



# Generic strategy LCA and LCC

**Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain**



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# Table of Contents

|          |   |           |
|----------|---|-----------|
| <b>1</b> | <b>Executive summary</b>  | <b>7</b>  |
| <b>2</b> | <b>Introduction</b>   | <b>7</b>  |
| 2.1      | Objective   | 10        |
| 2.2      | Approach  | 11        |
| 2.3      | Definitions used in this report   | 15        |
| <b>3</b> | <b>REFRESH situations</b>   | <b>18</b> |
| 3.1      | Prevention of side flow (RS 1)  | 18        |
| 3.2      | Side flow valorisation (RS 2)   | 20        |
| 3.3      | Valorisation as part of waste management (RS 3)   | 22        |
| 3.4      | End-of-life treatment (RS 4)  | 23        |
| 3.5      | Decision tree for determining REFRESH situation   | 24        |
| <b>4</b> | <b>Generic LCA and LCC of side flows – method recommendations</b>                                       | <b>28</b> |
| 4.1      | <b>LCA modelling framework</b>  | <b>28</b> |
| 4.1.1    | Determining the modelling framework: attributional or consequential?                                    | 29        |
| 4.1.2    | Footprint studies: Functional unit, system boundaries, handling multi-functionality and data inventory  | 34        |
| 4.1.3    | Intervention studies: Functional unit, system boundary, handling multi-functionality and data inventory | 39        |
| 4.1.4    | Cut-off principle in footprint and intervention studies   | 47        |
| 4.1.5    | Impact assessment in footprint and intervention studies   | 47        |
| 4.1.6    | Interpretation in footprint and intervention studies  | 50        |
| 4.2      | <b>LCC modelling framework</b>  | <b>50</b> |

|  |            |
|--|------------|
| 4.2.1 Determine the type of LCC                    | 51         |
| 4.2.2 E-LCC modelling                              | 54         |
| <b>4.3 Combining LCA and E-LCC</b>                 | <b>66</b>  |
| <b>5 Recommended stepwise procedure</b>            | <b>71</b>  |
| <b>6 References</b>                                | <b>80</b>  |
| <b>7 Annex A: Examples of intervention studies</b> | <b>83</b>  |
| 7.1 Example case: Moving from RS 3 to RS 1         | 83         |
| 7.2 Example case: Moving from RS 3 to RS 2         | 93         |
| <b>8 Annex B: Definition of food supply chain</b>  | <b>102</b> |
| <b>9 Annex C: Comparison between CLCA and ALCA</b> | <b>104</b> |

## List of Tables

|   |    |
|---|----|
| <i>Table 1: Overview of what is in and out of scope of guidance in this report</i>  | 15 |
| <i>Table 2: Distinction between RS 2 and RS 3</i>   | 23 |
| <i>Table 3: Recommendations on selection of impact categories</i>   | 49 |
| <i>Table 4: System boundaries typology and consequences for E-LCC</i>   | 56 |
| <i>Table 5: Example of typology for cost categories used in E-LCC</i>   | 60 |
| <i>Table 6: Example of portfolio presentation</i>   | 67 |
| <i>Table 7: Example of normalization</i>  | 70 |
| <i>Table 8: Recommendations on selected method issues for footprint studies</i>   | 72 |
| <i>Table 9: Recommendations on selected method issues for intervention studies</i>  | 76 |
| <i>Table 10: Examples of inventory data for LCA</i>   | 88 |
| <i>Table 11: Example of cost inventory</i>  | 90 |
| <i>Table 12: Example of cost distribution among cost bearers (numbers are not from a real case; revenues are not considered here)</i> | 91 |
| <i>Table 12: Example of inventory data for LCA</i>  | 98 |
| <i>Table 14: Example of cost inventory (numbers are not from a real case; revenues are show only for value added calculation)</i>     | 99 |

|  |     |
|--|-----|
| Table 14: Comparison between consequential and attributional LCA (Guiton et al., 2013) | 104 |
|--|-----|

