Reviewed socio-economic methodologies of the stakeholder categories included within PROTEIN2FOOD Social Life Cycle Assessment

	Description	Advantages	Disadvantages
Socio-economic Life-Cycle Assessment	Flexible methodology designed for studying the potential socio-economic impacts of products and services at different production stages	**Focuses** specifically on **products** and **services**. **Very compatible with Environmental LCAs**. Can be performed using generic data	Relatively recent and still-developing methodology. Reduced availability of specifically-developed tools and databases
Product Social Impact Assessment	Workable methodology based on S-LCA for assessing social impacts of products	Wide range of free useful tools available. Easy to implement. SH surveys already designed. Useful for social analysis in the processing phase.	Requires a large number of surveys. Many performance indicators not fully applicable to small companies or farms. Very focused on the processing phase
Cost-Benefit Analysis	Compares which of several alternative reaches the same goal using less resources	Useful for economic analysis (when data is available)	Requires large amounts of data and detailed information about all of the different costs in each of the alternatives under evaluation
Cost-Effectiveness Analysis	Compares the amount of benefits with the costs (always in monetary terms)	Useful for economic analysis (when data is available)	Requires large amounts of data and detailed information about all of the different costs in each of the alternatives under evaluation
Input/ Output	Studies interdependencies between different materials and sectors in a national economy	Input/ Output National databases are public	Focuses mainly on evaluating interdependencies between economic sectors, and used as a tool for national and regional economic planning
Life Cycle Costing (LCC)	Assesses all of the direct and indirect costs incurred during the lifetime of a product	Useful for economic analysis (when data is available)	Time-consuming, and requires large amounts of data and detailed information about all of the different costs through each product's life cycle.

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Socio Economic Impact Assessment (Mackenzie)	Designed for determining socio-economic impacts of developments on the Mackenzie Valley's conditions (Canada)	-	The methodology's process is not very clear. The analysis is addressed for regions with many cultural and tribal features
Fiscal Analysis	Estimates the impact of a project on the revenues and costs of governmental institutions	-	Not applicable

After a thorough review of these methodologies, Socio-economic Life Cycle Assessment (S-LCA) was finally selected as the most promising methodology towards assessing the socio-economic performance of PROTEIN2FOOD products. There were two main reasons behind this decision. First, S-LCA has been specifically developed for studying the socio-economic performance of products (instead of projects, actions or public policies), which makes it very effective towards identifying the socio-economic impacts related to agri-food products. Second, its life-cycle scope makes it very suitable for complementing Environmental Life Cycle Assessments (hereinafter LCAs) (UNEP-SETAC, 2009). This complementarity is particularly important within this project, since the LCA will focus only on environmental impacts and needs to be complemented with socio-economic information (impacts on social agents) in order to support decisions from a sustainable perspective (Barthel et al., 2014).

Nevertheless, although both assessment methodologies (LCA and S-LCA) have been developed for analyzing impacts through the life cycles of products, there are significant differences amongst them. Some of these differences have been gathered in Figure 1.

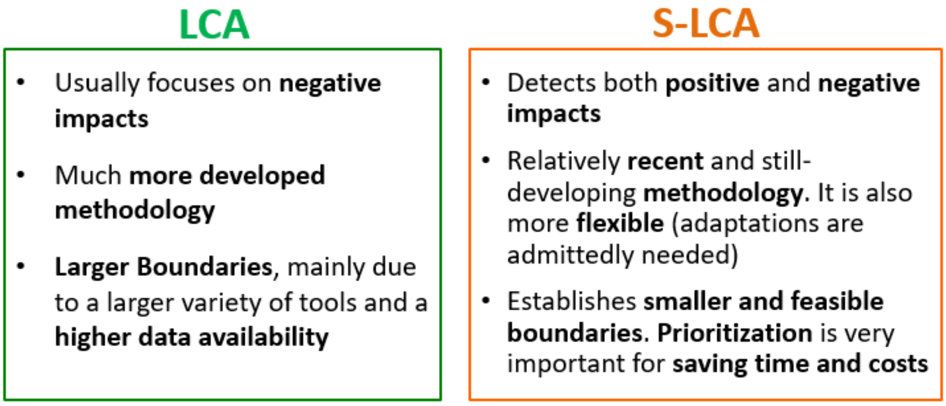

Figure 8: Main differences between LCA and S-LCA
Source: Own elaboration. Based on information from UNEP-SETAC (2009)

As Figure 1 highlights, one of the main differences, which is that LCA usually focuses only on negative impacts, while S-LCA also takes into consideration the positive impacts related to the life cycle of products. However, S-LCA is a relatively recent and still-developing methodology. In turn, its availability of tools, databases and indicators is still very reduced when compared to LCA, and to establish identical boundaries for both assessments may not be realistic (Kruse, et al., 2009). This is precisely the reason why the S-LCA is going to be conducted as a separate analysis with different boundaries, a complement to rather than an integrated piece of the LCA (Kruse, et al., 2009). Thus, both assessments will analyze separately the products' life cycles, contributing together to the Integrated Sustainability Assessment of protein products.

3.1.2. Methodological Framework of the Socio-economic Life Cycle Assessment Assessment

3.1.2.1. Brief Introduction to the S-LCA

The Social Life Cycle Assessment (S-LCA) is a relatively new methodology for the socio-economic assessment of products, and relies on the procedures established by the *Guidelines for Social Life Cycle Assessment of Products* (Revéret et al., 2009). These guidelines (from now on S-LCA Guidelines) were developed by the 'United Nations Environment Programme' and the 'Society of Environmental Toxicology and Chemistry' in 2009, with the aim of contributing to the full assessment of goods within the context of sustainable development (UNEP-SETAC, 2009).

The S-LCA methodology establishes an assessment system where impacts are evaluated through the use of indicators. These indicators are classified through impact categories and subcategories,

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which may include one or more indicators and are directly related to a specific stakeholder group or category (see Figure 2). These stakeholder categories represent groups of social agents potentially impacted by the production of a specific product, and form the basis of a S-LCA (UNEP-SETAC, 2009).

