FoodE

D2.2 Methodological Framework to develop Life Cycle

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List of abbreviations

BCRS	Benefit-cost ratios
BMs	Business Models
CBA	Cost-benefit analysis
C-LCC	Conventional Life Cycle Costing
CRFS	City Region Food System
CRFSI	City Region Food System Initiatives
E-LCC	Environmental Life Cycle Costing
FIA	Financial investment appraisal
FU	Functional Unit
GA	General Assembly
GCM	General circulation model
ILCD	International Reference Life Cycle Data System
IRRs	Internal rate of returns
KPI	Key Performance Indicators
LCA	Life cycle Assessment
LCC	Life cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
LCT	Life Cycle Thinking
SDGs	Sustainable Development Goals
S-LCC	Societal Life Cycle Costing
SME	Small and medium enterprises

1. Executive Summary

The current deliverable describes the developments and outputs of the Methodological framework development of FoodE (Food Systems in European Cities) European research project. The contribution is part of the Task 2.2 in WP2 and consists in the development of a **coherent and flexible methodology for the integrated sustainability assessment of City/Region Food Systems Initiatives (CRFSI)**. The methodology is presented in two complementary deliverables, namely the methodological framework to develop Life Cycle (D2.2) and the data collection protocol (D2.3).

While the data collection protocol is intended to provide City/Region Food Systems (CRFS) stakeholders with further details for implementing both the simplified and the extensive assessment framework, the present methodological framework to develop Life Cycle supports the evaluation and ranking of the sustainability of diverse existing CRFSI at local and international level, presenting some key innovative features.

The framework adopts a **Life Cycle Thinking** (LCT) approach, integrating the social, economic, and environmental pillars and advancing on existing knowledge and past projects, with a detailed and operative guidance on several methodological issues, study parameters, related consequences, CRFS-related examples.

It operationalizes the **CRFS approach** from a system to an initiative (i.e. integrated local supply chain with multiple services) level, through a tentative definition of main typologies, products and services provided, sectors covered, etc. This definition is crucial to identify the aim of the study, the possible function(s) and system boundaries, the potential impacts and hotspots. Overall, CRFSI are profit or non-profit entities involved in one or more of the food systems stages, spanning from small to larger scale, with a relatively reduced workforce, the involvement of volunteers, and diffused use of digital solutions or online channels to disseminate their activities and/or sell their products.

The assessment framework consists of two main layers of assessment:

- a **simplified method, with a quali-quantitative perspective** and reduced data requirements, which can be adopted also by non-LCT practitioners aiming to a more synthetic and rapid appraisal of generic hotspots of impact;
- an **extensive method, with a quantitative approach** and increased data requirements, which is providing recommendations for LCT practitioners looking for more detailed guidance on specific methodological choices and more comprehensive impact assessment.

These two layers ensure a **flexible application** to various uses (e.g. preliminary scoping or perspective assessment), by different users (LCT experts or not), and towards different audiences (public, scientific community, initiative owners). In addition, in the case of the simplified assessment, a qualitative **scoring mechanism** allows to reach a single scoring equally weighing the 3 pillars.

Finally, the framework was designed with a **participatory process**, engaging a diversity of stakeholders with different expertise and background. In the specific, an open consultation process was adopted for the design of the simplified layer of assessment, while detailed guidance for the application of **co-design tools** was included in the extensive layer.

The graphical abstract (Figure 1) describes the possible application of this framework from the perspective of CRFSI.

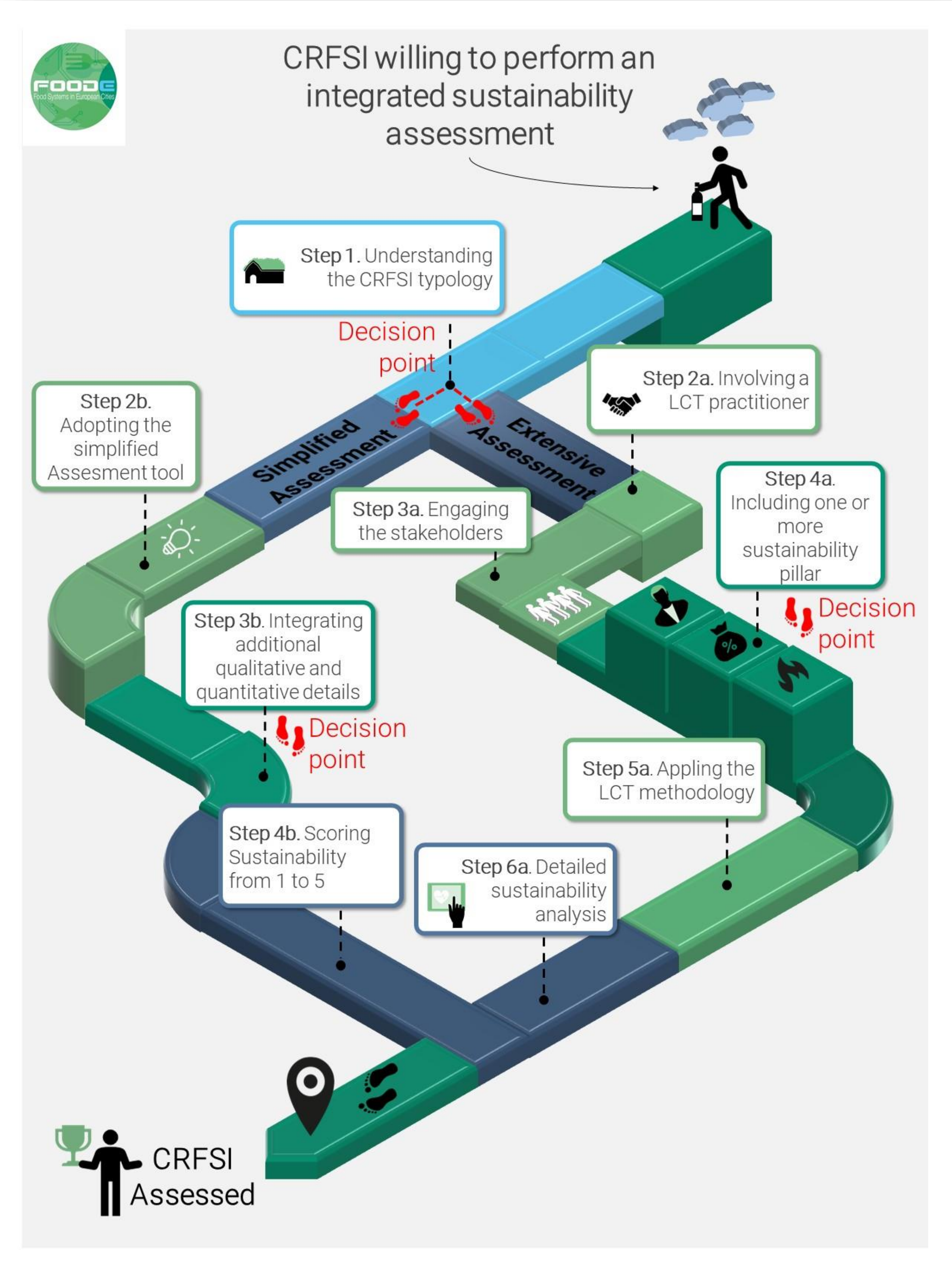

Figure 1 - Graphical Abstract

2. Background

FoodE – Food Systems in European Cities - objective

The main objective of FoodE is to involve European Union local initiatives in the design, implementation, and monitoring of environmentally, economically, and socially sustainable CRFS. The key challenge of the project is to improve food and nutrition security of European citizens by shaping a sustainable environment able to increase accessibility and availability of affordable, safe, and nutritious food. This challenge will be tackled by setting a co-created mechanism, based on Citizen Science and Responsible Research & Innovation principles, where public authorities, citizens, SMEs, and non-profit organisations can share ideas, tools, best practices, and new models, supporting cities and regions in developing innovative and sustainable food systems.

WP2 Objective

Considering and integrating all the recent advancements on sustainability assessment of CRFS, this WP aims at developing a methodological framework and an analytical decision support tool for the development of innovative business models and initiatives to enhance CRFS. More specifically, WP2 roadmap (Figure 2) foresees to:

- Create an inventory of innovative CRFS projects.
- Develop an integrated methodology for the interpretation and analysis of innovative business models and their suitability to apply in specific contexts.
- Apply, validate and refine the integrated methodology on case studies, including a sustainability assessment, also integrating revisions proposed by stakeholders during cross-pollination (WP3).
- Develop business case reports and carry out comparative analyses to identify barriers and key drivers of change.
- Develop an analytical decision support tool, based on the FoodE integrated methodology, to support decision-making of innovative business models and improve their performances and sustainability.

Figure 2 - Roadmap WP2

T2.2 Objective

Aim

An integrated methodology for the interpretation and analysis of more than 100 existing CRFS has been developed based on crucial KPIs identified in T2.1 and on existing knowledge (i.e.: past H2020 projects and relevant literature) and tools. The methodology allows a comprehensive comparative sustainability assessment of CRFSI and will be applied to analyse more than 100 selected in Europe, representing the different contexts and geographical regions, as well as the linkages between them. Coherently with the foundation of circular economy, a LCT approach has been adopted to assess both environmental (e.g.: carbon footprint, land use, etc.), economic (costs, net present value, value added, etc.), and social (labour, health, vitality of regions, innovation, etc.) impacts, in a cradle (biomass supply) to grave (final use) to cradle (re-use / recycle) perspective.

Integrated methodology composition

The integrated assessment framework is composed of two items helping CRFS stakeholders in implementing the sustainability assessment:

- Methodological framework (D2.2)
  This contribution presents a coherent and flexible methodology for scoping the evaluation of CRFS initiatives sustainability, with two layers: a simplified and ready to use assessment framework, and a detailed guideline for an extensive LCT study. The framework includes methodological guidance for the stakeholders and main actors related to the definition of consistent functional unit(s) and system boundaries that can allow a comparative evaluation, the typology of data to be collected for the assessment, and the appropriate indicators to be used.
- Data collection protocol (D2.3)
  This contribution presents the protocol for the data collection process related to the methodological framework. It provides guidance on the procedures and methods for retrieving coherent and useful information from the various CRFS initiatives to enable both the simplified and the extensive assessment. The data collection focuses on retrieving standardised data with an adequate level of detail for each assessment layer. To this end, several data collection protocols were created: they range from an initial, exploratory survey to a preliminary investigation of key sustainability features to a full LCT assessment.

These two items are complementary and provide a complete methodological and implementation guide for CRFS stakeholders. However, in case of specific needs, they can be used as separate sources of information (e.g.: by using D2.2 to build another type of collection protocol; by adopting D2.3 simplified DCP within the context of other sustainability assessment; by using the extensive DCP for other type of LCT studies).

Linkages with other WP2 contributions

Synergies and/or potential risks of duplication/overlapping with other WP2 activities have been explored and discussed. The methodological framework development has two major collaboration hotspots (Figure 3):

- Data collection and inventory (T2.3)
  A detailed data collection on the 100+ CRFS is conducted in a separate project section, building on the present simplified assessment framework. These two integrated contributions have been conducted in parallel to ensure adequate collaboration, correct timing and consistent participatory reviews. This collaborative approach ensured a recurrent and iterative dialogue as well as appropriate knowledge sharing. Additionally, literature reviews on specific themes related to CRFS conducted in a separate project

sections are envisaged to complement the primary data collected within the survey dissemination and deliver a sustainability assessment of the 100+ CRFS.

- Assessment of pilots and identification of best performances (T2.4)
  Building on the extensive assessment framework, a complete LCT analysis is conducted on the FoodE pilots. The codesign and participatory approach described here is aimed at delivering sustainability assessments with an effective impact on pilots' decision-making and continuous improvement.

Linkages with other tasks in other WPs

The present contribution is expected to provide outputs to and receive inputs from several FoodE WPs. Linkages mostly refer to three areas (Figure 3):

- The development of a framework of initiatives to foster **networking of CRFS stakeholders** (WP3). This step will develop (T3.2.2) and update (T3.2.3) the FoodE app, one of the major outcomes of the project. Apart from the mobile app aimed at improving the interaction between CRFS and citizens, a web app with a back-office and a landing page will be created to facilitate the introduction of by CRFS owners. This data will be also used as basis of the calculations for the sustainability assessment of CRFS. During the first stages of the app development, the link with WP2 will strictly be in terms of data collection and inventory processing (T2.3) to gain insight on the best way to proceed. Moreover, at later stages of project, the app will be one of the major tools to collect data from the CRFSI. Based on this data filled by CRFSI owners through the back-office web, key indicators identified in T2.2, T2.3 and T2.4 will be integrated in the app.
- The international challenge for the **co-design of innovative CRFS pilots** (on both established and newly implemented projects) (WP4), which will nourish with new data and indicators the sustainability assessment explored in the present report. More precisely, the FoodE Challenge (T4.1) was developed also based on the here explored sustainability assessment indicators.
- The **business models and validation of CRFS** (WP5), which uses the present simplified methodology for the CRFSI assessment developed as background for the selection of relevant sustainability indicators. The specific environmental, social and economic sustainability indicators identified in WP2 will be integrated within the business models of CRFSI to allow a greater understanding of their sustainability impacts. This integration will allow the development of innovative BMs integrated with the LCT methodology. Furthermore, previous activities of sustainability assessment in existing pilots (WP2) will allow for compiling the simplified dataset of indicators suitable for the online survey tool (T5.3) and certification standard (T5.4) and will also guide the elaboration of upscaling policies and tools in WP6.