## List of Figures

|   |     |
|---|-----|
| Figure 1: The scope of this report covers all levels in the waste hierarchy   | 14  |
| Figure 2: Decision tree for determining the REFRESH situation for side flows. Only mass flows originating from the food supply chain are considered                                       | 24  |
| Figure 3: Decision tree for determining type of study (footprint/intervention) and corresponding modelling framework, adapted from the ILCD handbook (EC, 2010) and Laurent et al. (2014) | 33  |
| Figure 4: FU and system boundary when at least one of the compared scenarios involves preventing a side flow, example of moving from RS 3 (A) to RS 1 (B)                                 | 42  |
| Figure 5: Resulting system of moving from RS 3 to RS 1 (example)  | 42  |
| Figure 6: FU and system boundary when the scenarios compared do not involve preventing side flow  | 43  |
| Figure 7: Resulting system of moving from RS 3 to RS 2 (example)  | 43  |
| Figure 8: Decision tree outlining the 5-step procedure for identifying the processes affected by a change in demand for a specific intermediate product (adapted from Weidema 2003)       | 46  |
| Figure 9: General scoping of LCC  | 52  |
| Figure 10: Example of percentage based portfolio presentation with life cycle stage contribution  | 68  |
| Figure 11: Example of plotting of impacts (footprints)  | 68  |
| Figure 12: Example of plotting of impacts (interventions)   | 69  |
| Figure 13: Process flow diagrams for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 1   | 86  |
| Figure 14: Resulting process flow diagram for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 1  | 87  |
| Figure 15: Process flow diagrams for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 2   | 96  |
| Figure 16: Resulting process flow diagram for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 2  | 97  |
| Figure 17: Definition of food supply chain from FUSIONS (2014)  | 103 |

## List of Boxes

|   |           |
|---|-----------|
| <i>Box 1: Additional examples of RS 1</i>   | <i>19</i> |
| <i>Box 2: Additional examples of RS 2</i>   | <i>21</i> |
| <i>Box 3: Additional examples of RS 3</i>   | <i>22</i> |
| <i>Box 4: Additional examples of RS 4</i>   | <i>23</i> |
| <i>Box 5: Example of attributional and consequential LCA of milk production<br/>(excerpts from Thomassen et al. 2008)</i> | <i>32</i> |
| <i>Box 6: EU Initiative on Product Environmental footprint of driving products</i>  | <i>38</i> |

## List of abbreviations

|                 |  |
|-----------------|--|
| <b>ALCA</b>     | Attributional life cycle assessment                                      |
| <b>CLCA</b>     | Consequential life cycle assessment                                      |
| <b>C-LCC</b>    | Conventional life cycle costing  |
| <b>CoE</b>      | Community of experts   |
| <b>E-LCC</b>    | Environmental life cycle costing   |
| <b>EP&amp;L</b> | Environmental Profit and Loss  |
| <b>EVA</b>      | Economic Value Added   |
| <b>FAO</b>      | Food and Agriculture Organization of the United Nations                  |
| <b>FLW</b>      | Food Losses and Waste  |
| <b>FSC</b>      | Food supply chain  |
| <b>FU</b>       | Functional unit  |
| <b>FUSIONS</b>  | Food Use for Social Innovation by Optimising Waste Prevention Strategies |
| <b>GWP</b>      | Global warming potential   |
| <b>ILCD</b>     | International reference life cycle data system                           |
| <b>IRR</b>      | Internal rate of return  |
| <b>ISO</b>      | International organization for standardization                           |
| <b>KPI</b>      | Key performance indicator  |
| <b>LCA</b>      | Life cycle assessment  |
| <b>LCC</b>      | Life cycle costing   |
| <b>LCI</b>      | Life cycle inventory   |
| <b>NPV</b>      | Net present value  |
| <b>PEFCR</b>    | Product environmental footprint category rules                           |
| <b>PCR</b>      | Product category rules   |
| <b>RS</b>       | REFRESH situation  |

- SB** System boundary
- S-LCC** Societal life cycle costing
- WEEE** Waste electrical and electronic equipment
- WP** Work package



## Glossary

The definition of terms in the glossary have been based on the ISO standard for life cycle assessment (ISO, 2006), the ILCD handbook (EC, 2010), the PEF guide (EC, 2013), Hunkeler et al. (2008) and Citroth et al. (2011), and adapted for this report when necessary.