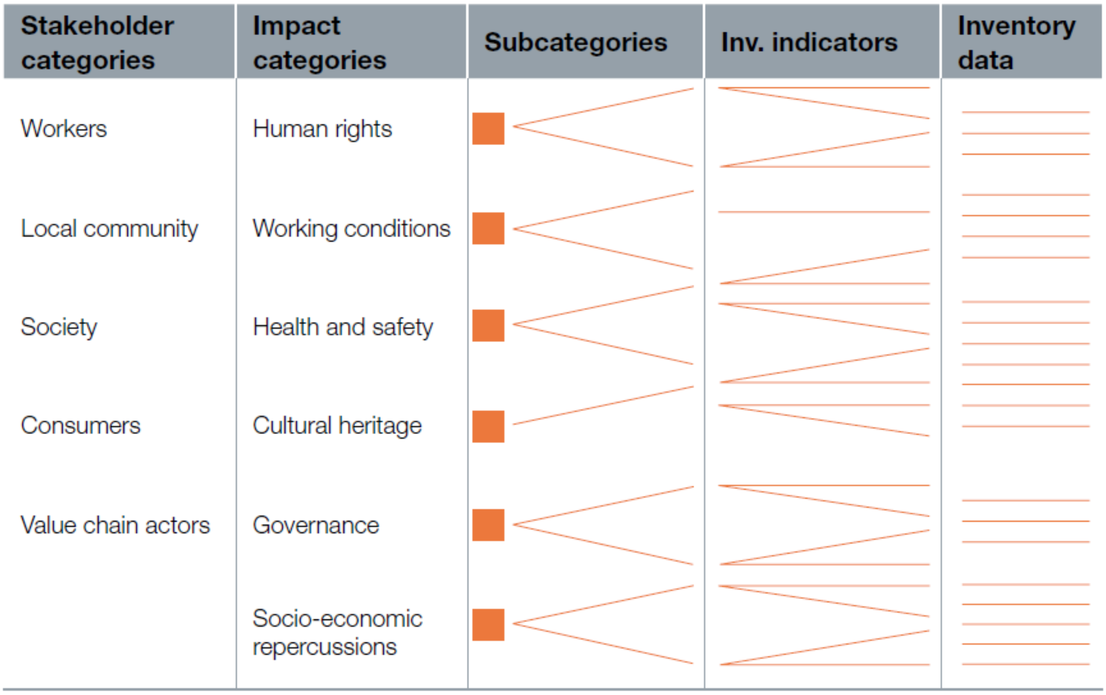

Figure 9: S-LCA assessment system
Source: UNEP-SETAC (2009)

The S-LCA Guidelines propose five general stakeholder categories potentially impacted by the production of products: workers, consumers, society, value chain actors and local community. However, it is possible to add, exclude, differentiate and define more stakeholder categories depending on the study's boundaries and the sector's particularities (Revéret et al., 2012).

Regarding the impact categories, the Guidelines list the following five main groups: human rights, working conditions, health and safety, governance, cultural heritage and socio-economic repercussions.

Besides, the S-LCA methodology proposes four assessment phases that are in line with LCA and the ISO Framework. These assessment phases are:

- Goal & Scope
- Inventory Analysis
- Impact Assessment
- Interpretation of Results

These phases comprise all the actions that need to be performed within a S-LCA, including the definition of the purpose and structure of the study, the data collection, the impact assessment and the interpretation of results. These phases will be properly described through the next section, explaining, at the same time, how are they planned to be performed within this particular S-LCA.

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3.1.2.2. Application of the S-LCA for the Evaluation of Protein Products

The Socio-economic Life Cycle Assessment relies on the S-LCA Guidelines. Nevertheless, although these Guidelines provide a general framework for conducting this type of assessments, every S-LCA is different and has its own context and goals (UNEP-SETAC, 2009). This subsection focuses on explaining how the S-LCA methodology is going to be adapted to the assessment of protein products and indicates how the different S-LCA phases are planned to be applied. Figure 3 represents these working phases.

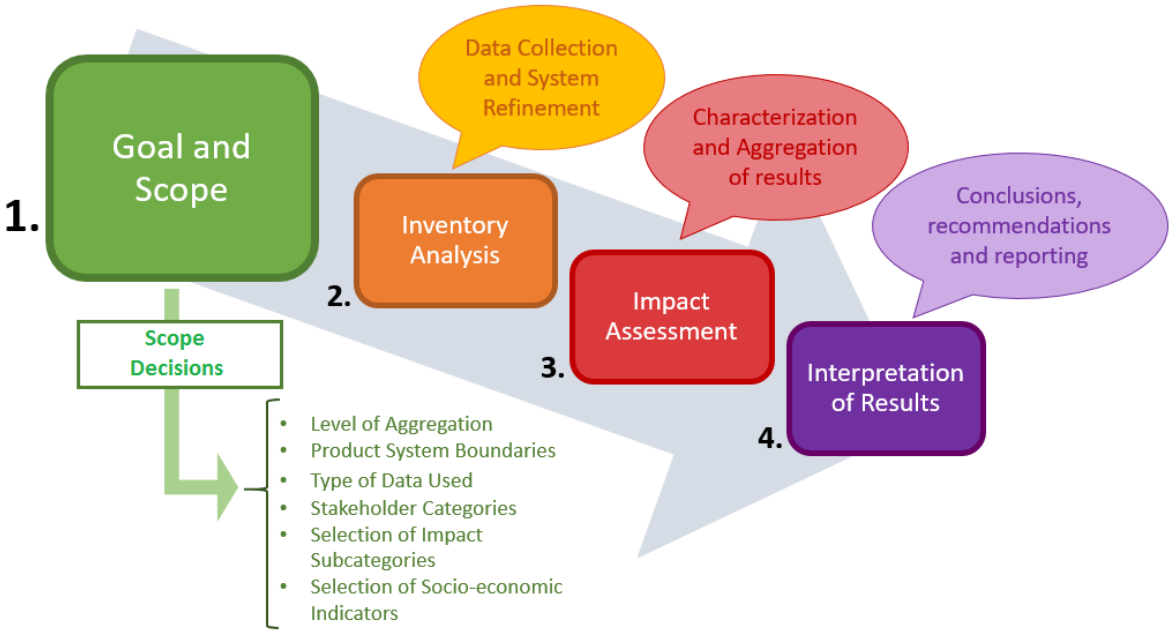

Figure 10: Main phases of a Social Life Cycle Assessment
Source: Own elaboration based on Sala et al. (2015)

As seen in Figure 3, developing the specific assessment framework of each S-LCA will require, first, to establish the specific goals of the study, and then to address many scope decisions that will help to correctly orientate the assessment towards fulfilling those goals (scope of the study) (UNEP-SETAC, 2009). These actions belong to the working phase 'Goal and Scope', which has been divided into two sections ('Goal of the Study' and 'Scope of the Study') in order to facilitate its understanding.

After all of the scope decisions have been taken (these will be properly addressed further ahead), the next phase is the 'Inventory Analysis', where data will be collected for all the products. Besides, the initial system will be refined as the data collection process advances.

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The next S-LCA phase is the 'Impact Assessment' phase, where data will be processed and results will be characterized and assessed. Finally, the last phase is the 'Interpretation of Results' phase, where results will be interpreted and conclusions about the socio-economic impacts of these products will be reached.

As already mentioned, the objective of this section is to describe the specific S-LCA Assessment framework developed for the assessment of products. With this in mind, this section has been subdivided into five subsections that focus separately on each of the aforementioned working phases (please note that the first working phase 'Goal and Scope' has been divided into the phases 'Goal of the Study' and 'Scope of the Study' in order to simplify its understanding). Each subsection will describe how these phases are planned to be performed towards assessing PROTEIN2FOOD protein products.

3.1.2.2.1. Goal of the study

The overall objective of any Social Life Cycle Assessment is "to assess the social and socio-economic aspects of products and their potential positive and negative impacts during their life cycle" (UNEP-SETAC, 2009). However, although every S-LCA share the aforementioned objective, each S-LCA will has its own specific goals depending on the purpose of the study. This purpose may be, for example, to assess the current socio-economic performance of a single product in a single country (e.g. S-LCA of Milk Production in Canada (Revéret et al., 2012)), to analyze and compare the social impacts of a single product in several countries (e.g. S-LCA of rare earth minerals in China, United States, Malaysia and Australia (Schlör et al., 2015)) or to assess the socio-economic performance of a local product when using different production techniques (e.g. comparing the impacts of raspberry production using 'mulching' and 'covering' production techniques in Cuneo, Northwest Italy (Tecco et al., 2016)). To identify and define this specific purpose is one of the first things needed when initiating an S-LCA, as the study will then be defined to meet that purpose (UNEP-SETAC, 2009).