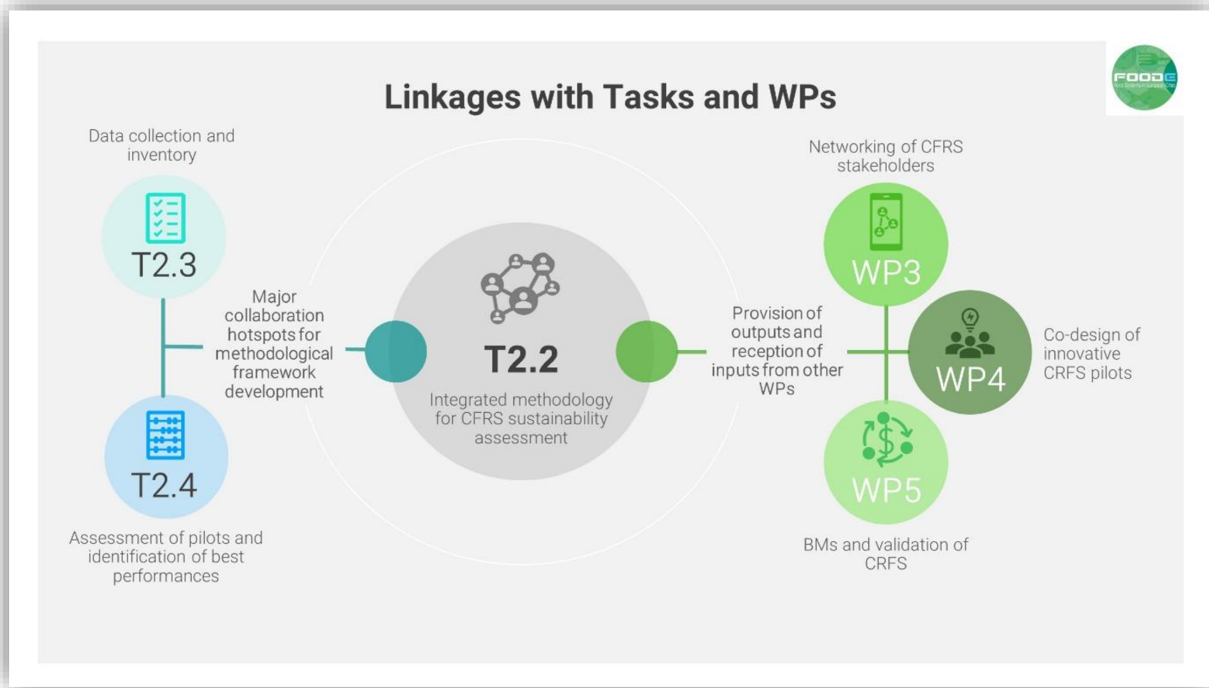

Figure 3 - Linkages with Tasks and WPs

3. Methodology

This section describes the general approach that was adopted to build a consistent and flexible framework, in coherence with FoodE strategy and objectives. Figure 4 provides an overview of this approach.

LCT constitutes the first conceptual foundation of the framework. The evaluation of sustainability of food systems within city-regions implies embracing the multiplicity and complexity of supply chains, impact pathways, and affected stakeholders in different areas. This challenge can be addressed only by going beyond the production site and related processes and by including all sustainability dimensions. Thus, the systemic and holistic perspective proper of LCT was adopted. Section 3.1 elaborates on this foundation, providing non-LCT practitioners with a general understanding of LCT approaches and methodologies and explaining how they were included in the development of the framework.

The CRFS perspective featured within FoodE constitutes the second key conceptual approach. Starting from the general framework described by FAO-RUAF (2016) and the characteristics of the 600+ initiatives surveyed in previous project steps (T2.1), a working definition of CRFS initiatives was identified focusing on the type of organization, food-related operations, workforce, size, and relations with customers. This definition was used for the selection of the 100+ CRFS initiatives to be assessed and for the initial identification of the framework goal and scope. Section 3.2 describes the definition and the criteria.

The backbone of FoodE methodology for sustainability assessments of CRFS builds on key projects and initiatives conducted by FoodE partners in recent years and peer-reviewed literature (e.g.: Sanyé-Mengual, 2015, Gasperi et al., 2016; De Menna et al., 2018). These studies allowed the definition of innovative tools, moving away from purely environmental or economic analysis, towards more comprehensive approaches. The existing body of knowledge, which was extensively reviewed as presented in Section 3.3, represented the basement of the framework.

Coherently with the Citizen Science and Responsible Research & Innovation principles, a participatory approach was adopted to co-design the assessment framework. The process consisted of various activities aimed at informing, consulting and/or engaging various experts and stakeholders. These steps allowed a continuous dialogue between LCT practitioners, researchers from various fields, civil servants, SMEs in the definition and tailoring of the scope and methods of the framework. Section 3.4 provides a more detailed summary of this process.

Finally, framework testing and validation aimed at ensuring the applicability of the framework. Also in this case, a participatory approach was adopted, involving selected CRFS initiatives owners in testing the final survey of the simplified assessment for comprehensibility, duration, and easiness of response. A guidance for the engagement of CRFS initiative owners was also added for the testing and validation of the extensive framework. Section 3.5 describes these specific features.

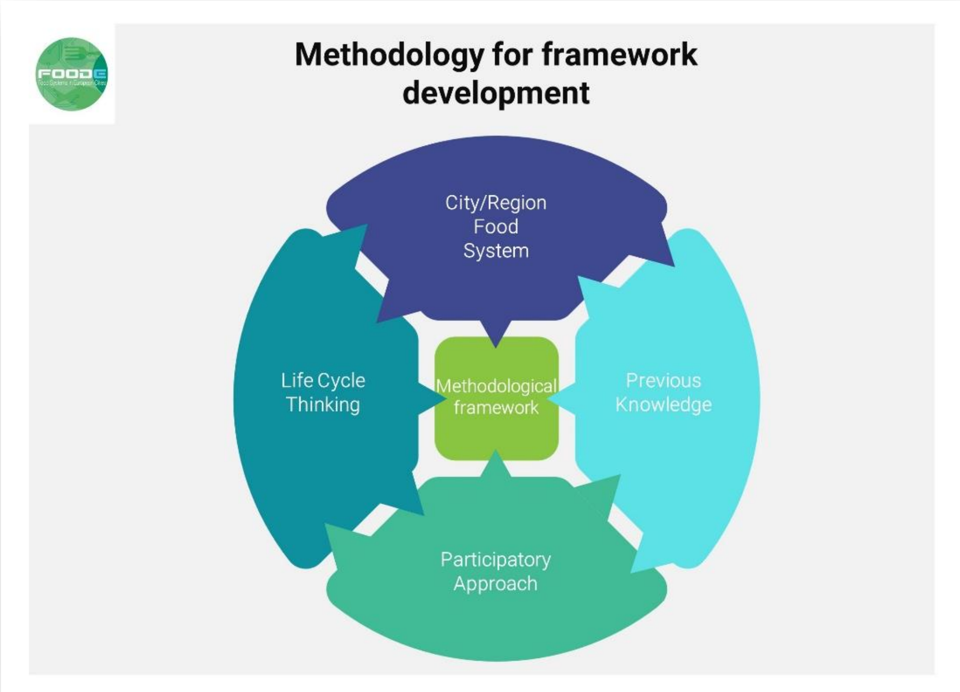

Figure 4 - Methodology for framework development

3.1 Life cycle thinking

LCT is "a holistic approach that considers sustainability factors over the entire life of a product" (Mcconville & Mihelcic, 2007). Its perspective of products and systems allows including all stages and impacts from raw material extraction and manufacturing to end of life treatments (ISO, 2006).

Sustainability pillars division

The LCT assesses the three pillars of sustainability: social impact (e.g. labour, health, innovation, etc.); economic impact (costs, net present value, value added, etc.); environmental impact (e.g. carbon footprint, land use, transport, etc.). The three pillars of sustainability are not mutually exclusive and can be mutually reinforcing. In fact, the pillars are interdependent, and cannot exist without the others.

The Social pillar focuses on the process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work at.

The Economic pillar represents a broad interpretation of ecological economics where environmental and ecological variables and issues are basic but part of a multidimensional perspective. Social, cultural, health-related and monetary/financial aspects have to be integrated into the analysis (Soederbaum, 2008).

Finally, the Environmental pillar concerns the human impact on ecology, as well as enhancing ecosystem services. Three broad criteria for environmental sustainability are: 1) renewable resources should provide a sustainable yield (the rate of harvest should not exceed the rate of regeneration); 2) for non-renewable resources there should be equivalent development of renewable substitutes; and 3) waste generation should not exceed the assimilative capacity of the environment (Daly, 1990).

These three pillars served as a common ground for numerous sustainability standards and certification systems in recent years, in particular in the food industry.

Methodologies

The main tools that have been developed in the past decades are divided in the three sustainability pillars: a complete LCSA of a product or a system will encompass the quantification of its environmental performance (LCA), economical costs and value (LCC) and social impacts (S-LCA).

LCA is based on ISO 14040, and is used "to address the environmental aspects and potential environmental impacts [...] throughout a product's life cycle from raw material acquisition [...] to final disposal" (ISO, 2006). It consists of four main phases carried out iteratively, as outlined in Figure 4 - Methodology for framework development (1) Goal and Scope, (2) Life Cycle Inventory, (3) Life Cycle Impact Assessment and (4) Interpretation.

LCC, which has been standardized for a set of products (ISO 2000, 2008), assesses costs occurred during the life span or cycle of products and services (De Menna et al., 2018). Hunkeler et al. (2008) distinguished three approaches, C-LCC, E-LCC, and S-LCC, differentiated by the single vs. multiple actor perspective and the inclusion of direct cost only or the monetisation of environmental and/or social externalities for more actors (Gluch and Baumann, 2004; Hunkeler et al. 2008; Korpi et al.,2008; Woodward, 1997)

S-LCA assesses social impacts of products and services across their life cycle, through a systematic qualitative-quantitative evaluation. It can focus on both positive and negative effects, classified in impact categories, on various stakeholders, from consumers to value chain actors and local communities. S-LCA can be applied either a or in combination with LCA and/or LCC.

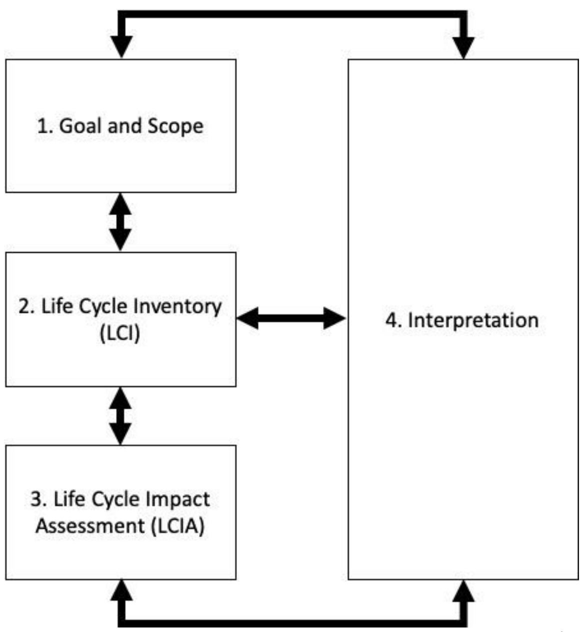

Figure 5 - Four main phases of LCA according to ISO 14040 (ISO 2006)

FoodE advancement: Tailoring LCT to CRFS

> *FoodE Advancement*
>
> *Tailoring LCT to CRFSI*
>
> Adopting an integrated LCT methodology to build a simplified and an extensive layer of assessment for CRFSI and providing guidance on their implementation.

Starting from the three mentioned tools, the novelty of the present FoodE methodological development consists in the **modelling of the LCT on CRFS initiatives**. These tools were then adapted to build the two layers of the assessment. The simplified one adopts the same pillars and includes several key indicators with a mixed quali-quantitative approach with the aim of a final scoring. The extensive one provides CRFS-related full guidance on methodological options and related consequences, including examples. When applied simultaneously, LCA, LCC, and S-LCA should follow the same 4 phases, sharing specific methodological features. A description of these phases is provided here to offer non-LCT practitioners a basic understanding of their general features and how they were addressed in the present framework.

- **Goal and scope:** the framework provides guidance on the possible different goals, application, audience, and reasons when assessing a CRFS initiative. It offers potential options on crucial parameters and related consequences, such as the system function and related functional unit (FU) (the reference quantity of product that will be used to normalize all inputs and outputs), and the system boundaries, which establish the processes included and excluded in the assessment. Quality of data, assumptions used, potential limitations and data quality requirements are also part of the goal and scope phase.
- **LCI:** the framework recommends what flows to include depending on the study, how to collect data about such flows, and how to attribute them to the functional unit, especially in the case of multifunctionality. Considering the general iterative approach of LCT, the data collection process foresees the use of both primary and secondary data sources as an accepted practice. The related collection protocol is included in D2.3.
- **LCIA:** the framework highlights what are the possibly relevant impact categories that can be selected to evaluate the environmental, costing, and social performance of the system under study. Both the mandatory steps of classification and characterization depends on this choice, as each elementary flow from the LCI related to the FU must be allocated to specific impact categories and then multiplied by characterization factors that define how harmful that elementary flow is for that specific impact category. Moreover, there are two optional phases in LCIA: the normalization step aims at comparing the values of the impact categories to a default reference information while the weighting step creates single values through the aggregation of impact categories by defined weighting factors. The framework includes ideas also for such optional steps.
- **Interpretation:** the framework addresses the specific features related to the joint results interpretation, organisation, contextualisation, and communication. This final step is crucial in providing an overview of the results consistent with the goal and scope definition and identifying improvement options.