|  |  |
|--|--|
| <b>Allocation</b>                      | Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems   |
| <b>Attributional LCA</b>               | Refers to process-based modelling intended to provide a static representation of average conditions, excluding market-mediated effects   |
| <b>Background system</b>               | The background system are those processes that are not specific to the system, they support the processes that are specific (in the foreground system). Due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process in the background system. An example of a process in the background system is production of electricity bought from the national grid. |
| <b>Consequential LCA</b>               | Modelling principle that explores effects on a system due to changes and therefore involves comparison of scenarios; identifies and models all processes that are affected in the foreground and background system of a system in consequence of decisions made  |
| <b>Co-product</b>                      | Any of two or more products coming from the same unit process or product system  |
| <b>Cradle to gate</b>                  | A partial product supply chain, from the extraction of raw materials (Cradle) up to the "gate" (e.g. manufacturer's or retailer's gate). The use stage and end-of-life stages of the supply chain are omitted.   |
| <b>Cradle to grave</b>                 | A product's life cycle that includes raw material extraction, processing, distribution, storage, use and disposal or recycling stages. All relevant inputs and outputs are considered for all of the stages of the life cycle.   |
| <b>Conventional life cycle costing</b> | An assessment of all costs associated with the life cycle of a product, directly covered by anyone or more of the actors in the life cycle.  |
| <b>Cost</b>                            | The cash or cash equivalent value sacrificed for goods and services that are expected to bring a current or future benefit to  |

the organization.

|   |   |
|---|---|
| <b>Cut-off (criteria)</b>               | Specifications of the amount of material or energy flow or the level of environmental or economic significance associated with unit processes or product system to be excluded from the study.  |
| <b>Discounting</b>                      | Converting future costs (and revenues or value) to equivalent (net) costs at a common point in time (e.g. present year).  |
| <b>Driving product</b>                  | The product(s) or material(s) that is/are at least partly responsible that a food supply chain (FSC) is in place. If there were no need for this product, certain processes in the FSC would not take place. Driving products can also include non-food products. The stakeholder in the FSC producing this product wants to produce it, and a process step in the FSC might have more than one driving product (e.g. milk, cream and butter from a dairy). (definition from this report) |
| <b>Environmental cost</b>               | It can express environmental damage expressed in monetary terms or the market-based cost of measures to prevent environmental damage, including end of life processes. Market-based costs are part of life cycle costing.   |
| <b>Environmental impact</b>             | Any change to the environment, whether adverse or beneficial, that wholly or partially results from an organisation's activities, products or services.   |
| <b>Environmental life cycle costing</b> | An assessment of all costs associated with the life cycle of a product that are directly covered by one or more actors in the product life cycle (e.g., supplier, manufacturer, user or consumer, or end of life actor) with potential inclusion of externalities that are anticipated to be internalized in the decision-relevant future.  |
| <b>Externalities</b>                    | Environmental and social impacts not directly borne by any of those taking part in the product life cycle, such as the firms, consumers, or government bodies that are producing, using, or handling the product.   |
| <b>Food supply chain</b>                | Starts when the food is ready for harvest, slaughter or caught in the net/on the hook and is considered to have left the food chain as it is consumed/used.   |
| <b>Foreground system</b>                | The foreground system is defined as those processes of the system that are specific to it. This means that data for the specific e.g. technology, supplier etc. is most appropriate.  |
| <b>Functional unit</b>                  | Quantified performance of a product system for use as a reference unit (comment: in the PEF guide the term "unit of analysis" is used).   |

|  |  |
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| <b>Impact category</b>                     | Class representing environmental issues of concern (e.g. climate impact) to which life cycle inventory analysis results may be assigned.   |
| <b>Life cycle</b>                          | Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal   |
| <b>Life cycle assessment (LCA)</b>         | Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle  |
| <b>Life cycle impact assessment (LCIA)</b> | Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product   |
| <b>Life cycle inventory analysis (LCI)</b> | Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle  |
| <b>Marginal LCI data</b>                   | Data that describes how a process, or production mix, reacts to small changes in production volume. E.g. for electricity production, the average data might be 50% nuclear electricity and 50% hydroelectricity, whereas the marginal data might be 100% fossil-fuel based (the technology that would be used if the consumption of electricity changed slightly up or down).                                    |
| <b>Process</b>                             | Set of interrelated or interacting activities that transforms inputs into outputs  |
| <b>Process flow diagram</b>                | Graphic representation of the system boundary defined  |
| <b>Product</b>                             | Any goods or service   |
| <b>Product system</b>                      | Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.  |
| <b>Side flow</b>                           | A material flow of food and inedible parts of food from the FSC of the driving product, including wasted driving product, and also final disposal of inedible and edible parts of unconsumed food product after use, e.g. plate leftovers. The stakeholder in the FSC producing this flow tries to have as little as possible of it, "the less, the better" applies for this flow (definition from this report). |
| <b>Societal life cycle costing</b>         | An assessment of all costs, including costs of externalities, associated with the life cycle of a product, covered by any actor  |