The purpose of this S-LCA will be to assess the socio-economic implications of the proposed novel PROTEIN2FOOD plant-protein products and of the traditional products they aim to replace. The aim will be to identify potential positive and negative impacts along their life cycles and compare each product's performance in relation to different socio-economic issues. Nevertheless, it should be noted that this study does not intend to categorically declare some alternatives as superior to others. As a matter of fact, the S-LCA Guidelines emphasize that it is the most probable that one alternative may not be simply better than the others (UNEP-SETAC, 2009). Instead, and in line with the Guidelines approach, this study will focus on highlighting trade-offs between alternatives and in gaining understanding of under what circumstances and regarding which issues one of the alternatives is preferable (UNEP-SETAC, 2009).

Therefore, the main objectives of this assessment will be:

(1) To identify potential positive and negative impacts along the life cycle of novel PROTEIN2FOOD plant-protein products in Europe, as well as of the traditional products they aim to replace.

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(2) To assess and compare traditional and novel products' performances in relation to different socio-economic issues, with the aim of identifying differences and trade-offs between the different products' life cycles studied.
(3) To obtain valuable socio-economic information and an increased understanding of each product system.

Nevertheless, and as the Guidelines state, it is important to clarify that an S-LCA will not provide information on the question of whether a product should be produced or not, but it will certainly help to track the socio-economic implications of the consumption and production of products (UNEP-SETAC, 2009).

The results of this assessment, together with the results of the Environmental LCA, will contribute to Task 5.3 (Integrated Sustainability Assessment) and Task 5.4 (Policy Synopsis), but also to other WP tasks such as the Multi-Criteria Assessment (Task 4.3) that will be carried out in WP4.

3.1.2.2.2. Scope of the study

As with Environmental LCAs, it is impossible to completely cover the entire life cycle of a product in an S-LCA. Products always rely on many different inputs which, at the same time, have their own intricate life cycles, full of inputs of their own (UNEP-SETAC, 2009). Consequently, both E-LCA and S-LCA need to prioritize and establish system boundaries in order to make their analysis feasible and economically viable. These and other issues must be faced while defining the scope of the study.

Thus, defining the scope of the study is one of the most critical steps towards performing an S-LCA, since it encompasses many key decisions that need to be taken towards correctly orientating the assessment and fulfilling its specific objectives. The S-LCA Guidelines provide a very clear framework towards addressing these scoping decisions, which include the selection of stakeholders to be studied, the product system boundaries and the type of impacts to be considered (UNEP-SETAC, 2009). Moreover, the authors of the S-LCA Guidelines propose generic categories for these sections and have even published a complementary document named 'Methodological Sheets for the Subcategories in S-LCA', which includes a wide repertoire of impact subcategories and socio-economic indicators (Benoît et al., 2009). However, it must be stated that the S-LCA Guidelines have been designed as a relatively flexible methodology for conducting a broad range of product socio-economic assessments, and therefore, it provides a general framework where adaptations are admittedly needed (UNEP-SETAC, 2009).

The objective of this section is to present the specific assessment framework that will be used for evaluating and comparing the socio-economic performance of traditional and novel protein products in Europe. The aspects to be defined within this section are: the level of aggregation, the product system boundaries, the type of data, the stakeholder categories, the selection of impact subcategories and the selection of socio-economic indicators.

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Level of Aggregation

This Social Life Cycle Assessment will assess and compare the socio-economic performance of traditional and novel protein products in the European Union. Under this premise, data used within this assessment should be as representative as possible, and therefore the data collection process will be performed prioritizing European average data. Thus, European average data will be used whenever possible, but national statistics of several countries, as well as specific data from the SMEs in the PROTEIN2FOOD consortium, could be used for specific crops, products or raw materials attending to data availability reasons.

Product System Boundaries

The S-LCA Guidelines recommend to establish the S-LCA system boundaries bearing in mind the system boundaries of the other complementary assessments (UNEP-SETAC, 2009). With this in mind, the S-LCA product system has been defined using the LCA system developed by IFEU (2016) (see PROTEIN2FOOD Deliverable 5.1 ‘Report on the Scenarios’) and building upon it (see Figure 4). Nevertheless, and also in line with the S-LCA approach, the compartmentalization of the product life cycle into life cycle stages has been developed taking into account the different actors involved instead of focusing on processes. Thus, the S-LCA product system has been divided into the following main life cycle stages:

- **Production:** including the primary production of crops for human consumption, and the production of feed crops and cattle farming in those products with animal proteins. The socio-economic performance of inputs will not be analyzed, although this does not exclude the possibility of performing a rapid scan of some punctual elements using Social Hotspot Database tools like ‘Risk Tree-maps’.

- **Processing & Retail:** from the moment the raw material (with an animal or vegetable origin) is sold by the primary producers and until the product is purchased by the final consumer. It therefore includes the processes performed by the food industry (such as food storage, protein extraction, design, food processing, packaging, etc.) and by distribution enterprises (product distribution and sale).

- **Consumption:** from the moment the product is purchased until it is used or consumed by the final client.

These life cycle stages are differentiated with colors in Figure 4, which is included as an example of the product system of this S-LCA and has been built upon two LCA product flow charts in PROTEIN2FOOD’s Deliverable 5.1 (IFEU, 2016). These product systems represent the life cycles of a traditional beef burger and of a potential vegetable-protein fibre-like alternative (pages 35 and 32 of Deliverable 5.2). Gray rectangles and gray dashed lines represent processes and products that appeared in the LCA flowcharts but will not be studied in this S-LCA.

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Nevertheless, it should be noted that, although extracted from Deliverable 5.1, this figure is a simplified scheme of the LCA, and it does not include several processes and sub-processes that will be included in it (such as energy supply, storage or production of auxiliary materials).