3.2 Defining CRFS initiatives

The CRFS approach goes beyond the city limits and reinforces the food flows of both urban and rural areas, promoting sustainable food supply chains in a multidisciplinary framework (Jennings et al., 2015). It encourages the sense of community through diverse, and resilient food systems (Hamm, 2015), and stands to improve the ecosystem status and natural resources management (FAO and RUAF, 2015). Given its nature, the CRFS approach leads to an assessment of actors' interactions supporting recurrent exchanges and participatory actions across stakeholders (Dubbeling et al., 2017).
Building on the CRFS definition from FAO & RUAF (2015) that defines "it as an approach aimed to foster the development of resilient and sustainable food systems within urban centres, peri-urban and rural areas surrounding cities by strengthening rural-urban linkages", data collected in previous step of the FoodE project (T2.1) allowed to **move from the *approach* to the CRFS *initiative*** definition.

> *FoodE Advancement*
>
> Moving from CRFS approach to CRFS initiative
> CRFS initiatives can be defined as profit or non-profit entities involved in the food system and being in one or more of the following activities: agriculture & fishing, food processing (transformation of agricultural products into food etc.), food distribution (wholesale, retail, community supported agriculture etc.), food service and consumption (catering, cooking, restauration, etc.), food waste management and education and services. Their workforce is often composed by less than 10 employees, with volunteers involved in several cases, and diffused usage of digital solutions and/or online channels to disseminate their activities.

In particular, the phase of data collection and identification of key features allowed to characterise European CRFSI and to define them through their key activities, relevant external and internal partnerships, impact areas, innovation strategies, collaborative attitudes and COVID-19 structural adaptations. Overall, CRFS initiatives can be defined as profit or non-profit entities involved in urban and periurban food system as described in the Box.

3.3 Previous knowledge

Past projects

Among **key projects** and initiatives operated in the recent past by FoodE partners, the ones with relevant contribution towards an integrated methodology **for a sustainability assessment of CRFS were selected to build on existing knowledge.** The full list of selected projects is presented in Appendix 1, along with the covered pillars and the general methodology. Here a brief overview is provided.
SustUrbanFoods (2016 – 2018) implemented an integrated sustainability assessment of social and technological innovations of eleven urban food systems in five European cities. Among these, five were dedicated to social innovation and six to technological innovation. In the context of SustUrbanFoods, scientific papers were produced for results dissemination. Specifically, Sanyé-Mengual et al (2018) assessed the eco-efficiency of home gardens as a type of urban agriculture. To do so, a case study in Padua (Italy) was evaluated via LCA and LCC, employing the ReCiPe method for the impact assessment. Another study of Pennisi et al. (2019) quantified the environmental and economic profile of Light Emitting Diodes lighting in indoor farming systems. In this case, the International Reference Life Cycle Data System method was employed for the impact assessment.
Two projects addressed food waste streams. Re-fresh (Resource Efficient Food and dRink for the Entire Supply cHain, 2015-2019) delineated the generic strategy for the evaluation of food side streams valorisation through the incorporation of LCA and LCC methodologies. The project implemented generic models for the FORKLIFT tool, aiming at the assessment of food side streams valorisation into valuable compounds through diversified routes, such as fertilizer application, anaerobic digestion and disposal and providing a valuable reference for such

scenarios. On the other hand, FUSION (Food Use for Social Innovation by Optimising Waste Prevention Strategies, 2012-2016) contributed significantly to the harmonisation of food waste monitoring, validated the feasibility of social innovative measures for optimised food use in the food chain and contributed to the development of a Common Food Waste Policy for EU28.
Valumics (Food Systems Dynamics, 2017-2021) tackled social and economic pillars focusing on the development of fairness indicators for food systems and food value chains, the modelling of traceability information and prices, and systems implementation. In particular, Gudbrandsdottir et al. (2021) assessed fairness in food systems via simulation modelling by defining the social construct of fairness in model operational terms. Five indicators were chosen: profit margin as an indicator of distributive fairness and four indicators of procedural fairness related to market power and bargaining power. Price fairness was recently addressed by other studies and recognized as a key sustainability feature of products in the perspective of consumers (Samoggia et al. 2021).
EdiCitNet (Edible Cities Network, 2018-2023) developed “Guidelines for participatory impact monitoring including Citizen Science”, which provides a framework that helps citizens monitoring the impact of their production systems and gather significant data to be analysed. In particular, “training and education” and “business attracted” are included as economic indicators, “participation” and “ownership and agency” as social indicators, and “amount of food/garden waste composted” as an environmental indicator. In the context of Climate KIC, UrbaClim (Urban Agriculture – Climate Benefits Compared with Conventional Food Chains, 2017-2018) and CIPURA (Climate and Innovation Potential of Urban Agriculture, 2016-2017) mainly addressed the environmental impacts of food chains and urban agriculture.
The EUphoros project (optimal greenhouse climate systems, minimal resource requirement, 2008-2012) performed an LCA-based environmental study coupled with a complete financial assessment for several scenarios. Interesting results from GROOF (Greenhouses to Reduce CO_2 on Roofs, 2017-2021) and FEW-meter (an integrative model to measure and improve urban agriculture towards circular urban metabolism, 2018-2021) are expected in 2021. The first is investing in 4 pilot plants designed to prove the effectiveness and durability of the models related to different building types, in Belgium, Germany, France and in Luxembourg. The second uses an extensive data collection on all 3 pillars from 70 different gardening and farming initiatives in France, Germany, Poland, the UK and the US to explore the food-energy-water nexus efficiency and the social impact of UA (Caputo et al. 2020; Kirby et al. 2021) and develops scenarios at the city level modelled with a LCA approach to identify pathways for an optimal use of urban resources, including two experiments regarding soil remediation and anaerobic digestion.
Finally, Fertilecity I and II projects tackled all 3 sustainability dimensions of urban food production along 6 years of continuous research. Altogether with the analysis of consumer’s perception or business models for urban agriculture, Fertilecity I and II focused on the potentials and limitations of Integrated Rooftop Greenhouses (I-RTG), one of the newest and more complex forms of urban agriculture. Thanks to the implementation and monitoring of a real-case I-RTG research laboratory, several doctoral theses with impacting LCT focus papers have been produced (e.g. Llorach-Massana 2017; Sanjuan-Delmás 2017; Rufí-Salís 2020)
Some of the research linked to the above-mentioned projects used more standardised methods for their indicators choice while other studies focused on the development of new indicators, especially regarding the S-LCA, for example when it came to the assessment of innovation in urban agriculture. In general, while the evaluation of the environmental impacts through LCA is already standardised, its integration with other methods to include economic and social impacts of food production systems has been tackled in a variety of ways, and it calls for a more integrated approach, to be eventually generalised for CRFS.

Literature review

To integrate previous projects, a **critical literature review of integrated LCSA of CRFS** was carried out using the keywords "life cycle sustainability assessment" and "food" on the Scopus database to derive an overview of current knowledge, possible indicators, assessment methods, etc. Appendix 2 summarizes some of the relevant works along with information on pillars, general approach, and methodology.

None of the studies above mentioned performs a sustainability assessment of CRFS that integrates LCA, LCC and S-LCA methodologies, but some partial or alternative integrations have been found. Stillitano et al. (2021), dealing with a systematic review of the agri-food processes, highlights that 52 out of 84 analysed case studies implement a stand-alone LCA to specifically evaluate benefits and impacts of circular economy strategies in the context of agri-food activities. On the other hand, only 8 studies combined LCA with the LCC approach, while none of the analysed papers dealt with S-LCA. Only few studies came up with specific indicators for Circular Economy assessment while the vast majority applied most common indicators such as global warming potential, eutrophication (for marine, freshwater, and terrestrial ecosystems), human toxicity.

Among the studies shown in Appendix 2, Dorr et al. (2017) is the only paper directly integrating LCA and LCC approaches specifically dedicated to a sustainability evaluation of a CRFS, a rooftop garden in Paris producing tomatoes and lettuce. The environmental impact categories considered are midpoint categories, as described by ReCiPe 2008, and include climate change, human toxicity, water depletion, marine eutrophication, and fossil fuel depletion. These indicators were chosen because they reflect issues that are paramount in agricultural systems. Concerning the LCC analysis (ISO 2008) for the evaluation of the economic impacts of the garden, Total Cost was used as indicator.

Results from a recent study of Harun et al. (2020) implementing LCA to evaluate the environmental performance of rice production agri-food systems in Malaysia showed that rice cultivation impacted the environment, particularly in relation to three impact categories: global warming potential, water consumption and fossil fuel depletion. The cultivation phase of rice production was the main contributor to environmental impacts due to the production and application of fertilizer and pesticides.

A life cycle impact category indicator was evaluated for 17 different impact categories at the midpoint, and then the indicators were divided into three damage assessment categories at the endpoint level through the ReCiPe 2016 method developed by Huijbregts et al. (2016). Chami et al. (2015) designed a novel framework to assess the sustainability of winter wheat under climate change conditions and irrigation as an adaption measure to reduce yield variability. The methodology covers social, economic and environmental pillars by integrating a LCA model and economic modelling with outputs from a general circulation model, the Food and Agriculture Organization's for the social part, and crop growth model (AquaCrop). Two climate change scenarios were compared, a low emission (B1) and a high emission one (A1). For the evaluation of the economic efficiency a cost-benefit analysis was a key component of the integrated framework for the financial investment appraisal of different options. The net present values were calculated as an indicator of economic viability over the life cycle of the project. Other economic indicators were also selected for this aim, namely the internal rate of returns and the benefit-cost ratios. The evaluation of the environmental sustainability was performed by using a selection of water-related indicators and CO_2 emission indicators to evaluate the negative externalities of wheat production on air and water resources. The first indicator was the global warming potential. Water-related indicators were selected according to data availability: surface water withdrawals and introduced by FAO as a key environmental integrity indicator of water resources (FAO, 2013b); irrigation use efficiency (used as an indicator to maximise water productivity and to sustainably allocate resources). The added value of water (extra benefit of irrigation generated per unit volume of water) showed, in economic terms, how water contributes to the production value. The social dimension was covered by adopting the food security indicator classified under the safety indicators by the FAO, which could support shocks and increase human well-being. In this case, food security was measured through the yield increase. The study also stresses how income increase could also be considered a social indicator as the extra money generator would be spent on farmers' well-being. Finally, the study carried out a sensitivity analysis to find out how the added value of winter wheat would respond to price fluctuations and variations in the total costs of production.

Regarding livestock, an interesting study of Hiablie et al. (2018) tackled the environmental sustainability assessment of beef production systems in USA by using the LCA approach. Impact metrics included emissions in water, cumulative energy demand and land use. Air emissions were acidification potential, photochemical ozone creation potential, global warming potential, and ozone depletion potential. The remaining metrics calculated were abiotic depletion potential, consumptive water use, and solid waste. Among the relative points adding up to 1 for each impact category, 0.93 was the contribution of livestock feed phase only to the human toxicity potential. Finally, a systemic analysis of Food Supply and Distribution Systems in City-Region Systems was performed by Armendáriz et al. (2016) through the examination of FAO's Policy Guidelines towards Sustainable Agri-Food Systems. The model analysis stressed the importance of enhancing sustainability and resilience of food systems with large emphasis on: estimation of local territorial carrying capacities; land use planning to encourage connections among rural supplies and city needs; city policies, to regulate emergent market size and local scale of production; technological efficiency at farm, distribution and market levels; urban, peri-urban and rural functional linkages embedding social metabolic balances; rural development as a core point for building sustainable food systems and counteracting the urbanization growth.

This literature was used in combination with knowledge from previous projects to derive an overview of existing tools and indicators that constitute the base of the framework. The initial design of the simplified and extensive layers included the most common of these indicators to then start an iterative participatory consultation for the final framework development.

3.4 Co-design and participatory consultation

As envisaged by the project structure, the **involvement of a variety of stakeholders** had a key role to support the development of the integrated assessment methodology and was deemed necessary to deliver a coherent tool. To this aim, a participatory consultation was used to promote the framework co-design, the engagement of youth and professionals, and the networking outside the FoodE project. The participatory consultation was conducted in three main phases. The consultation process was constructed to include multiple hierarchical levels, from the institutional perspective to CRFS actors. Due to the multifaceted nature of the sustainability concept, it was necessary to involve a variety of professionals with different knowledge and backgrounds to get a better understanding of the topic. Overall, more than 100 people were involved in various steps from M1 to M16.

A first consultation step, aiming at involving the FoodE actors on a recurrent basis, was organised during the GA FoodE meetings. The FoodE consortium is composed by 23 partners with a wide diversity of perspectives and expertise on urban food systems. The GA thus includes professors and researchers, food businesses and FoodE pilots' owners, NGOs professionals and municipal actors dealing with food policies.