in society. Transfer payments are not considered in societal LCC.

**System  
boundary**

Definition of aspects included or excluded from the study. For example, for a “cradle-to-grave” environmental footprint (EF) analysis, the system boundary should include all activities from the extraction of raw materials through the processing, distribution, storage, use, and disposal or recycling stages.

**Transfer  
(payments)**

Payments between governments and private persons or organizations, involving taxes and subsidies. Payments for public services, like for waste management, may fall under this heading if paid (for example) by a local municipality from taxes or levies.

**Value added**

The difference between the cost of products purchased and the proceeds of products sold, as gross value added, being the costs of labour and capital, including profits. Net value added is obtained by subtracting depreciation from gross value added.

**Waste  
hierarchy**

Priority order of waste management strategies, placing prevention at the top, followed by preparing for re-use, recycling, recovery, and as the last option, disposal (EC, 2008)

# 1 Executive summary

Urged by the importance of resource efficiency and circular economy agenda of EU and national policy makers, many stakeholders are seeking alternatives for current surplus food or side flows within the food supply chain. Any new valorisation route for side flows (i.e. not the main product) will be associated with impacts (monetary and environmental). To allow informed decision making at all levels, from individual stakeholder to policy level, robust, consistent and science based approaches are required. The EU H2020 funded project REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain) aims to contribute to food waste reduction throughout the food supply chain, and evaluate the environmental impacts and life cycle costs.

Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) are well documented and generic approaches for assessing the environmental and cost dimensions of a system. Both LCA and LCC are characterised by allowing for a large flexibility in system scoping. To allow for comparison between different options consistent approaches are required. Furthermore, there is a need to bridge the gap between assessors who might have a deep knowledge of the systems they are assessing, but are not in depth method experts on LCA or LCC. Highlighting challenging methodological aspects and encouraging the practitioner to ask the most relevant questions contributes to a better scoping practice of LCA and LCCs.

The objective of this study was to develop a consistent approach, *combining* LCA and LCA *specifically* to assess impacts of prevention of resource inefficiencies, valorisation routes and waste handling in the food supply chain. The recommendations build on existing standards and state-of-the-art LCA/LCC research, and provide guidance on how to overcome specific methodological challenges. They focus particularly on the goal and scope stage of an LCA and Environmental LCC and on side flows from the food supply chain.

To categorise systems in order to be assessed, the concept of “REFRESH situations” (RS) has been developed (De Mena *et al.*, 2016; Unger *et al.*, 2016). The four REFRESH situations (RS) are: Prevention of side flow (RS 1), side flow valorisation (RS 2), valorisation as part of waste management (RS 3), and end-of-life treatment (RS 4). The REFRESH situations can take place at any point/process in the life cycle, within the remit of any stakeholder (including consumers) and are independent of the perspective taken, i.e. of the producer of side stream or the receiver. For each REFRESH situation, specific recommendations on setting of system boundary, functional unit(s) and handling of multi-functionality in relation to the stated problem are provided (beside some other aspects). The importance to differentiate between attributional and consequential approaches is discussed in detail. This consistent approach contributes towards more harmonised use of LCA and LCC for informed decision for handling side flows in the food supply chain.

The focus of the specific recommendations given in this report is primarily on change-oriented studies on interventions for side flows since foot print studies are to a higher degree covered in existing frameworks such as the ILCD-handbook and the PEF framework under development.