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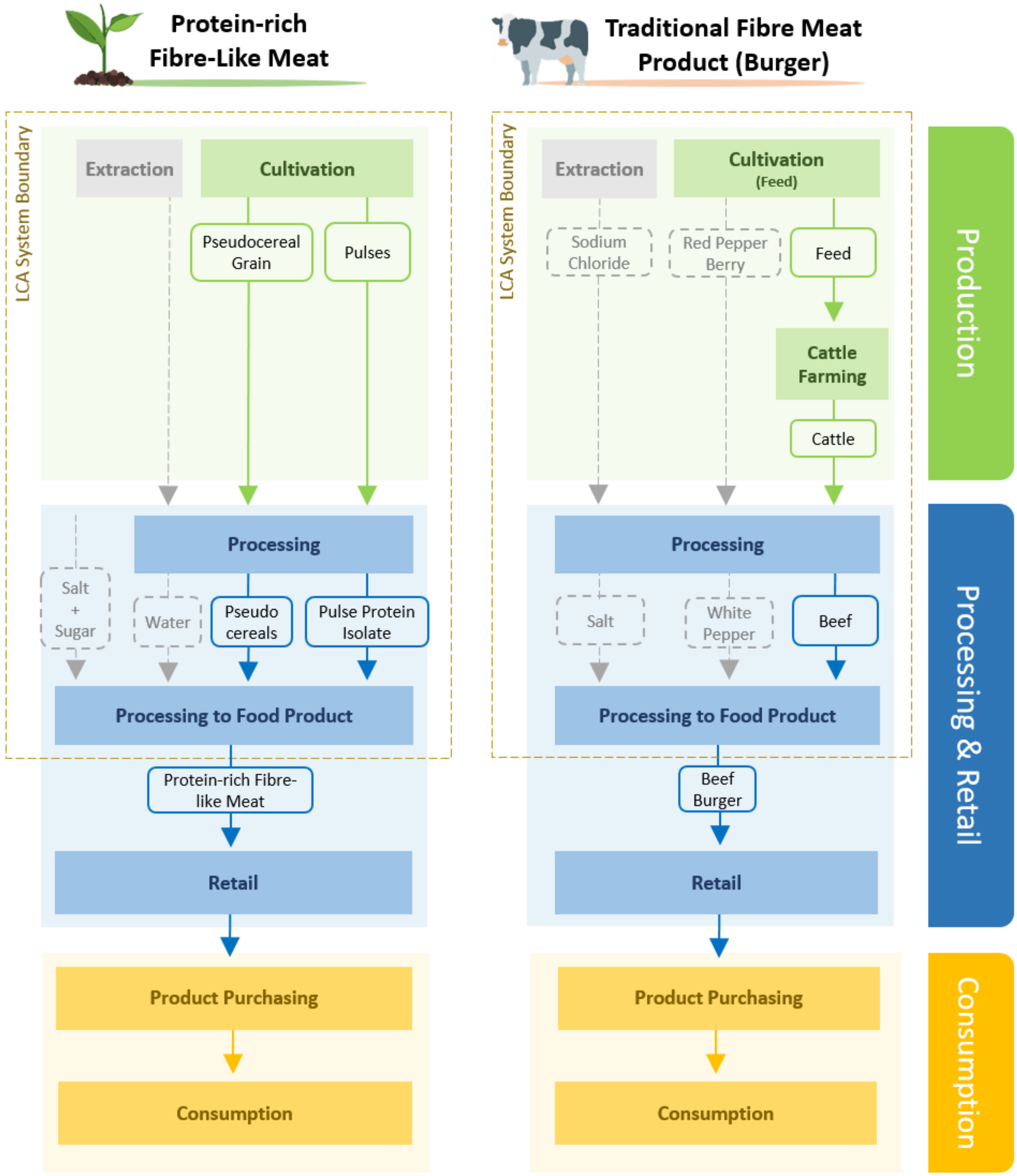

Figure 11: S-LCA product system and LCA system boundary (brown dashed line). Built upon LCA Process Flow Charts in PROTEIN2FOOD's Deliverable 5.1 (IFEU, 2016)

As it can be observed in Figure 4, the LCA and S-LCA product systems will coincide in their main phases. Nevertheless, there are several relevant differences between both product systems. First of all, the S-LCA will focus only on the most important raw materials and crops within the composition of each product, while the LCA system will encompass several other inputs with

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their related value chains. This is the most common way to proceed, as the ultimate goal of LCAs is to study the full range of environmental effects assignable to products and its way to achieve this is to quantify all inputs and outputs of material flows (Curran, 2006). In contrast, as Revéret et al. (2009) indicate, in S-LCA, it is not always possible, necessary or relevant to assess in detail all of the inputs and stages throughout the life cycle of a product, and especially due to practical constraints such as data limitations and budget restrictions. Besides, LCA is still a much more developed methodology and, in turn, its wider availability of tools, databases and indicators makes it easier to perform more exhaustive analysis (Kruse et al., 2009)**.**

Another relevant difference is that, although the S-LCA product system shares the production and processing phases with LCA, it goes beyond the supply chain and includes also the consumption phase (see Figure 4). This is because the consumer is in fact one of the most important stakeholder groups in S-LCA, since it is included amongst the five stakeholder categories suggested by the S-LCA Guidelines (UNEP-SETAC, 2009) and it is regularly used in a large amount of S-LCAs (Sala et al., 2015).

Type of Data

After establishing the product system boundaries, the next key decision is to decide on which type of data, site specific or generic, the assessment should rely. As pointed out in the S-LCA Guidelines, site specific data refers to “data collected for a specific process, occurring in a specific enterprise, in a specific location with those stakeholders affected”, while generic data means “data that has not been collected on site” (UNEP-SETAC, 2009). Thus, while Case Specific S-LCAs focus on studying specific products and their specific supply chain using surveys or questionnaires, Generic S-LCAs (or Social Hotspot Assessments) rely on average data and are better for studying an average product with a generic supply chain (UNEP-SETAC, 2009).

Since the aim of this S-LCA is to study the socio-economic performance of traditional and novel protein products in Europe, reducing the scope and conducting surveys for analyzing specific products in very specific supply chains (e.g. Local Skimmed Milk produced by one or several companies in ‘Comarca de Ordes’ in Galicia) does not seem like the most representative option. This would be an interesting approach for local companies who wish to report the effects of their product lines on social well-being, but not for studying the socio-economic performance of these products at a European level. Instead, to conduct a Generic S-LCA will enable the possibility of identifying potential socio-economic impacts while using average and representative data from national and international data sources. Besides, although the data collection process in the Generic S-SLCA will still require a considerable time, it will certainly be less time-consuming than conducting surveys within a Case Specific S-LCA (UNEP-SETAC, 2009). This is a very important aspect to be considered, as data from several product supply chains (instead of just one) will need to be located in order to compare the performance of the different products included within this S-LCA.

Generic data will be collected from a broad range of data sources, including national statistics, international databases, scientific literature, public literature and existing reports. Nevertheless, it is important to restate that although this is a Generic S-LCA, whenever generic data are not available, it might be necessary to resort to specific data from the SMEs in the PROTEIN2FOOD

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consortium. This should only be done for covering very concrete data gaps in relevant indicators, which are more likely to arise within the supply chains of the novel protein products.

Stakeholder Categories

In the same way that an environmental impact assessment aims to assess the impacts of products on the environment, socio-economic assessments aim to analyze their impacts on social agents. Accordingly, the assessment of socio-economic impacts in S-LCAs is stakeholder-oriented, and therefore the identification of stakeholder categories will establish the basis for the articulation of impacts categories and indicators (UNEP-SETAC, 2009).