Primarily, the FoodE kick-off meeting (M1), served to launch a preliminary brainstorming on the CRFS definition and its sustainability dimensions. During the WP2 session, a live survey was launched and all attendees (around 68 staff from consortium partners) were involved in a participatory discussion. This initial activity was used to set the scene and create a common vocabulary on CRFS sustainability. After compiling the database of CRSFI in Europe, one year later (M13) during the third FoodE GA meeting a second online session was organised. It consisted in simplified participatory review to get feedback on the most effective KPIs to be used when measuring sustainability and on the relative selected questions needed to investigate them. The discussion was developed via collective brainstorming guided by T2.2 task participants. Outputs were used to design the KPIs for the simplified methodological assessment and the relative questions.

A second consultation step on the sustainability of CRFS was developed during the FoodE Winter School, taking place online in M13.The winter school was elaborated on purpose to simoultaneously obtain awareness creation and stimulate participatory co-design for the assessment indicators and as a contingency strategy to counteract Covid19 limitations. The involved arena including young and senior researchers, students and professors, interested in the food system sustainability evaluation. It was composed both by FoodE and non FoodE members, for around 50 individuals from different universities such as Universitat Autònoma de Barcelona, University of Bologna, University of Milano, University of Napoli, Norwegian University of Life Sciences and University of Bath, among others. A total of 18 organisations from 7 different countries (Spain, Italy, France, Germany, Netherlands, United Kingdom and Norway) were involved in the FoodE Winter School either as participants, speakers or organizers.

Within the workshop (that lasted 24 hours and was awarded by 3 ECTS by partner universities), participants were involved in two afternoon sessions on the environmental and on the integrated economic-social assessment, respectively. The different working groups were set up to share expertise in a mixed way across the different discussion tables to ensure multidisciplinary knowledge sharing. In each group, exercises on specific CRFS case studies were carried out to stimulate participants to offer their views and experiences on how to assess the sustainability of CRFS.

The sessions were finalized by a public survey tool (i.e. Mentimeter) asking participants insights into their perception of:

1. how a CRFS should be defined; and
2. which are the most important characteristics a CRFS should have to be considered sustainable.

Outputs were used to improve the simplified methodological development. The final consultation phase involved experts only and was conducted in M15-M16. It consisted in a final round of participatory revisions from around 15 well-recognised researchers working specifically on the sustainability of the agri-food sector. Starting from the finalized simplified survey, a methodological refinement was advanced. Professionals from fisheries, growing systems and animal husbandries were asked to verify whether the question structure was appropriate for respondents and if the required information was likely to be measured and shared by the respondents. Discussions were organised online, both on a bilateral basis and as mixed working group and results were used to revise the simplified survey.

3.5 Testing and validation

The final feature of the approach was the testing and validation of the assessment framework. **This phase aimed at ensuring the applicability of the framework and at validating the data collection protocol.** Also in this case, the involvement of relevant experts and stakeholders played a crucial role. Experts and researchers addressed in the co-design and participatory consultation provided various feedbacks on the efficacy, the detailedness and the clearness of questions. Selected five CRFSI owners were involved in testing the final survey of the simplified assessment. They were asked to answer the various questions and then to provide feedbacks on the following aspects:

- Comprehensibility;
- Duration;
- Ease of response.

As for the extensive framework, considering its flexibility and the potentially different uses, it was deemed useful to add a specific guidance for the engagement of CRFS initiative owners in the 4 main phases of the life cycle thinking approach. Recommendations are provided for the iterative testing and validation of the extensive framework during the co-design of its goal and scope and impact assessment decisions. Section 3.5 describes these specific features.

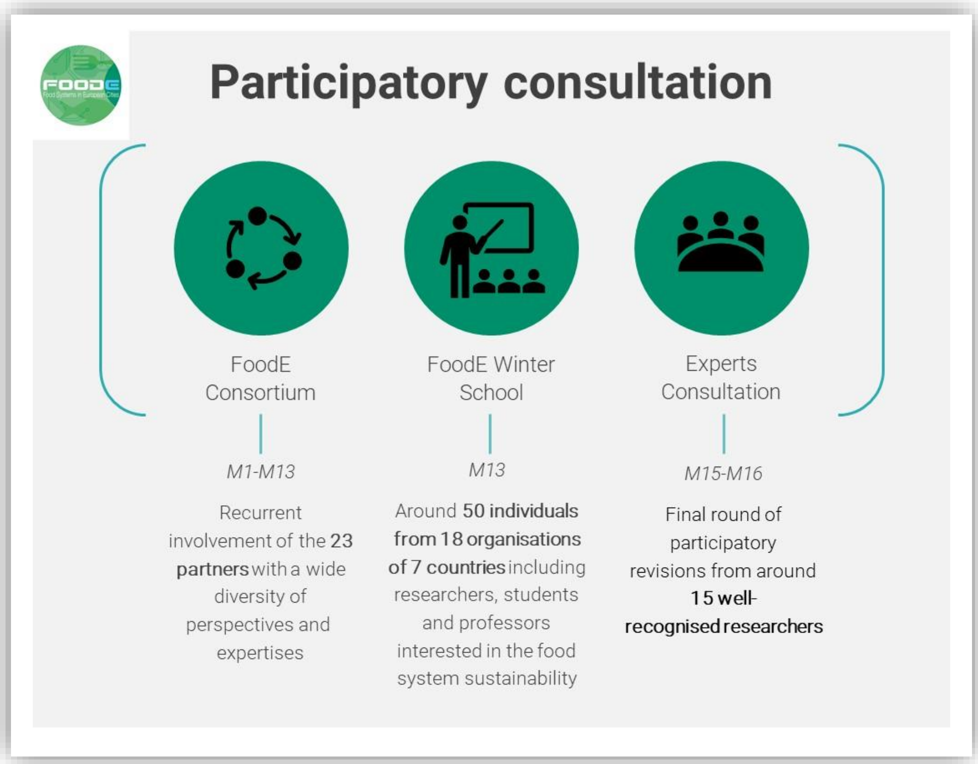

Figure 6 - Participatory Consultation

4. CRFS Assessment framework

Simplified Framework

General description

The aim of the simplified framework is to provide a rapid quali-quantitative appraisal tool for the evaluation of CRFSI that builds on LCT approaches as outlined in Section 3, but that can be applied by LCT practitioners for a preliminary scoping and also by non-LCT practitioners for a generic analysis and understanding.

The goal and scope of this framework, the selection of impact categories and related KPIs, and the final scoring mechanism are presented here below. The related data collection protocol that identifies the process to select CRFSI, the survey, its dissemination strategy, and data management, is provided in D2.3.

Goal and scope

The goal of this simplified framework is to analyse the sustainability of CRFSI through a single synthetic but comprehensive and coherent tool that can be easily managed by non-LCT practitioners (such as CRFSI owners or relevant stakeholders) and provide reliable quali-quantitative information about CRFSI general performances. Results can be used to identify aspects needing improvement or attention and valorise efforts towards an increased sustainability in an effective and communicable way. As such, it is not intended to substitute for a full LCA, LCC, and S-LCA assessment, but it can be used as a scoping tool by LCT practitioners in the design phase of a complete study comparing scenarios.

The scope of the simplified framework is constituted by the CRFSI as defined in section 3.2. Such initiatives are characterized by a wide diversity of functions, products, and processes, making it difficult to identify a unique function and related reference flow. In addition, the framework has a mixed quali-quantitative nature. Therefore, it adopts an organizational perspective, focusing on the yearly operation as common functional unit. Similarly, since CRFSI might deal with various stages or activities within the food supply chain, the system boundaries and related data collection are cradle to gate, including food production (either farming, animal husbandry, fishing), inputs for processing and/or service, transport to consumers. The selection of impact categories and KPIs (see following paragraph) was limited to focus on the relevant hotspots, based on previous knowledge and the open consultation (see Section 3). Therefore, the preciseness and completeness of data is forcibly reduced in comparison with a full LCT study.

Impact categories and KPIs selection

The Impact categories and KPIs are formulated to translate the complexity of sustainability to clear and manageable metrics. The factors that primarily contribute to the impact of a CRFS in each of the pillars are synthetized and converted to practicable indicators. These KPIs are then refined and detailed in an iterative process of literature review, insights from previous projects and participatory consultations with experts from research and industry.

Each sustainability pillar described in Section 3 is investigated through a set of impact categories, each of them composed by selected KPIs.

The Social Pillar focuses on both the embedment of the CRFS in the community, as well as the quality and safety of their food.

- Job (quantity, quality, diversity) - A direct social impact is the creation of jobs within the community. Important factors are the number of jobs, compensation, workforce composition and training. Furthermore, gender balance is another predictor of a positive impact.
- Community outreach, engagement & education - The direct social impact on the community is also closely related to engagement of a certain demography. It is

measured in number and type of events organised or even community training opportunities.
- **Food quality and safety** - Quality characteristics include several perception factors (appearance, texture, and flavour) and products characteristics (price, animal welfare degree etc.).

The **Economic Pillar** focuses on the general cost structure and market of each CRFS.
- **Organisation profitability and outlook** - Key aspects are the general profitability in terms of profit margins, revenue diversification (product revenue, activity revenue or other forms of income such as public or private funding) and the business future outlook.
- **Local economic development** – The embeddedness of CRFSI within the local economy represents an important source of economic impact. This is proxied by assessing the locally sourced supply and labor, as well as fair practices towards suppliers.
- **Customer and users' profile** – the customer profile is analysed to give an overview of the market and operations of the CRFSI, to assess if CRFSI meet citizens' and consumers' dietary habits, perceptions, values, and attitudes, on CRFS food offer and food commercialization. This sustainability analysis allows to assess to what extent the various CRFSI types satisfy the various customers' purchasing behaviour habits.

Finally, the **Environmental pillar** focuses on the ecological footprint of the products and services from each CRFS.
- **Food production/supply** - this stage represents a relevant hotspot of environmental impact. It can be predicted by verifying e.g., the typology of technology used for crops production, the animal feed provenance, the typology of fishing gears, the inclusion of agricultural biodiversity measures, and certain food characteristics.
- **Resource use efficiency** - The use of different resources, such as water, energy, fossil fuel, has a direct environmental impact. It is important to investigate how these resources are used and potentially reused.
- **Waste management** - Another direct impact is constituted by waste. Waste production and measures to reduce or reuse waste are mapped.
- **Transport** – Transport of food from suppliers and to consumers represents another relevant impact category.

Several other impact categories and KPIs could be considered. Some of them were entirely excluded based on prioritisation by stakeholders engaged, to ensure a reduced data intensiveness and guarantee the comparability of the framework. As an example, animal welfare is considered just from a costumers/users perspective while it is not investigated in terms of production systems as not all investigated CRFSI involve animal husbandry or have access to information regarding the animal welfare practices carried out at farm level. Hence, including specific sections on such a sustainability dimension would have excluded from the framework application a set of CRFSI, endangering the innovativeness of the present contribution and limiting results.

Others were included in the simplified framework and in the related data collection protocol, but not considered for the sustainability scoring of the CRFSI. Specifically, these include additional information on the consumers/users' profiles of CRFSI and on the environmental behaviour of the initiative. In the first case, some additional characteristics of consumers/users were considered as important to contextualise the CRFSI activities but were not suitable for a sustainability degree assignment. Examples are the age and the household conditions of the customers/users. In the second case, a much-detailed environmental performance is inquired asking for quantification of inputs and outputs of the different CRFSI. This section was designed to allow the analysis of the environmental performance but is considered as an optional appendix to be conducted only for CRFSI able to provide the set of required data with a predefined unit (kg, m^3, tonnes, kWh).

Table 1 - Social Pillar

Social			
Impact category	KPI	Description	Unit
Job (quantity, quality, diversity)	Waged jobs	The number of employees that receive a financial compensation	n of full time and part time paid employees
	Contract typology	The prevalent typology of contracts within the organisation	Degree of fixed term/temporary contracts
	Average gross monthly salary	The average monthly gross wage received by employees.	€/employee
	Workplace Trainings	The frequency of workplace trainings per employee	Hours/year/employee
	Gender gap	Share of female waged employees over the total number of employees	%
Community outreach, engagement & education	Frequency of events	Frequency of events organised by the initiative for the local community public.	frequency events/year
	Disadvantaged people	Activities for the disadvantaged people of your community	Y/N
	Connection with local producers	Management of food coming from local producers.	Y/N
	Volunteering activities	Involvement of community people in volunteering activities	Y/N
Food quality	Product characteristics	Taste, freshness, healthiness and nutritional quality, availability, affordability and fair price, animal welfare, food safety, food chain fairness, variety of food offer, being local, environmental sustainability	Importance degree

Table 2 - Economic pillar

Economic			
Impact category	KPI	Description	Unit
Organisation profitability and outlook	Annual net profit margin	Annual net profit margin in positive or negative percentage	%/year
	Sales revenue	The revenue produced by product sales.	%/year
	Activity revenue	The revenue produced by organised activities.	%/year
	Public funding	Funding received from public institutes.	%/year
	Private funding	Funding received from private institutes.	%/year
	Business future	Expectancy on the change of the business for the upcoming 3 years relative to product sales, other revenues, profits and number of customers/clients/users	Degree of change
Local economic development	Provenance of employees	Area of provenance of the waged employees	Administrative levels
	Locally sourced supply	Supplies sourced locally (from suppliers within a distance of maximum 50 km from your venue)	%
	Suppliers practices	The presence of specific fair practices towards suppliers	Y/N
Customer and users	Customers/ users acquisition	New customers or users per year	Degree level
	Customers/users return	Quantity of customers coming back after the first time	Degree level
	Customer/user expenditure	Expenditure increases of each customer/user	Degree level

	Customers/users return reason	Quantity of customers/users coming back because recommended by others	Degree level
	Direct sale	Customers per month	N/Month
	Target end customers	Age, household typology, interests of the end customers	-
	Online selling	Presence of online selling channels	Y/N

Table 3 - Environmental Pillar

Environmental			
Impact category	KPI	Description	Unit
Food production/ supply	Technology used for crops	The technology used for the crops produced, managed or sold	Typologies
	Animal fed provenance	The distance of the meat feed produced, managed or sold	Distance degree
	Fishing Gear types	Gear types used for the fish produces, managed or sold	Typologies
	Ancient cultivar or local breed	Cultivation, management or sell of ancient cultivar and local breed	Y/N
	Characteristics of the products	The preferences on some specific characteristics of the food produced, managed or sold	Importance degree
Resource use efficiency	Water saving practices	Importance of working saving practices	Importance degree
	Electricity sources	Typology of electricity used	Renewability degree
	Heating sources	Typology of heating used	Renewability degree
Waste management and circularity	Waste recycling	Amount of recycled waste according to each waste typology	%
	Sustainability commitment	The commitment towards the adoption of a set of practices regarding energy, water, organic waste, materials and packaging	Commitment degree
	Packaging and materials recyclability and compostability	The usage of composable and recyclable packaging and materials.	Recyclability and compostability degree
	Packaging and materials reusability	The usage of reusable packaging and materials.	Reusability degree
Transport	Distance from clients/ customers	The distance between the initiative and key clients/customers	km
	Type of transport to clients/ customers	The type of transport used between the initiative and key suppliers.	Degree of Fossil fuel employment
	Type of transport of supplies	The type of transport used between the initiative and their supplies.	Degree of Fossil fuel employment

Sustainability Scoring

> *FoodE Advancement*
>
> Sustainability Scoring of CRFSI
> Providing a final sustainability scoring from 1 to 5 for each CRFSI, guaranteeing an equal weight to the different sustainability pillars

The simplified framework is built to provide a final sustainability scoring for each initiative. The KPIs measured on collected data are converted to a comprehensive, integrated sustainability scoring for the three spheres of sustainability (social, economic, environmental).
To this end, a survey can be built using two types of questions. The first type is a 5-points Likert-scale with 5 options as answers. The options correspond to a score going from the least sustainable solution (1 point) to the most sustainable solution (5 points). The second type is a binary question (yes/no). As before, the no option corresponds to the lower sustainable solution (1 point), and the yes option to the most sustainable one (5 points).
The overall sustainability assessment is then obtained by aggregating the points. To guarantee an equal weight to the different KPIs, impact categories, and sustainability pillars, the points of each question are weighted accordingly to the number of questions in the relative KPIs. In turn, points of each KPIs are weighted accordingly to the number of KPIs in the relative sustainability pillar. In doing so, each pillar has a final score between 1-5 which aggregated to the remaining sustainability pillars composes the single sustainability score of each CRFS initiative (1-5). As an example, is provided in Figure 7. D2.3 presents the related detailed survey and data collection protocol.

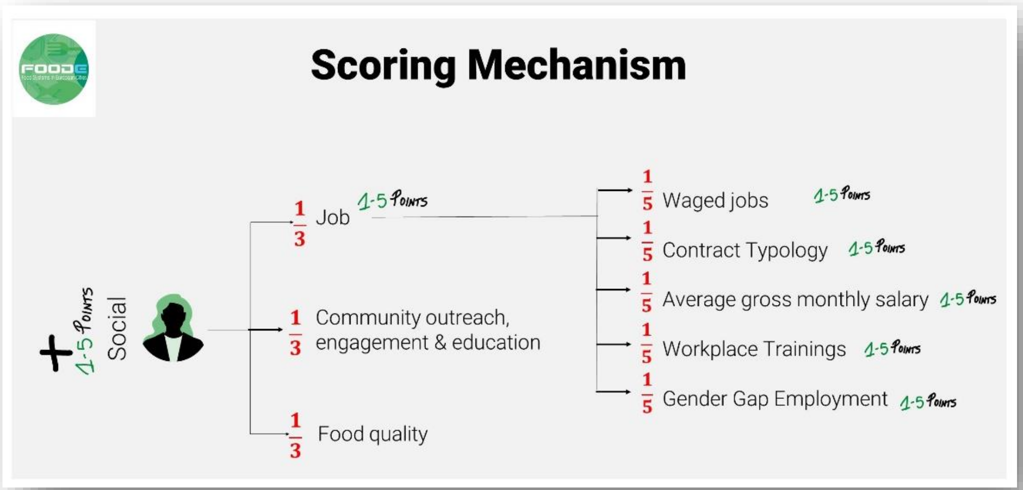

Figure 7 - Survey Scoring Mechanism

The CRFS initiatives with the highest scores (5) are the ones performing best in sustainability terms, while CRFS initiatives having the lowest scores (1) are the ones performing poorest. Results are interpreted both on individual sustainability pillars and on the overall integrated sustainability degree.
The underlined approach represents an innovation to the commonly used CRFS assessment process, since it allows to equally weight the 3 sustainability pillars more than that to arrive at a final quantitative score enabling to compare results of very different CRFS typologies.

Extensive Framework

General description

The aim of the extensive framework is to **quantify the economic, social, and environmental impacts of CRFSI** adopting a life cycle perspective. The framework provides a methodological one-stop shop to LCT practitioners looking for specific recommendations and tools translating theory into practice. In later phases of FoodE, this extensive framework will be specifically used to evaluate the performance of pilots, as a base for the development of decision support tools and interactive software.

In order to develop this framework, existing knowledge from established frameworks, past projects, and recent literature were combined and used to develop recommendations specifically designed for the study objective, CRFSI. In each LCT phase, a short methodological explanation is followed by key recommendations on specific issues in relation with potential assessment situations and goals. The guidance is provided for all the 3 pillars (LCA, LCC, and S-LCA) and suggests also possible options in the case of participatory approaches to the co-design of LCT studies.

Goal and Scope

Function and assessment goal

Before defining the best FU for the CRFSI under assessment, a detailed analysis on the functions of the different CRFS typologies has to be made. As an example, a CRFSI consisting of a small extension of land dedicated to growing tomatoes, will likely be related to the function of providing tomatoes to the local market or even to the same family that is taking care of the system on a daily basis. On the other hand, CRFSI consisting on a small fishery will have high chances of having an associated function related to the provision of fresh fish to the local market. Similarly, a CRFSI consisting on a big fishery will also be providing fresh fish, but maybe to a bigger market than the small fishery. Thus, the function of a specific CRFSI is highly dependent on its size and the products it supplies. Moreover, a CRFSI only focusing on the distribution of goods may entail a completely different function.

Additionally, a specific CRFSI can provide different functions depending on the perspective of the person in charge of assessing its performance. Considering the example of a dairy farm, the same LCT practitioner could consider different functions: provision of milk, provision of butter, provision of meat, provision of economic value (considering the sum of milk, butter and meat in monetary terms), provision of nutrients (considering the sum of milk, butter and meat in caloric terms), etc. Since the definition of a function may entail a specific FU and specific system boundaries, it is highly relevant that the function is clearly stated before defining the FU and the system boundaries. In addition, this definition will also entail to what extent the assessment of the CRFSI is comparable to similar CRFSI.

Considering the above, the finally selected function by the LCT practitioner must align with the predefined goal of the assessment, the major parameter within the "Goal and Scope" phase. In fact, an LCT study might serve different purposes and fit with various assessment situations, all of which largely influence methodological choices.

The first turning point relates to the inclusion of one or more sustainability pillars: while this framework includes LCA, LCC and S-LCA, the assessor could decide to select only one of these methodologies if the goal of the evaluation is to analyse the environmental, economic, or social impacts or a combination of them. Limiting the goal to just one pillar has a large direct consequence on data and competences requirements. However, considering the scope of CRFSI, it is rather preferrable to include all the three pillars and reduce the amount of impact categories if there is the need to simplify the study.

The second crucial turning point regards the difference between **footprinting** (i.e. measuring the current situation), **comparative** (i.e. comparing different systems), **perspective** (i.e. identifying potential impacts), or **consequential** studies (i.e. evaluating consequences of a choice). There are several methodological issues deriving from this choice in terms of FU, system boundaries, type of data to be collected, etc. As an example, if the goal of the assessment is to analyse the environmental, costing and/or social performance of a specific CRFSI that produces only tomatoes, it is likely that the function that aligns most with this goal is the provision of tomatoes. If the goal of the assessment is to compare different CRFS that produce tomatoes, we can still maintain the function related to the provision of tomatoes since it is common in all CRFSI. However, if the goal of the assessment is to compare a CRFSI (A) that produces tomatoes with a CRFSI (B) that produces a broad range of vegetables, the function related to the provision of tomatoes is only valid for CRFS (A). Hence, alternative functions like the overall provision of vegetables or the provision of economic value can link again CRFSI. In the case of perspective studies, several primary data might be related to an experimental or small-scale situation and a combination of secondary data and parametrization could be useful to derive realistic impact figures as well as projection of future scenarios. Similarly, if the study aims at evaluating the consequences of a change from the current scenario (e.g. what would change if all the food production of an entire city would rely on a specific technology), depending on the scale of the change and related market outcomes, a consequential modelling could be appropriate, taking into account external modifications in the overall systems.

Functional Unit

The FU in which the LCT practitioner bases all inputs, outputs and impacts on will be highly dependent on the previously selected function, which is in turn based on the goal of the assessment. Table 4 provides an alignment between possible functions of CRFSI, their potential FUs and the main reported limitations.

Table 4 - Relationship between functions and functional units and the main limitations to overcome

Function	Functional Unit	Limitations
Provision of a specific product	Kg of individual product (1)	Limited only to CRFS that provide a single product or need to isolate single-good production systems
Provision of a set of products	Kg of individual product (2)	Requires the classification of elements among different production systems
	Kg of mixed products (3)	Mass-based mix of different products is not really consistent
	Kg of mixed products (prior CRFS typology definition) (4)	Mass-based mix of different products is not really consistent
	Organization-level (5)	Absolute impacts are highly dependent on the size of the activities
Provision of energy value	Kcal of energy value (6)	Caloric value of every product should be transparent
Provision of market value	Unit of market value (7)	Intra and interannual fluctuations

It is important to mention that additional perspectives may entail additional functions and thus also additional FUs. Here we are presenting some of the most commonly used ones.
The FU consisting on kg of individual products is one of the most extensively used in the assessment of agricultural production. If a CRFSI is only producing a specific good (A), the LCT practitioner should just gather all the relevant data for the entire production system and divide the LCI and LCIA data by the amount of good (A) generated for a certain period of time, obtaining the environmental, costing and social impacts per kg of product. After this quantification, the CRFSI performance can be compared to similar CRFSI that also produce the same specific good (A) by highlighting why different values are obtained. If a CRFSI is producing a variety of goods but we are only interested in the environmental, costing and social evaluation of a good (A), a deeper analysis should be made to determine which elements of the production system should be allocated to the production of good (A).

If a CRFSI is producing a variety of goods and we are interested in the environmental, costing and social performance of all of them, there are four main functional units to be used, each one with their potential and limitations for the assessment.

If we are interested in the isolated environmental, costing and social performance of all the goods produced of a CRFS, we should base the impact to kg of individual products. However, the inventory of the entire CRFSI should be divided consistently to allocate the flows in parallel production systems accordingly. This division may be easier in some CRFS than others. If a big CRFSI has separated areas to produce tomatoes and lettuce, each of them with its specific irrigation system, fertilization regime, infrastructure, labour force, etc, the division of inventories will be straightforward. On the other hand, if a small CRFS grows a variety of vegetable products at the same place, using the same irrigation system and quantifying the water flows with a single flowmeter, with the same infrastructures and labour force, there are high chances that isolated production systems will be designed based on several assumptions and unavoidable allocations.

Another option when we have a set of products is to use a FU based on kg of mixed products, either without or with a prior classification of CRFS typologies. The main limitation of a mass-based FU with different products is the assumption that the function of providing fish, lettuces, chicken or tomatoes can be simplified in mass terms without accounting for differences in economic value or water, energy and nutrient content, infrastructure and labour costs, for example. In this sense, a prior classification according to CRFSI typologies (e.g. fish value chain, livestock production chain and vegetables production chain) can help mitigate these differences.

The last option when considering the function of providing a set of products is an organizational-level or system-level FU. An organizational-LCT approach considers the activities of an entire organization (i.e. a CRFSI) potentally including also upstream and downstream activities. However, the main limitation of this approach is that it is not recommended for comparative purposes (Martínez-Blanco et al., 2015).

Moving away from mass-based FUs and including a comparative aim in the goal of the assessment, there are two slightly explored FUs that could be useful. Considering the energy value of food, a FU consisting in 1 kilocalorie of energy value could be the basis to compare the performance of CRFS. This approach has however some limitations. The selection of a consistent reference data in terms of kcal/kg of each type of food produced will highly affect the quantitative values of the indicators. In addition, the energy value of food products is only one of the relevant nutritional properties and in some cases it does not reflect the real function of some products, as their added value is linked to other characteristics (e.g., herbs and spices).