A stakeholder category is defined in the S-LCA Guidelines as a "cluster of stakeholders that are expected to have shared interests due to their similar relationship to the investigated product systems" (UNEP-SETAC, 2009). The stakeholder categories included within an S-LCA should reflect the main group categories impacted by the life cycle of products. The Guidelines propose five categories commonly impacted by products: workers, consumers, society, value chain actors and local community. However, it is possible to add, to exclude, to differentiate or to simply define more precisely these proposed categories depending on the study's boundaries and the sector's particularities (UNEP-SETAC, 2009). Table 2 includes a definition of the 5 stakeholder subcategories that have been selected to be studied within PROTEIN2FOOD S-LCA

Table 16: Definition of the stakeholder categories included within PROTEIN2FOOD Social Life Cycle Assessment

SH Category	SH Subcategory	Definition
Workers	Agricultural Worker	This category refers to employees within the production sector, who work in farms or holdings but do not own those agricultural businesses.
	Processing & Retail Worker	This category refers to employees working within the processing and retail sectors
Value Chain Actors	Farmer	This category refers to agricultural producers of proteins (mainly family-owned farms) who own businesses and whose economic situation and well-being depend on the profitability and performance of what they produce
Consumer	Idem.	This category refers to the persons that will buy these protein products for personal use

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Society	Idem.	This category refers to the aggregate of people, institutions and interest groups who share customs, laws and acknowledged social values

As Table 16 shows, PROTEIN2FOOD S-LCA will focus on four categories: workers, value chain actors, consumers and society. Besides, the group 'workers' has been divided into 2 subgroups: 'Agricultural workers' and 'Processing & Retail' workers. This selection has been performed after a review of the existing literature and simultaneously with the development of impact subcategories and their associated indicators. Besides, and in line with the S-LCA Guidelines, different stakeholder categories may be present depending on the life cycle stage (UNEP-SETAC, 2009). This can be observed further ahead in the section 'Selection of Impact Categories' (see Table 17).

Selection of Impact Subcategories

Impact subcategories are socially significant themes to be assessed by the use of socio-economic indicators (UNEP-SETAC, 2009). Subcategories are the basis of an S-LCA, as they help to organize socio-economic indicators into more general issues that are directly related to a specific stakeholder group. Thus, it is essential to select carefully these subcategories, which should be appropriate to the particular context of the study. Besides, as also indicated in the S-LCA Guidelines (UNEP-SETAC, 2009), "Impact Subcategories should preferably reflect internationally recognized categorizations and/or result from a multi-stakeholder process". With this in mind, most of the impact subcategories of this S-LCA have been selected using the internationally recognized list of subcategories proposed in the S-LCA Guidelines' Methodological Sheets' (Benoît et al., 2009), which also includes a list of associated socio-economic indicators. Nevertheless, although most of the subcategories have been taken from the list proposed in the Methodological Sheets, not all of the subcategories proposed have been used within this assessment. As Réveret et al. (2009) indicate, although many of these subcategories may be relevant in a study's context, some of them may not be necessarily relevant for the assessment (e.g. 'Prevention of armed conflicts' in a European context).

Additional subcategories have been defined using the outputs of a multi-stakeholder consultation performed at the end of May in Naples within the 2nd Annual Meeting of PROTEIN2FOOD. This consultation, developed by UPM within the frame of PROTEIN2FOOD work package 4 'market analysis', was conducted using two different methods. First, specific questionnaires were carried out with an international group of stakeholders, including producers, farmer associations, food-processing companies, research institutions and non-profit associations. The objective of these questionnaires was to obtain, in an individual and anonymous way, the stakeholders' views and opinions about the current situation of the plant protein sector and also about barriers and constraints they find. Besides, they were also invited to use their experience as consumers and indicate the product features they believe to be valued the most. Second, a focus group exercise was developed to generate debate and obtain group responses, where different techniques were

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combined (as the brainstorming or card techniques). Using the results of the questionnaires and focus groups permitted to complement the 'Methodological Sheets' list (more general and created to fit within many studies) with several tailored categories chosen by sector-specific stakeholders. Finally, two more subcategories have been taken from literature on S-LCA (Kruse et al. (2008) & Paragahawewa et al. (2009)). The final selection of subcategories is depicted in Table 17, where it is also indicated the stakeholder category to which they are related. In addition, the corresponding source of each impact subcategory has also been included in this table.

Table 17: Impact Sub-categories with their corresponding source, stakeholder subcategories and S-LCA stage

	SH Subcategory	Impact Subcategory or 'Social Issue'	Source
Production	Agricultural Worker	Fair Salary	S-LCA Methodological Sheets
		Hours of Work	S-LCA Methodological Sheets
		Equal Opportunities/Discrimination	S-LCA Methodological Sheets
		Health and Safety	S-LCA Methodological Sheets
	Farmer	Contribution to Farm Income	Kruse et al. (2008)
		Economic Security	Stakeholder Consultation
		Management Attributes	Stakeholder Consultation
	Society	Contribution to Economic Development	S-LCA Methodological Sheets
		Contribution to Food Security	Stakeholder Consultation
		Commitment to Sustainability Issues	S-LCA Methodological Sheets
Processing & Retail	Processing & Retail Worker	Fair Salary	S-LCA Methodological Sheets
		Hours of Work	S-LCA Methodological Sheets
		Equal Opportunities/Discrimination	S-LCA Methodological Sheets
		Health and Safety	S-LCA Methodological Sheets
	Society	Contribution to Economic Development	S-LCA Methodological Sheets
Consumption	Consumer	Health and Safety	S-LCA Methodological Sheets
		Choice	Paragahawewa et al. (2009)
		Product Features Relevant for Consumers	Stakeholder Consultation
	Society	Contribution to Protein Affordability	Stakeholder Consultation

As Table 17 shows, several impact subcategories may be related to different stakeholders and phases (e.g. 'Health and Safety') (UNEP-SETAC, 2009). It should also be noted that these

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subcategories have not been selected in an isolated manner, but in close association with the selection of indicators that are meant to assess them. In turn, subcategories have also been selected taking into account the availability of indicators adequate for the study's goal. For instance, one of the main constraints in the selection of subcategories for this specific assessment was the absolute necessity of selecting subcategories having product-specific (or sectorial) indicators, instead of national average indicators valid for any product being produced within a country. Using national indicators when sectorial data is not available (e.g. using a national average wage instead of the average wage level in the milk sector) is very common in S-LCAs assessing just one product (or comparing the same product but in different countries). Nevertheless, using national average indicators for comparing different products within the same countries would not make sense, as these indicators would give the same score for every product and would not allow us to glimpse any difference in the socio-economic performance of products.

Selection of Socio-economic Indicators

After defining impact subcategories as the basis of S-LCA, it is essential to find and define appropriate socio-economic indicators to evaluate them, adapted to the particular context of the study (UNEP-SETAC, 2009). With this in mind, the selection of indicators has been performed examining their suitability towards the achievement of these S-LCA goals and also after having conducted a preliminary scan on data availability. As with the impact subcategories, the selection of indicators for PROTEIN2FOOD S-LCA rests on three main sources: the S-LCA Methodological Sheets, the aforementioned stakeholder international consultation and other S-LCA studies.