Finally, another non-mass-based option for the FU could be unit of market value. This FU, which responds to the function of providing market value, should be clearly defined since critical assumptions will highly affect its value. As an example, if fixed market values are considered for each good, parameters like geographical location or price fluctuations are omitted from the assessment. Although this assumption may be useful to simplify the assessment from a methodological standpoint, the mentioned information is lost in the way, thus increasing the uncertainty of the obtained environmental, costing and social results. In this sense, although the addition of a parameter like seasonal fluctuations would make the analysis more complex and time-intensive, it may add a dynamic behaviour to the environmental, social and economic performance of CRFSI.

After considering all the alternatives shown in Table 4, a combination of FUs for the assessment of CRFSI is concluded to be the best way to tackle all the relevant limitations related to individual FUs. In terms of workflow, an organizational-LCT approach looks to be the best way to start since all the remaining FUs are compatible with having the data structured at system level. Additionally, complementary FUs that were not mentioned in this section may be used in specific assessments due to a possible focus on a particular sustainability dimension and a function that may not be entirely related to the production nature of a CRFS.

System Boundaries

Similar to the function and the FU, the system boundaries will vary according to the goal of the assessment. If the aim of the study is to focus on the distribution of goods, the system boundaries will be narrowed to this specific life cycle stage. On the other hand, if the focus of the assessment is the analysis of all the impacts of the production of goods up to the farm or processing gate (the so-called cradle-to-gate approach), the system boundaries would include the extraction of raw materials, the manufacturing and processing and all other relevant processes before the distribution of goods. However, a broader approach is needed to include all potential CRFSI to the same system boundaries.

In this sense, a cradle-to-grave analysis (or cradle-to-cradle if the end-of-life encompasses recycling or reusing processes) would include all life cycle stages in the system boundaries, leaving place to the LCT practitioner to classify the CRFSI depending on the life cycle stages their production has an implication in.

For the LCC, the decision on system boundaries has some specific implications. When adopting cradle-to-gate boundaries, the involvement of stakeholders for data provision is generally more agile and mostly carried out thanks to the LCT practitioner. However, this would not provide a measure of costs distribution burdens along the life cycle. Differently, when a cradle-to-grave approach is applied, the data collection requires an increased workload but guarantees the assessment of cost distribution across actors, leading to a more complete assessment.

Similarly, for the S-LCA, cradle-to-gate approaches potentially imply a reduced number of affected stakeholders, related impacts, and data collection efforts. However, this results in more limited options in terms of impact evaluation and potential burden shifting if decisions are taken following the results. On the other hand, the inclusion of more processes in a cradle-to-grave approach allows to have a full picture of stakeholders affected at the cost of more data requirements.

The choice on the approach to be used, also needs to consider the degree of multifunctionality of the system. Depending on the specific case study, multifunctionality can be addressed either adopting a consequential rather than an attributional approach or expanding system boundaries (REFRESH, 2017).

The major limitations and potentialities of each methodology for system boundaries definition are disclosed in Table 5.

Table 5 - Limitations and potentialities of each methodology for system boundaries definition

	Cradle-to-gate	Cradle-to-grave
LCA	– Omit the potential application of circularity strategies + Less need of secondary data or assumptions regarding waste scenarios	+ More complete assessment of impact distribution across LC stages – Assumptions required if the assessed product is still in the use phase
LCC	– Limited inclusivity of results + Less need of secondary data + More agile due to a lower stakeholders involvement	+ More complete assessment of cost distributions – Increased workload to a higher stakeholder involvement – Increased data requirements – Need for secondary data
S-LCA		+ More complete assessment of social hotspots and related distributions across stages and geographical areas – Increased workload to a higher stakeholder involvement

		– Increased data requirements – Need for secondary data

Similarly, to the approach proposed for the functional unit, three different value chains (vegetables, livestock and fisheries) can be identified to have specific modularity and structures.

Co-designing goal and scope

The co-design approach for the definition of objectives and scope of the analysis can be realised through approaches characterised by different levels of involvement. (Table 6). The stakeholder's selection for this stage follows the principle of completeness (Geibler et al. 2006) which underlies the inclusion of both internal (supplier, clients, firms, trade unions, industry associations) and external ones (NGOs, financial institutions, education, research). The objective of the participatory process in goal and scope stage is identifying which aspects are more relevant for the stakeholders collecting their concerns and interests of the system. The starting point of this step is providing an overview of the CRFSI to the stakeholders pointing out how the system is evolving, and which are the main strategies and goals at regional/national/European level. To achieve this task, it could be useful preparing an open-source dataset and using a digital map to visualize the data (Caspersen et al. 2009). Depending on the specificity of the analysis the information could be delivered at food system level, sectoral level or product level complemented by social, economic and environmental issues emerged by the recent studies. Taking in consideration the importance to give an overview of the system, the second step is deciding which degree of participation to apply and which are the outputs and goals expected from the stakeholders involved (Table 6). The lower degree of involvement is informing the different stakeholder on the goal and scope of the analysis using website, posters, videos taking care to use an engaging vocabulary. To get consensus on the goal and scope is possible to organize focus group discussion using the information to characterize the stakeholder's perception of the system analysed. By increasing the degree of participation, potential objectives can be jointly identified, prioritised, or defined applying multiple tools such as workshops, participatory decision making and citizen juries. In this type of participatory process is essential to ensure that all the actors involved can feel part of the analysis making critical the selection process taking in consideration their competencies to avoid disparities. These tools are time-consuming because they must be accompanied by training on life cycle thinking approach on how this phase affects the following ones and which are the problems related to the analysis distortions and simplification.

Table 6 - The spectrum of participation process approaches within Life Cycle Inventory stage adopted in FoodE

Step of LCA	Type of public participatory approach	Output
Goal and scope of the analysis	Inform	Dissemination
	Consult	Consensus on the goal and scope
	Involve	Define the potential objectives of the analysis
	Collaborate	Prioritize the potential objective of the analysis
	Empower	Define the objective of the analysis

Life Cycle Inventory

Short methodological explanation

While acquiring LCI data is important to acknowledge the differences between primary and secondary data. Primary data is collected by the LCT practitioner or other stakeholders from the CRFSI under study, while secondary data is collected from other systems and is made available through different channels. In terms of data quality, primary data will always be preferable since it includes the particularities that the system under study presents. For example, primary data on the irrigated water, or on the labour cost in a specific CRFSI will be preferable over an estimation based on climatic data, harvested crops and guild reports. This preference also applies to different types of secondary data, as it could be the case for territorialization of data. For example, the electricity production mix from a small region may present substantial differences when compared to the averaged production mix from the country that this region belongs to. Similarly, the processing costs for a small CRFSI can be very different from the ones for a larger CRFSI.

Based on the characterisation of the system under study and the system boundaries, data in the inventory will be classified between background and foregrounds processes. Background processes or data include inputs and outputs that are linked to the foreground processes through aggregated data without specific identifications on the precise operations. Therefore, the foreground processes are those that the LCT practitioner can control. Alike the background system, for which the information is mainly collected from LCI databases, the foreground system is mainly composed from primary data and known sources of secondary data. In environmental terms, for the background system, different LCI databases can be used: Agri-footprint, Ecoinvent, ELCD, LCA Food, etc. For a CRFSI, foreground processes will likely include the stages related to food products and/or services provided (e.g. food production, delivery, etc.) and depending on the degree of supply chain integration also further stages. For these processes, primary data should be preferred to measure or model direct inputs (e.g. fertilize use) and outputs (e.g. field emissions), while databases can be used to associate embedded impacts to inputs used in the foreground.

For the economic evaluation, background system LCI databases are intended as local and national institutions providing reference values for the costs items. Depending on the selected system boundaries and FU, most background processes can be retrieved starting from market prices or costs related to the specific cost flows considered (Hunkeler et al. 2008). Data can refer to a very broad set of activities, which are also linked to the LCT choices taken along the process. LCC inventory can be more or less dependent on the LCA inventory, depending on the purpose of the study. When conducting an E-LCC, flows should generally be modelled on LCA inventory items, finding ways to express them in monetary terms. Differently, for the C-LCC and S-LCC, other items should be included such as labour, infrastructures and machineries, translated from their unit of measure into monetary terms (REFRESH, 2017). For a CRFSI, costs related to foreground processes such as hourly salaries or other direct expenses, should be collected and eventually converted into appropriate currency. For background processes (e.g. the cost of producing fertilizers used in the foreground), market price of products can be used as a proxy of the related input.

With specific reference to LCC, LCT practitioners should carefully consider three major challenges. First, the localisation of data for the background processes. The same cost item can include a whole set of different indications depending on the country it refers to. LCT practitioners should make sure data used for the assessment are correctly referred to the context they are studying, alternatively providing an adequate adaptation. Second, amortisation and depreciation rates, together with other discount rates, should be carefully analysed referring to the time span of the study and the related context. These can be very relevant when actualising the results and can extensively influence the data solidity. Third, indirect costs are key to perform a complete LCC. Basing on the selected system boundaries and allocation type, indirect costs can be included, referring it to the relative flow.

For the S-LCA, some databases are available (e.g. the Social Hotspot database) providing a social footprint and social risk mapping deriving by importing certain services and/or products from a country, based on the prevalence of certain issues. However, it is highly suggested that the choice of the different background processes is double-checked with an LCT practitioner with a strong expertise on LCA, LCC, and S-LCA databases to make sure the different processes are consistent. As an example, if primary data regarding the transport needed for the acquisition of specific materials for the CRFS can be obtained, it is important to make sure that these transport processes are not included in the backgrounds process referring to these specific materials, to avoid the risk of double-accounting. The same is true for example for the understanding of taxations systems, which can widely differ across countries and can be included in different costing background processes.

Guidance of data to be collected

Data to be collected for the foreground system highly depends on four relevant parameters. The first one is the goal of the assessment, which will define the aim of the study and therefore highly affect all other variables of the LCT, including the data to be collected.
The second one is the system boundaries. The inclusion or exclusion of specific parts or life cycle stages of the value chain affects substantially the data to be collected for the inventory. As an example, if the end-of-life is excluded from the analysis because we are considering a cradle-to-gate approach, we won't be collecting any data regarding the dismantlement or waste scenarios of the goods we are assessing.
The third one is the CRFSI typology. Relevant data is really typology and case-specific. Although some of the waste streams coming from vegetables and livestock production may be treated with composting technologies, with the related costing and social implications, the data for vegetable production is related to green biomass quantification and to specific picking techniques, while for livestock we would be quantifying manure and maybe solid-liquid separation techniques, requiring a different set of tools, labour forces and knowledge.
Finally, the fourth parameter affecting the data collection is the collection of impact methods and impact categories. If we already know which impact categories we want to communicate or analyse, we should put our efforts in gathering the information that is relevant for them. As an example, if we include eutrophication-related impact categories in the analysis, we must find a way to account for the potential phosphorus and nitrogen losses to the water bodies, since these two elementary flows play a major role in the mentioned impact categories. Although the quantification through analytical methods of daily samples seems the most accurate way to quantify these elementary flows, the LCT practitioner should acknowledge the available means and workload that could be attributed to the CRFSI owner to avoid it resigning from the study. Thus, it is important to look for complementary tools to quantify this effort-demanding flows like existing models and accurate estimations available in the previous literature. Another LCA example of elementary flows strictly related to specific impact categories are greenhouse gases like methane or nitrous oxide. The quantification of methane direct emissions is only relevant if our system includes a module that emits methane, such an anaerobic digester, and if we are including a climate change related impact category in our assessment (e.g. global warming potential with an emission factor = 34 kg CO_2 eq). On the other hand, the quantification of nitrous oxide flows is relevant in vegetable production since this greenhouse gas is produced by soil bacteria. Alike methane, nitrous oxide will not only be important if we are assessing the global warming potential of our CRFS (emission factor = 298 kg CO_2 eq), but also if we are including stratospheric ozone depletion impact category, with an emission factor of 0.011 kg CFC eq.
For the LCC, data to be collected can refer to different domains depending on the type of LCC. Overall, they can include labour, utilities including electricity, water and gases, fuel, infrastructures, and taxes which can have different unit of measures depending on the typology. Units of measures on which to collect the data depend on the FU to be used and the subsequent impact categories. If we include cost-related impact categories, we need to provide sufficient

contextualisation of the related market forces and conditions, since they are directly connected with costs definition and their changes over time.
For the S-LCA, data to be collected are heavily depending on the selection of affected stakeholders and related impact categories, as well as on the level of detail of the study. Considering the profile of CRFSI, it is likely that all inventory flows potentially related to job creation, community involvement, consumers health, and local economic development are key characteristics to be assessed.

Examples of data to be collected depending on the CRFS typologies and the related activities and flows are described in Table 7.

Table 7 – Examples of CRFSI data to be collected

CRFS Typologies	LCA	LCC			S-LCA
		C-LCC	E-LCC	S-LCC	
Primary Production	All inputs required for production divided between infrastructure and operational	Costs of production, Insurance, Depreciation, Repair	Material use, Energy use, Water use, Land use	Labour, wages and social security, Health and Safety Risks	Amount and type of jobs (contract, gender, salary, etc) Work safety procedure Contribution to local economy in taxes or GDP Contribution to local landscape
Food Processing	Energy consumption, relevant infrastructure	Cost of packaging, Insurance, Depreciation, Repair			
Transport and Storage	Transport distances, transport means and cargos	Costs for transport, Insurance, Depreciation, Repair			
Retail	Transport distances, transport means and cargos	Costs for distribution, Insurance, Depreciation, Repair			
Catering services	Additional inputs required for food processing	Costs for utilities including electricity, water and gases			Food safety and quality Consumer's satisfaction
End of life	Characterisation of waste streams	Costs for waste treatment			Property value change from disamenity due to landfilling

Co-design approach to Life Cycle Inventory

The participatory approach in Life Cycle Inventory could have several goals such as contextualise the analysis in the territory, understand the stakeholders' perceptions of sustainability and finally involve them in the data collection (Table 8). In this co-creation process the methodology of completeness can be applied for the selection of stakeholders (Geibler et al. 2006) for the consultation types of participatory approach. A focus group discussion could be applied to the analysis in the territory and can be used to validate the inventory and find consensual approach on the system analysed. By implementing in parallel in-depth interviews is it possible to identify the common perceptions of the stakes of sustainability within the stakeholders and then cluster them. Moreover, this type of participatory approach could be useful to be applied in an area or sector where are not present previous analysis applying life cycle thinking approach. For what concerns other typologies of participatory processes is preferred to use an opportunistic approach selecting the actors who can provide local data or information on their availability (Winjberg, 2000). In the case of involvement, a workshop can be organised with the aim of legitimising the analysis and jointly deciding on the degree of complexity required for the analysis to respond to the needs of the territory. Within the activity a Likert-scale could be used, as well as other scoring system to quantify the opinions of the stakeholder and in parallel receive feedback on the type of data used. Secondly, to promote a participatory decision-making method, a collaborative review of the guidance on the data collection aimed at identifying the degree of data availability at local level and other relevant data that could be included in the analysis or in the sensitivity analysis of the results. Finally, the empowerment of the stakeholders through the data collection could be implemented after the diffusion of a guidance for data collection realized with the support of an LCT expert. A key aspect of this collaboration is the sharing of proprietary data that could be difficult to be obtained especially if the core competence of the company lies on this aspect. In order to incentivise the data sharing, confidentiality agreement between stakeholders can be set, or data may be gathered across the value chain as a balance of material flows without the possibility of recalling specific proprietary data in the source model. Finally, it is important to ensure that actors can resign their consent on data use and participation in the study.

Table 8 - The spectrum of participation process approaches within Life Cycle Inventory stage adopted in FoodE

Step of LCA	Type of participatory approach	Output
Life Cycle Inventories	Inform	Raising awareness on the type of data collected
	Consult	Identify the perception of sustainability and validation of the analysis
	Involve	Level of complexity of LCA results
	Collaborate	Review of guidance on data collection; Local data availability and reliability
	Empower	Collection local data

Life Cycle Impact Assessment

Short methodological explanation

The LCIA is highly influenced by the goal and scope in terms of level of detail and choice of methods and impact categories (ISO, 2006). Therefore, the LCIA is not intended to be a description of the complete profile of a CRFSI, but to be able quantify those impacts that are mentioned in the goal and scope.

Similarly, the LCIA is highly influenced by the data gathered in the inventory. Uncertainty related to the background system or variability of foreground processes is attached to the data and reaches the LCIA phase, inevitably making LCIA results encompass a certain degree of uncertainty.

Guidance on impact selection

It is important to mention that impact methods and categories are not static. Additionally, to the fact that classification paths and characterization factors constantly evolve due to new scientific findings, impact categories (specially endpoints) also change based on the necessity to modify how LCT practitioners want to communicate the impacts of the assessments. Thus, the importance of clearly stating the version of the impact methods and the impact categories that we are considering is critical to increase the transparency and consistency of LCT outcomes.

Before selecting specific impact methods or categories, we should choose whether we want to quantify midpoint or endpoint impact categories. This decision should be based, among others, on the audience of our assessment. Midpoint indicators provide a more scientific-based effect with a lower degree of uncertainty. However, a certain level of understanding of these effects is required to comprehend midpoint scores. On the other hand, endpoint indicators entail another

stack of uncertainty in the assessment process, but the results are usually expressed in parameters that are easy to understand for the general audience. From an environmental perspective, examples of endpoint indicators are resource depletion, damage to ecosystems and potential harm to human health. From a C-LCC perspective, an example of endpoint indicator is the total cost, while midpoint indicators can possibly refer to variable costs and fixed costs. More in general cost categories depends on the activity of the CRFSI and on the system boundaries of the analysis. In some cases, costs can be referred to impact categories such as sales, marketing, production, consumption and disposal. An additional element is provided by the inclusion of indirect costs or externalities. When giving them a monetary value, the subsequent assignment to an impact category can be very much dependent on the scope of the assessment. But given the fact that a CRFSI might not have such a clear identification of the flows' separation, impact categories can be tailored specifying what they include or exclude. The level of details in the impact category explanation will directly influence the degree of comparability across FU of different CRFSI and will allow to avoid double counting (REFRESH, 2017). With respect to the E-LCC and S-LCC, a LCT practitioner has several ways to identify the impacts. A common one is the use of the abatement approach. This aims to monetize the cost to either prevent or restore the negative externality related to a specific impact. An example could be the cost needed to restore the amount of water polluted by the conducted activity. In S-LCC it can be explained by the cost needed to pay for the compensation of what a child forced to work missed in schooling. In the case of CRFSI such as social cooperatives carrying out rooftop social farming for people with disabilities or in social exclusion, the positive externality can be represented by the offer of a valuable and rewarding job opportunity that traditional market does not offer and would otherwise require alternative support measures. A second opportunity for social and environmental cost monetisation is the damage cost approach, which in turns provides the cost effects of a specific externality. Social insecurity can be compensated by providing welfare measures (i.e. personal compensations, increased benefits, therapies tec.) which are monetized.
Examples of indicators with the relative impact categories that can be used in the analysis of CRFSI can be found in Table 9. Units of measures are provided to offer concrete guidance on the impact evaluation, but LCT practitioners should tailor them on the scope of their analysis, choosing different nominators and denominators. Although the decision on whether we quantify midpoints or endpoints is not a one-way trip since they require the same LCI data, it is important to acknowledge the audience for our study from the beginning of the goal and scope phase.

Table 9 - Examples of CRFSI sustainability indicators

	Impact category	Indicator	Unit of measure
LCA	Climate Change	Global Warming Potential	Kg CO_2 eq.
	Eutrophication	Freshwater eutrophication	Kg P eq.
		Marine eutrophication	Kg N eq.
	LC Energy demand	Cumulative energy demand	MJ
	Ecotoxicity	Terrestrial ecotoxicity	Kg 1,4-DB eq.
		Freshwater ecotoxicity	Kg 1,4-DB eq.
		Marine ecotoxicity	Kg 1,4-DB eq.
	Human toxicity	Human carcinogenic toxicity	Kg 1,4-DB eq.
		Human non-carcinogenic toxicity	Kg 1,4-DB eq.
LCC	C-LCC		
	Labour use	Efficiency of labour	Product/Working hour
	Productivity	Labour Productivity	Euros/ product
		Land productivity	Euros/land area

		Capital productivity	Euros/farm capital
	Profitability	Return on sales	Euros/ sale
		Return on assets	Euros/ euro
		Net present value	euro/euro
		Labour profitability	euro/product
	E-LCC		
	Water use	m^3 of water	euro/product
	GWP	Tons of CO2-eq	euro/product
	S-LCC		
	Labour quality	Enslaved people	euro/product
		Child labour	euro/product
		Forced labour	euro/product
	Wages	Sufficient income	euro/product
		Social security	euro/product
S-LCA	Job quantity and quality	Amount of jobs	N° of jobs
		Gender balance	% of women in the workforce
		Workplace safety	N° of accidents
	Local economic development	Contribution to local GDP	€/FU
		Local supply	% of supply sourced locally
	Human health	Consumers' health	Nutritional score

Guidance on impact characterisation

After impact selection, it is important to identify appropriate factors or evaluation methods allowing characterizing the inventory flows into impact equivalents. Several methods exist for various LCA impact categories. It is good practice to adopt methods issued or recommended by international institutions (e.g. IPCC GWP most updated characterization factors, the ILCD handbook or the PEF). Such methods are usually included in softwares for LCA calculations.
As for the LCC, some inventory flows might need to be characterized (e.g. hours of works in a certain activity per hourly salary or amount of CO_2 emitted per carbon price) while other might be already characterized (e.g. indirect expenses in €). Further factors might be needed if dealing with different currencies (e.g. purchasing power parity)

Guidance on impact normalisation

According to the ISO 14044 standard on LCA, normalisation is defined as "calculating the magnitude of category indicator results relative to reference information" and weighting as "converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices" (ISO, 2006b).
Even though normalisation is an optional step under the ISO, it could help to support the interpretation of the impact profile and are steps towards a fully aggregated result. The normalisation of the life cycle impacts of a certain product or process is carried out following the equation:

$$Ni = Ci/NFi$$

That is, for an impact category i, Ni is its normalised result, Ci is the impact of the product or process, and NFi is the normalisation factor, i.e. the impact of the reference against which the results are compared. The choice of the reference system to calculate NFs needs to be consistent with the system boundaries defined in the previous steps. Clearly, the choice of reference system largely influences the results and the way by which they are interpreted.

To date, there are two main types of normalisations defined as internal and external.

- The first type is used to compare impacts through the development of alternative scenarios allowing the identification of the best choice in reference to a certain dimension of a specific case study. Through this method it is possible to understand the level and the magnitude of the results, allowing the interpretation of impact assessment results, facilitating the communication of results to non-practitioners, or comparing different assessment (Pizzol *et al.*, 2017).

- External normalization, on the other hand, takes place through references to specific geographical areas (which can be global, regional, national or local (ISO, 14044:2006, 2006b)) at specific times and periods (Roibás, Loiseau and Hospido, 2018). Such a category included national, regional production-based, and global normalization refences and it is the most applyied due to its efficiency to solve trade-offs between different results. (Pizzol *et al.*, 2017).

So, the arbitrariness of the choice of normalisation references can represent a critical aspect to keep in mind in the normalisation phase since it may change the conclusions drawn from the LCIA phase (Pizzol *et al.*, 2017). In spite of its drawbacks, NFs can be useful for designing international and global policies and identifying hotspots of a product and process (Roibás, Loiseau and Hospido, 2018).

Leaving aside the purely product or process context of an LCT, the external approach can also be useful to be applied to CRFS, organisations and initiatives by trying to understand what kind of impact such activities generate on the territory. In this case the Sustainable Development Goals (SDGs) may represent the reference by which the practitioners want to normalize their results. In this context, the normalization phase can help to estimate the magnitude of their impacts at territorial level by comparing the results with an external or independent reference situation from the case study. The Sustainable Development Goals can be used as a reference for the impact categories. This can facilitate the interpretation and communication of impact results. In such a context, the impacts can be normalized with the national/international reference of the SDGs report that are external from the case study and thus independent of the object of the LCA.

Guidance on impact aggregation and weighting

The aggregation of environmental, economic and social impacts and the related weighting can be conducted from LCT practitioners to obtain a single score out of the assessment. As indicated by the ISO 14044, this step is however not compulsory and sometimes debated since it entails value judgments assigning a specific importance to each impact category and influencing the overall results. The aggregation and weighting are indeed very much connected with the goal and scope of the study and the intended interpretation of results. When needed, LCT practitioner can then apply it choosing among one or more of the following weighting factors typologies.

Weighting factors can be obtained from three major typologies:

1) The monetisation implies the translation of the impact's importance into monetary terms. It relates with the willingness to pay for specific impact prevention or repair. Depending on the goal and scope of the assessment, a set of impacts can be more or less costly to be prevented or repaired, reflecting then a related weighted factor. Clearly, this weighting typology requires very extensive value choices, possibly biasing the final outcome. Additionally, for the LCA and S-LCA, it partially overlaps with the E-LCC and S-LCC, where environmental and societal impacts are monetized. However, as previously explained, in the LCC mostly refers to the actual cost of a specific prevention or repair action, while the monetization weighting refers to the willingness to pay for that action.
2) The distance from a specific target. In this case the LCT practitioner can consider policy targets as well as personal targets depending on the goal and

scope of the study. Once identified the set of targets that mostly fits the purpose of the assessment, the weighting factors of each impact can be defined considering that the further the assessed impact is from this target, the higher the weighting score. This approach can be very much suitable for that impacts that have an effective target to be respected. This is generally more common for environmental and costing aspects rather than for societal ones. However, with the EU adoption of the UN SDGs, now specific targets exist for a very broad range of impacts.

3) The panel weighting. This opportunity is quite relevant in the CRFS context since it entails a participatory approach, able to stimulate the inclusion of context dependent priorities and needs within the assessment. It is based on the mobilisation of different actors, which are called to define the impacts priority. This process could be done through by semi-constructed interview to key actors to get the motivation behind their decision followed by a focus group discussion to confirm the data. To identify which factor is the more important could be used a scoring method such as Likert scale or be directly estimated by the sentence during the discussion.