As already mentioned, the S-LCA Methodological Sheets, developed as a complement for S-LCA Guidelines, provide a list of socio-economic indicators (generic and specific) for each impact subcategory proposed. Many of these indicators and subcategories are included within the Social Hotspot Database, a pragmatic tool and socio-economic database developed by New-Earth in 2009 and specifically with the aim of assisting Social Life Cycle Assessments (Sala et al., 2015). This Social Hotspot Database covers 227 countries and 57 types of products or sectors, to be assessed by a pool of almost 150 socio-economic indicators. This database is commonly used within life cycle sustainability assessments, since its ease of use, comparison tools and interactive maps are very useful for detecting social differences between countries, sectors or along the life cycle of products (Sala et al., 2015). For all of these reasons, and especially since this database contains a large number if indicators from the S-LCA Methodological Sheets, the Social Hotspot Database will be used in the assessment, helping to save time in the data collection phase.

The rest of socio-economic indicators are tailored indicators, as every study has its specific purpose and, in turn, it is advisable to complement general indicators with tailored and more specific ones (Sala et al., 2015). Tables 18, 19 and 20 show the socio-economic indicators selected for the 'Production', 'Processing & Retail' and 'Consumption' S-LCA stages, respectively.

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Table 18: Selection of socio-economic indicators for the 'Production' stage, with their corresponding source, impact and stakeholder subcategories

Stakeholder Subcategory	Impact Subcategory	Indicator	Description	Source
Agricultural Worker	Fair Salary	Risk of Sector Average Wage being lower than country's non poverty guideline	Sector Average Weight related to country's non-poverty guideline	S-LCA Methodological Sheets/ Social Hotspot Database
		Risk of Sector Average Wage being lower than country's minimum wage	Sector Average Weight related to country's minimum wage	S-LCA Methodological Sheets/ Social Hotspot Database
	Hours of Work	Risk of Excessive working time by sector	Percentage of employees working more than X hours a week	S-LCA Methodological Sheets/ Social Hotspot Database
	Equal Opportunities/ Discrimination	Risk of Gender Inequality by Sector based on representation in the workforce	Female representation in the workforce by sector	Social Hotspot Database (Based on the S-LCA Methodological Sheets)
	Health and Safety	Risk of Fatal Injury by Sector	Fatal injury rate by sector per 100.000	Social Hotspot Database (Based on the S-LCA Methodological Sheets)
		Risk of non-fatal Injury by Sector	Non-fatal injury rate by sector per 100.000	Social Hotspot Database (Based on the S-LCA Methodological Sheets)
Farmer	Contribution to Farm Income	Profitability	Gross or Net Margin per hectare/head	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
		Production Efficiency	Revenue divided by total costs	Kathage et al. (2015)
		CAP Support	Specific Coupled Payments	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
	Economic Security	Yield Variability	Average deviation of the variable 'yield' within a specific period	Kathage et al. (2015)

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		Production Price Variability	Average deviation of the variable 'price' within a specific period	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
	Management Attributes	Main Cultivation/ breeding attributes and difficulties	Diseases and pests, cultivation advantages and disadvantages, hours of work, etc.	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
Society	Contribution to Economic Development	Relevance of the considered sector for the economy	Wage level, share of GDP, etc.	S-LCA Methodological Sheets/ Social Hotspot Database
	Contribution to Food Security	Contribution to Protein Security	Protein production per hectare	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
	Commitment to Sustainability Issues	Contribution to the Sustainable Production of Proteins - Input use and efficiency	Inputs required per 100g of protein produced	Paragahawewa, Blackett & Small (2009)

Table 19: Selection of socio-economic indicators for the 'Processing & Retail' stage, with their corresponding source, impact and stakeholder subcategories

Stakeholder Subcategory	**Impact Subcategory**	**Indicator**	**Description**	**Source**
Processing and Retail Worker	Fair Salary	Risk of Sector Average Wage being lower than country's non poverty guideline	Sector Average Weight related to country's non-poverty guideline	S-LCA Methodological Sheets/ Social Hotspot Database
		Risk of Sector Average Wage being lower than country's minimum wage	Sector Average Weight related to country's minimum wage	S-LCA Methodological Sheets/ Social Hotspot Database
	Hours of Work	Risk of Excessive working time by sector	Percentage of employees working more than X hours a week	S-LCA Methodological Sheets/ Social Hotspot Database
	Equal Opportunities/ Discrimination	Risk of Gender Inequality by Sector based on representation in the workforce (female representation in the workforce by sector)	Female representation in the workforce by sector	Social Hotspot Database (Based on the S-LCA Methodological Sheets)
	Health and Safety	Risk of Fatal Injury by Sector (fatal injury rate by sector per 100.000)	Fatal injury rate by sector per 100.000	Social Hotspot Database (Based on the S-LCA

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				Methodological Sheets)
		Risk of non-fatal Injury by Sector (non-fatal injury rate by sector per 100.000)	Non-fatal injury rate by sector per 100.000	Social Hotspot Database (Based on the S-LCA Methodological Sheets)
Society	Contribution to Economic Development	Relevance of the considered sector for the economy	Wage level, share of GDP, etc.	S-LCA Methodological Sheets/ Social Hotspot Database

Table 20: Selection of socio-economic indicators for the 'Consumption' stage, with their corresponding source and impact and stakeholder subcategories

Stakeholder Subcategory	**Impact Subcategory**	**Indicator**	**Description**	**Source**
Consumer	Health and Safety	Level of contribution to consumer health or safety	The product improves health, reduces risk of disease, increases risk of disease or none of the above	Fontes, J. (2016)
	Choice	Accessibility	Easiness for obtaining the product.	Paragahawewa, Blackett & Small (2009)
		Product Affordability (price competitiveness)	Price per 100 g of product	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
	Product Features Relevant for Consumers	Organoleptic properties	Flavor, texture, aroma, etc.	Paragahawewa, Blackett, and Small (2009) / International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
		Nutritional Value (and functional benefits)	Nutritional profile, main functional benefits, anti-nutritional components	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
		Ease of Preparation	Preparation time	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)

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		Protein Content	Protein content per 100 g of product	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)
Society	Contribution to Protein Affordability	Contribution to Protein Security	Price per 100 g of protein with the product	International SH Consultation. 2nd Annual Meeting Protein2Food (2017)

These tables include both quantitative and qualitative (or descriptive) indicators. As quantitative indicators describe social issues using numbers, they may help to speed the assessment of impacts (UNEP-SETAC, 2009). Nevertheless, there are issues relevant for the study (as a crop management attributes) that cannot be simply described using numbers, and therefore they will be analyzed using qualitative indicators (UNEP-SETAC, 2009). The nature of each indicator (qualitative or quantitative) can be consulted in Table 21 within Annex 1 (section 3.4.1).

Nevertheless, it should be noted that, although all indicators within these tables are quantitative or qualitative, Table 21 (in Annex 1(section 3.4.1)) points out that they may be used as semi-quantitative or semi-qualitative. This has to do with the fact that, in order to ease the assessment and interpretation of results, S-LCA data is often translated into easy understandable characterized scores (e.g. negative, positive and very positive) (Barros et al., 2016). In fact, as Sala et al. (2015) point out in their study of the current state of the S-LCA art, a 56 % of the indicators used in S-LCAs are semi-quantitative.

Moreover, most of the socio-economic indicators within the Social Hotspot Database already include a characterized result (low risk, medium risk or high risk) apart from their official indicator result, and therefore, they have been also classified as semi-quantitative. However, tailored indicators have also been described as semi-quantitative and semi-qualitative, as they may also be characterized with the aim of making results more easily understandable and visually compare protein-product's socio-economic performances.