The panel approach can be very effective for a comprehensive evaluation, considering opinion related to different knowledge and sustainability domains. However, the selection of involved actors represents a critical issue since it can broadly influence the final outcome of the assessment. LCT practitioners can consider discussing the impacts aggregation and weighting directly with the specific CRFSI they are working with. By doing so, it would be possible to create a tailored set of aggregation and weighting factors. Besides that, within the participatory process the choices made for other weighting processes can be evaluated. This process can be carried out by asking for an estimation of the economic value by the actor or by asking for an opinion on the estimation made by the analysis for the monetization part. On the other hand, for the weighting process related to the distance from a specific target, the stakeholder may be asked to put the different targets in a hierarchical order, thus incorporating local interests that may be influenced by the time the analysis is carried out. Both of these activities can be carried out through a focus group discussion or interviews applying the completeness approach for stakeholders' selection (Geibler et al. 2006) by gathering information from internal and external stakeholders affected by the analyzed process/product.

In the context of CRFS LCT, this step can mostly serve to draw comprehensive conclusions from the final results. As previously explained, CRFSI can be of a very different nature and can involve a very broad range of activities, thus making it complicated to evaluate one initiative against the other. By finding ways to combine the impacts, LCT practitioners can apparently solve the comparability problem and support effective communication of results.
However, LCT practitioners should carefully manage this step and conduct it only when strictly necessary for the scope of the study. As indicated by the LCA ISO 14040 and 14044, weighing cannot be adopted for actual comparative assertions tailored for the wider public. This warning is based on the awareness that the wider public would not always be able to understand the ratio behind the single score they are provided with, thus ending up with the disclosure of unprecise dissemination of results. Hence, a very precise and conscious evaluation has to be conducted on a case-to-case basis, with the LCT practitioner providing all elements which are necessary to understand the aggregation and weighting mechanism.

Results Interpretation

Short methodological explanation

The interpretation phase evaluates and discusses the outcomes of the LCI and LCIA. From an iterative approach, the interpretation phase should reconsider the goal and scope parameters and its consistency with the data gathered in the LCI, also in terms of data quality and the assumptions.

Guidance on results organisation, contextualisation and communication

There are different ways of organising the interpretation phase, but ISO (2006) states that three different blocks of information should be included: conclusions than can be reached, limitations that were encountered and recommendations that can be provided.

In terms of conclusions that can be reached, we should make sure to highlight the detected hotspots for each impact category. These detected hotspots can be compared with previous research and tendencies detected in similar systems to provide a context to our results. If our assessment already entails the comparison between different systems or scenarios, the differences between them should also be highlighted, providing potential hypothesis or explanations on these differences.

In terms of limitations that were encountered, we should describe how they affected the final environmental outcomes and to what extent. For example, if multifunctionality is handled through mass or economic allocation, the interpretation phase should discuss how this choice have affected the results.

In terms of recommendations that can be provided, we should consider the audience (or potential audience) of the assessment stated in the goal and scope phase. If the LCA is carried out with environmental education purposes, the recommendations will be different if the aim is to disseminate the results to scientific community or policy-makers.

Participatory results interpretation

Finally, the participatory approach can be used to support this final stage of the analysis providing suggestion on how to present the results, gather relevant information to support the sensitivity analysis and foster eco-designing strategies to reduce the impact of the case study analyzed. (Table 10) For the stakeholders` selection process, the principle of completeness (Geibler et al. 2006), which underlies the inclusion of both internal stakeholders (suppliers, clients, firms, trade unions, industry associations) and external ones (NGOs, financial institutions, education, research) could be applied. However, as these actors have different interests and knowledge, it is advisable to develop the participatory activities with homogeneous groups using the results as input for a general discussion with the other actors. This can be done through the production of a written document where the results are presented in bullet pointers that are sent to the different groups for feedback. Multimedia materials such as animated video and posters could be used to inform the stakeholder taking care on the different level of communication and target making distinction between level of knowledge, age, and interests. As mentioned in the previous chapter, the indicators that are used at the communication level are mainly those referring to the endpoint. The challenge in this step is to find a balance between the analysis capacity that LCA tools could provide to the actors and the ease of use for them (Renouf et al. 2018b). Rouault et al. (2020) suggest a multilevel analysis where are identified the hotspot of the impact and provide some detail about the source of the impact. A single score environmental performance based on a panel-based weighting method (Serenella et al. 2018, Botreau et al. 2018), a customized chart showing the contribution of each operational unit and details about the impact categories contributing to the impact of each unit operations could be useful to give an overview of the system. In the consultation type of participatory stage several ways to present the results could be shown and qualitative and quantitative approaches could be used to assess the capacity of the stakeholders to understand the results. A Likert-scale questionnaire could be used to score the stakeholders' comprehension of the graphs and collect comments and improvement by focus group discussion and individual interviews. Moreover, within the qualitative approach it would be possible to explore the potential variable that could be included in the sensitivity analysis. Finally, to promote the development of local strategies, a live-data tools (e.g. VitiPoly®) could be used giving the possibilities to the stakeholders to change different variable and directly see the difference between the original system and the co-created system. (Rouault et al. 2020). In this process several physical objects that can be manipulated by participants and that could help designing a system and manipulating data about the system should be created. This strategy similar to the gaming process is extremely relevant, since it could assist actors and extension services in designing new systems required to convert scientific concepts into usable forms of support. However, it should be considered that the overall participatory approach composed by the information delivery and the strategies development is time-consuming and expensive. Indeed, to realize this participatory approach moderators expert in LCA and in the sector studied are needed as well as the availability of the stakeholders for contributing to several meeting.

Table 10 - The spectrum of participation process approaches within the results interpretation stage adopted in FoodE

Step of LCA	Type of participatory approach	Example tools	Output
Results interpretation	Inform	Multimedia material	Informing on the analysis results
	Consult	Focus group discussion, interviews	Defining the level of complexity of the results and identifying variable for the sensibility analysis
	Involve/collaborate	Workshops, live-data tools	Developing of local strategies

5. Conclusions

The described contribution represents an innovative basis supporting CRFSI in assessing the sustainability of their activities. Building on previous knowledge and past project and adopting a participatory approach, the assessment stands to evaluate the social, economic, and environmental pillars with a LCT methodological basement. CRFSI are provided with a detailed and tailored roadmap that guide them along the entire process. CRFSI can decide whether to perform a simplified or an extensive assessment, they can select the sustainability pillars of interest and can eventually decide to include more or less accurate details on qualitative and quantitative aspects. The framework provides coherent instructions starting from the understanding of the CRFSI typologies and leading toward the final sustainability scoring and a detailed sustainability analysis. It hence guarantees a precise tailoring of results.

Research outcomes from the present report will serve to nourish the complete LCA, E-LCC and S-LCA assessment to be performed in future project steps, undertaking a methodology refinement and adaptation. Additionally, it will serve to define the indicators for the CRFSI online survey tool and to create the CRFSI FoodE label certification standard. Finally, a comprehensive simplified tool, will be developed from the present results to support the decision-making processes of innovative and co-designed business models in the FoodE pilots.

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Appendixes

Appendix 1 - FoodE partners' previous key projects and initiatives useful for an integrated life cycle sustainability assessment of CRFS

Projects	Food-E Partner	Pillars	Methodology
SustUrbanFoods (Integrated sustainability assessment of social and technological innovations towards urban food systems, EU-H2020-MSCA-708672), 2016-2018	UniBo	Social, Environmental	Case studies assessment on social and technological innovations
Re-fresh (Resource Efficient Food and dRink for the Entire Supply cHain, EU-H2020-641933), 2015-2019	WR, UniBo	Social, Economic, Environmental	Development of DSS tools, protocols, integrated models and simplified approaches
Valumics (Food Systems Dynamics, EU-H2020-SFS-33-727243), 2017-2021	UniBo	Social, Economic	Structural analysis including system analysis; system simulations using system dynamics.
EdiCitNet (Edible Cities Network, EU-H2020-SCC-2-776665), 2018-2023	NBL AS, WR	Social, Economic, Environmental	Study, plan and implement successfully proven urban food systems
UrbaClim (Urban Agriculture – Climate Benefits Compared with Conventional Food Chains, Climate KIC), 2017-2018	APT, UniBo	Environmental	Quantitative assessment of urban farms' impacts on Climate Change
CIPURA (Climate and Innovation Potential of Urban Agriculture, Climate KIC), 2016-2017	APT	Environmental	Systematic review
ECO-SCP-MED (Integrating Experiences and Recommendations in Eco-Innovation for Sustainable Production and Consumption in the Mediterranean Area, EU-1-CAP MED-12-12), 2013-2015	UAB, BOL	Economic, Environmental	Methodologies, tools, multilevel governance models developed in previous MED projects.
ECOTECH-SUDOE International network in lifecycle analysis and eco-design for environmental technology innovation, EU-INTERREG) 2011-2013	UAB	Environmental	Networking, education, piloting
GROOF (Greenhouses to Reduce CO2 on Roofs, Interreg NEW project), 2017-2021	UAB	Social, Environmental	Combining energy sharing and local food production
FERTILECITY I (CTM2013-47067-C2-1-R, Spanish Project), 2013-2016	UAB	Economic, Environmental	Unidirectional Building-Integrated Urban Agriculture
FERTILECITY II (CTM2016-75772-C3-1-R, Spanish Project), 2016-2019	UAB	Economic, Environmental Social	Bidirectional Building-Integrated Urban Agriculture
FEW-meter (an integrative model to measure and improve urban agriculture towards circular urban metabolism, JPI-H2020-730254), 2018-2021	ILS, APT	Environmental, Social	Co-creation of methods of gathering, measuring and analysing data in collaboration with urban farmers for resource flow modeling
FUSION (Food Use for Social Innovation by Optimising Waste Prevention Strategies, EU 7th FP-311972), 2012-2016	WR, UniBo	Social, Environmental	Establish a tiered European multi-stakeholder Platform to generate a shared vision and strategy to prevent food loss and reduce food waste across the supply chain through social innovation
EUPHOROS (optimal greenhouse climate systems, minimal resource requirement. EU-FP7-KBBE-211457), 2008-2012	WR	Economic, Environmental	LCA-based environmental study coupled with a complete financial assessment
SiEUGreen (Sino-European innovative green and smart cities, EU-H2020-774233), 2018 - 2021	-	Social, Economic, Environmental	Guidelines for a new interactive impact assessment approaches, Key questions on how to evaluate resource-efficient UA

			on social and economic aspects.

Appendix 2 - Literature review results of integrated life cycle sustainability assessment of CRFS

Articles	Authors and date of publication	Pillars	Methodology	Approach
Systemic Analysis of Food Supply and Distribution Systems in City-Region Systems - An Examination of FAO's Policy Guidelines towards Sustainable Agri-Food Systems	Armendáriz et al. (2016)	Social Economic Environmental	Development of an epistemic ground to understand FSDS; Analysis of the document from FAO "Studying Food Supply and Distribution Systems to Cities in Developing Countries and Countries in Transition—Methodological and Operational Guide (Revised Version)"	Systems Thinking (ST) and System Dynamics (SD)
An LCA-Based Environmental Performance of Rice Production for Developing a Sustainable Agri-Food System in Malaysia	Harun et al. (2020)	Environmental	Life Cycle Assessment (LCA) through ReCiPe 2016 method	Life Cycle Thinking (LCT)
Sustainable Agri-Food Processes and Circular Economy Pathways in a Life Cycle Perspective: State of the Art of Applicative Research	Stillitano et al. (2021)	Social Economic Environmental	Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol	Systematic literature review
A life cycle assessment of the environmental impacts of a beef system in the USA	Hiablie et al. (2018)	Environmental	Life Cycle Assessment (LCA)	Life Cycle Thinking (LCT)
Proper selection of substrates and crops enhances the sustainability of Paris rooftop garden	Dorr et al. (2017)	Economic, Environmental	Life cycle assessment (LCA) and life cycle costing (LCC)	Life Cycle Thinking (LCT)
Assessing sustainability of winter wheat production under climate change scenarios in a humid climate - An integrated modelling framework	Chami et al. (2015)	Social Economic Environmental	General circulation model (GCM), the Food and Agriculture Organization's (FAO) crop growth model (AquaCrop), a life cycle assessment (LCA) model and economic modeling	Outputs combination from different modeling tools
Quantitative assessment of the Japanese "local production for local consumption" movement: a case study of growth of vegetables in the Osaka city region	Hara et al. (2013)	Environmental	Multiscale analysis and scenario analysis	Flows quantitative assessment

Identifying eco-efficient year-round crop combinations for rooftop greenhouse agriculture	Rufí-Salís et al. (2020)	Economic Environmental	Life Cycle Assessment (LCA) considering different functional units and eco-efficiency assessment with market prices	Life Cycle Thinking (LCT)
Eco-Efficiency Assessment and Food Security Potential of Home Gardening: A Case Study in Padua, Italy	Sanyé-Mengual et al. (2018)	Economic Environmental	Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) to draw eco-efficiency portfolios	Life Cycle Thinking (LCT)
Incorporating user preferences in rooftop food-energy-water production through integrated sustainability assessment	Toboso-Chavero et al. (2021)	Social Economic Environmental	Integrated sustainability assessment incorporating user preferences to assess the FEW nexus	Life Cycle Thinking (LCT), Musiasem and multiple sustainability indicators
Application of life cycle thinking towards sustainable cities: A review	Petit-Boix et al. 2017	Social Economic Environmental	Review of Life Cycle Thinking studies applied to urban systems	Life Cycle Thinking (LCT), Literature Review
Environmental and resource use analysis of plant factories with energy technology options: A case study in Japan	Kikuchi et al. (2018)	Environmental	Life Cycle Assessment (LCA) of different scenarios (energy technologies)	Life Cycle Thinking (LCT)