3.1.2.2.3. Inventory Analysis

After setting the goals of the S-LCA, and designing the scope for reaching them, the next phase is the 'Inventory Analysis'. This phase is composed of two main activities: data collection and system refinement (UNEP-SETAC, 2009).

As indicated in the guidelines (UNEP-SETAC, 2009), the data collection process is the most labor intensive and data consuming activity within an S-LCA. With this in mind, an intense bibliographic research and a previous scan of data sources were performed in order to define a clear and delimited scope that would help to shorten to the most possible extent this data collection

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process. Nevertheless, there are details and issues that will only emerge once the main data collection is performed within the 'Inventory Analysis' phase (UNEP-SETAC, 2009), and which will condition the next activity within this phase: system refinement.

LCA and S-LCA work as iterative procedures, which means that the initial assessment is susceptible of experiencing future changes as the assessment process advances (UNEP-SETAC, 2009). Most of these changes will occur during the system refinement carried out after the collection of data, where the product system and scope will be reviewed with the aim of reaching the final selection of impact categories and indicators (Benoît et al., 2009).

Data, when applicable, will also be related to the functional unit during this phase. A functional unit is a reference unit of product (or quantity of product) that is used in order to relate the magnitude of impacts to the production of a certain amount of product quantity impacts (e.g. 100 grams or 1 liter of product) (UNEP-SETAC, 2009).

3.1.2.2.4. Impact Assessment

The next phase will be the 'Impact Assessment Phase', where data collected will be processed and assessed. In this phase, the first step will be to characterize indicator results into a scale (or scoring system). This will be done with the aim of easing and speeding the comparison between the different protein products under study. This characterization system will be defined once the data collection process has been completed, and will be described for each of the indicators that will finally be analyzed (UNEP-SETAC, 2009).

The second step within the 'Impact Assessment' phase will be to cluster and aggregate results by subcategories and stakeholders. The purpose of aggregating these scores is to provide a simplified vision of results, which, according to literature, will facilitate decision-making processes (Barros et al., 2016). This means that average scores will be calculated per impact subcategory using the different indicator scores within that specific subcategory. This way, every impact subcategory will have its own average score, which will help to plot results of the products in a more easily understandable format. These aggregated results can be helpful for reaching to general conclusions during the interpretation phase. Nevertheless, these aggregated results must always be understood as complements for the indicator results, rather than substitutes (UNEP-SETAC, 2009).

3.1.2.2.5. Interpretation of Results

The last phase will be the 'Interpretation of Results'. In this phase, results will be analyzed and the main socio-economic issues of the products will be identified. The main goal of this phase is to use results in order to reach conclusions, state the limitations of the study, highlight the most relevant findings of the study and provide recommendations.

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All of these outcomes will be included and explained in detail in Deliverable 5.3 (Report on LCA). Deliverable 5.3 will also include an in-depth explanation of how the 'Inventory Analysis', the 'Impact Assessment' and the 'Interpretation of Results' phases have been performed, since there are many details and on-going decisions that can only be addressed once the real assessment has been started.

The distribution of all the study steps required to complete this assessment has been summarized in Figure 5, along with the main tools or procedures, database and bibliography that are planned to be used (in principle) within this S-LCA.

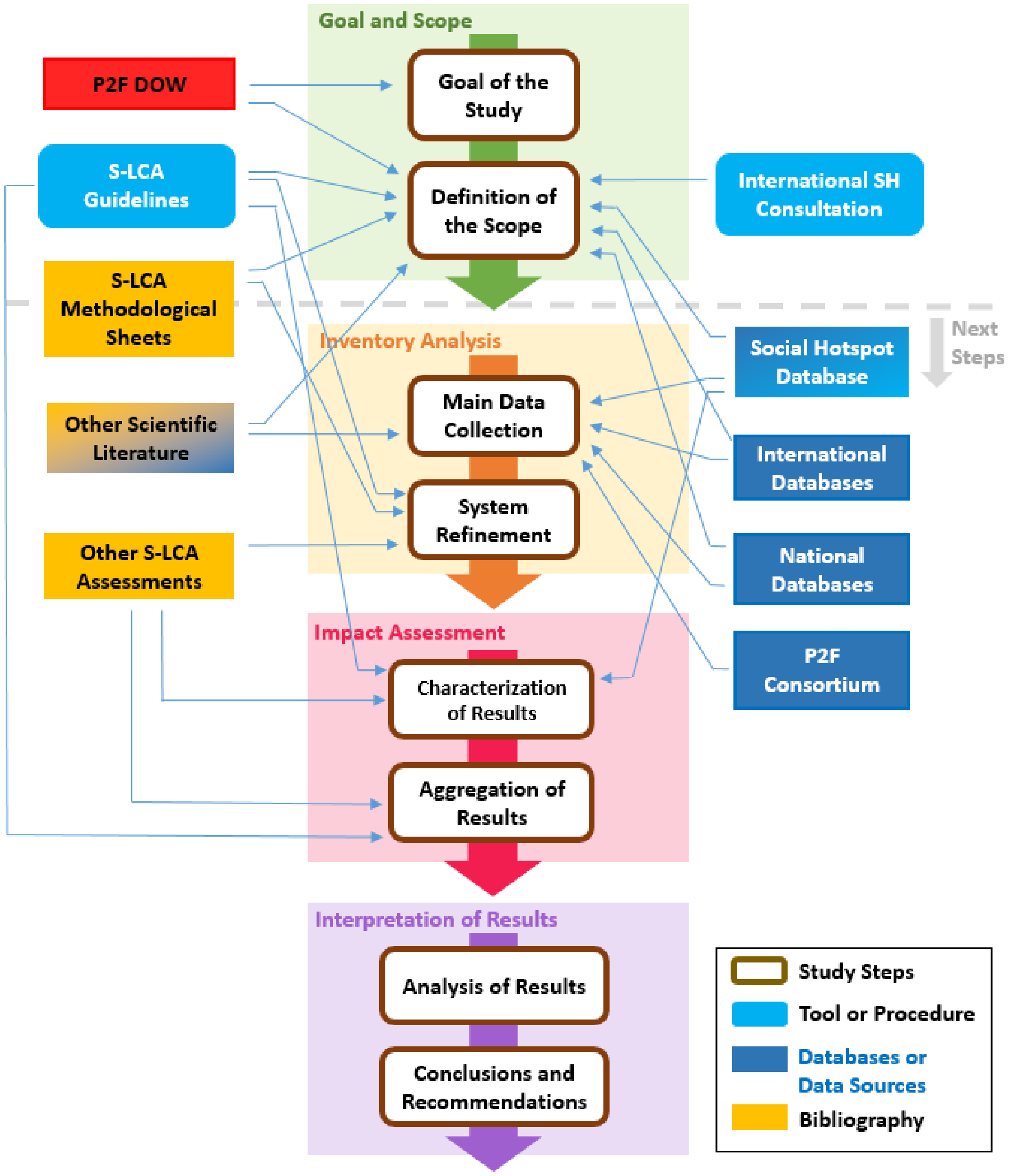

Figure 12: Planned distribution of study steps, tools or procedures, databases, data sources and bibliography within this S-LCA

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3.2. Final Remarks

The main objective of this document was to lay the foundations of the methodology for the socio-economic assessment of products within PROTEIN2FOOD. The S-LCA assessment framework explained within this document, tailored for the evaluation of different traditional and novel protein products, will serve as a guidance once the actual assessment of products starts, helping to save time and also to enhance a more coordinated approach with the environmental impact assessment (LCA) been performed by IFEU. Both assessments will complement each other, and will jointly shape the integrated sustainability assessment (Task 5.3) and contribute to the multi-criteria assessment carried out in work package 4 (Task 4.3).

As explained in section 1.2.2.1 (Goal of the Study), this S-LCA will focus on identifying potential positive and negative impacts along the life cycle of novel PROTEIN2FOOD plant-protein products in Europe, but it will also jointly analyze the traditional products they aim to replace. Therefore, this S-LCA will compare traditional and novel products' performances in relation to different social issues. However, although these performances will be compared with the use of indicator characterized results (in scale), it should be noted that the final aim of these comparisons will not be to aggregate results as far as possible to categorize products from 'best to worst', but to identify differences and trade-offs between the different product life cycles studied and obtaining valuable socio-economic information.

One of the main challenges towards performing this S-LCA will probably be the lack of data, since several PROTEIN2FOOD crops had never been produced in Europe until relatively recently. As specified in section 1.2.2.2., these data gaps could be overcome with the use of literature, or resorting to specific data from the SMEs in the PROTEIN2FOOD consortium. These and the other challenges arising during the assessment will be properly described and addressed in Deliverable 5.3 (Report on LCA).

Lastly, it is important to recall that an S-LCA is an 'alive' or iterative process, and therefore, the assessment framework described in this document is susceptible of changes or amendments as the assessment advances.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 635727.

3.4. Annex: List of Socio-economic indicators

Table 21: Socio-economic indicators classified by S-LCA stage, stakeholder subcategory, impact subcategory and type of analysis (quantitative or qualitative)

	Stakeholder Subcategory	Impact Subcategory	Indicator	Qualitative or Quantitative
PRODUCTION	Agricultural Worker	Fair Salary	Risk of Sector Average Wage being lower than country's non poverty guideline	Quantitative/ Semi-quantitative
			Risk of Sector Average Wage being lower than country's minimum wage	Quantitative/ Semi-quantitative
		Hours of Work	Risk of Excessive working time by sector	Quantitative/ Semi-quantitative
		Equal Opportunities/ Discrimination	Risk of Gender Inequality by Sector based on representation in the workforce	Quantitative/ Semi-quantitative
		Health and Safety	Risk of Fatal Injury by Sector	Quantitative/ Semi-quantitative
			Risk of non-fatal Injury by Sector	Quantitative/ Semi-quantitative
	Farmer	Contribution to Farm Income	Profitability	Quantitative/ Semi-quantitative
			Production Efficiency	Quantitative/ Semi-quantitative
			CAP Support	Quantitative/ Semi-quantitative
		Economic Security	Yield Variability	Quantitative/ Semi-quantitative
			Production Price Variability	Quantitative/ Semi-quantitative
		Management Attributes	Main Cultivation/ breeding attributes and difficulties	Qualitative/ Semi-qualitative
	Society	Contribution to Economic Development	Relevance of the considered sector for the economy	Quantitative/ Semi-quantitative
		Contribution to Food Security	Contribution to Protein Security	Quantitative/ Semi-quantitative

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		Commitment to Sustainability Issues	Contribution to the Sustainable Production of Proteins - Input use and efficiency	Quantitative/ Semi-quantitative
PROCESSING & RETAIL	Processing and Retail Worker	Fair Salary	Risk of Sector Average Wage being lower than country's non poverty guideline	Quantitative/ Semi-quantitative
			Risk of Sector Average Wage being lower than country's minimum wage	Quantitative/ Semi-quantitative
		Hours of Work	Risk of Excessive working time by sector	Quantitative/ Semi-quantitative
		Equal Opportunities/ Discrimination	Risk of Gender Inequality by Sector based on representation in the workforce (female representation in the workforce by sector)	Quantitative/ Semi-quantitative
		Health and Safety	Risk of Fatal Injury by Sector (fatal injury rate by sector per 100.000)	Quantitative/ Semi-quantitative
			Risk of non-fatal Injury by Sector (non-fatal injury rate by sector per 100.000)	Quantitative/ Semi-quantitative
	Society	Contribution to Economic Development	Relevance of the considered sector for the economy	Quantitative/ Semi-quantitative
CONSUMPTION	Consumer	Health and Safety	Level of contribution to consumer health or safety	Semi-qualitative
		Choice	Accessibility	Qualitative/ Semi-qualitative
			Product Affordability (price competitiveness)	Quantitative/ Semi-quantitative
		Product Features Relevant for Consumers	Organoleptic properties	Qualitative/ Semi-qualitative
			Nutritional Value (and functional benefits)	Qualitative/ Semi-qualitative
			Ease of Preparation	Quantitative/ Semi-quantitative
			Protein Content	Quantitative/ Semi-quantitative
	Society	Contribution to Protein Affordability	Contribution to Protein Security	Quantitative/ Semi-quantitative

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4. Conclusions

The goal of the study is a comparison of P2F food prototypes with already existing food items potentially being replaced or improved by P2F food prototypes. P2F food products should therefore not only be equal or ideally better regarding factors like nutritional benefits and taste but also regarding their environmental and socio-economic profile.

The method described in this deliverable for modelling the food systems of interest within the P2F project including the indicators selected for the environmental and the socio-economic assessment is tailored to food products to be consumed in the EU. Results based on those indicators are expected to help project partners to identify environmental and socio-economic hot-spots and need for improvement of P2F products during the development phase. They are also expected to provide meaningful information on the environmental and socio-economic performance of P2F products as compared to food products already available on the market.

The method for LCA applied in this study is oriented at already well established general LCA guidelines like ISO 14044/44 and ILCD on the one hand and guidelines such as for the Life Cycle Inventory of agricultural products recent guidelines provided by the World Food LCA Database. These guidelines provide a framework for a rather robust making of assumptions and decisions in the context of the P2F project when it comes to modelling and environmental assessment of the food products to be examined.

The methodology for socio-economic assessment is much less developed and guidelines applicable to food products are scarce or even lacking. For these reasons, the indicators proposed in this deliverable will still have to be tested for their practicability. The final method therefore might still be subject to adaptations and changes.

To a certain degree, this also applies to some of the categories of the environmental assessment especially that of biodiversity. In this deliverable, a qualitative approach for a comparative "measurement" of more or less favourable impacts of food products on biodiversity has been described. Here too, based on insights gained during its application, methodological adaptations might be necessary. Where applicable, those adaptations will be documented in deliverable 5.3.

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5. Delays and difficulties

While Milestone MS12 had been met according to the schedule, the deadline of this deliverable had to be shifted (the EU project officer was informed about this in an email of 14 July 2017). This was due to unexpected cases of illness. However, the overall timeline of the P2F project (including timelines of future deliverables) will not be affected by this delay.

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