### *Key recommendations:*

It is recommended to use the “REFRESH situations”. In addition to following the ISO standard on LCA, it is further recommended to go through the following steps, being detailed in the report, when performing an LCA, an LCC, or a combined LCA and LCC study, focusing on side flows from the food supply chain (FSC):

1. Phrase the question of your study; what is the purpose of the study?
2. Establish if the flow being investigated in the study is a side flow (if not, then it is outside the scope of this report), and which REFRESH situation is applicable, by using the decision tree provided. For several situations (scenarios) run through the decision tree for each situation.
3. Establish whether your study is a *footprint* or *intervention* study, by using the provided decision tree.
4. If cost is assessed, use the provided decision tree to establish if *E-LCC* is suitable for the study, if not, it is out of scope of this guide.
5. Utilise the provided summary table for recommendations on methodological choices in the LCA/E-LCC study.

Considering the environmental impact categories, unless specifically stated in the research question, it is recommended to have a multi-impact approach in order to have a broader understanding of environmental impacts and to be able to identify trade-offs. However, if data availability is limited, a list of prioritised impact categories is provided.

If the main aim of the *E-LCC* is on internal financial/budget aspects and there is only one cost bearer, it is recommended to assess cost hotspot (stages or processes determining relevant costs), Net Present Value (NPV) and Internal Rate of Return (IRR). If the main aim is to assess effects on the supply chain (and several cost bearers), then impact assessment should focus on distribution of costs among life cycle stages and/or cost bearers. Other assessment may focus on: cost/benefit ratios, profits, and value added. In the case of intervention studies, the focus being on potential systemic consequences, it is recommended to include an evaluation of value added generated by the system, as a proxy of economic consequences.

It is recommended to use portfolio presentations to show complete results of both LCA and E-LCC results in a common table, and to visualise selected impacts in a graph. As a second step, it is recommended plotting selected environmental and cost indicators to show eventual win-win or trade-offs between the environmental and cost dimension. Transparency should be a crucial element in all reporting.

The use of generic key performance indicators is not recommended for LCA and E-LCC. It should be emphasised that LCA and E-LCA provide objective numbers and does only respond to the environmental and cost dimensions. Reduction of food waste also has important social (e.g. availability of food) and political dimensions that need to be considered together with the results obtained from LCA and E-LCC.



## 2 Introduction

The REFRESH project aims at contributing towards the EU Sustainable Development Goal 12.3 of halving per capita food waste at the retail and consumer level and reducing food losses along production and supply chains, reducing waste management costs, and maximizing the value from un-avoidable food waste and packaging materials.

This goal can only be achieved if food is produced using the available resources efficiently and effectively from an economical and environmental perspective. This includes the prevention of unwanted side flows from the food supply chain, as well as utilising any value from such side flows to the best effect. Such an increase in resource efficiency will have an economic effect and reduce the pressures on climate, water and land use in a wider perspective.

Generally, a new valorisation route for side flows from the food supply chain will be associated with impacts (monetary and environmental), for example for capital investments or developing new technologies. In the long run, however, this may lead to better resource utilisation which will manifest itself in lower running costs and less environmental impact. In order to allow informed decision making at all levels, from individual stakeholder to policy level, robust, science based approaches are required.

This part of REFRESH aims at providing the environmental and cost dimension for prevention and valorisation by using life cycle assessment (LCA) and life cycle cost (LCC) methodologies. The specific objectives are:

Objective 1: Supply consistent LCA and LCC approaches by developing (i) measures and methodologies for evaluating the environmental sustainability dimension, including emissions of greenhouse gases, of food waste prevention, waste valorisation and waste management activities, (ii) measures and methodologies for evaluating life cycle costs of food waste prevention activities, waste valorisation and waste management activities and (iii) suggesting performance indicators based on LCA and LCC.

Objective 2: Supply consistent LCA and LCC data for selected cases of valorisation routes to be used for the identification of the most sustainable and economically viable solution.

Objective 3: Contribute to the development of the REFRESH decision support system and develop an accessible web-based tool providing consistent LCA and LCC data.

Objective 4: Support the development of a harmonized approach to EU food waste legislation by addressing environmental impacts and LCC of possible policy and consumption.

### 2.1 Objective

The objective of the present report is to develop a systematic methodology for LCA and LCC and how to combine them. A consistent methodology is required to



allow for more harmonised evaluations of the environmental and cost dimensions of alternatives for prevention of resource inefficiencies, valorisation and waste handling, associated with a food supply chain side flow. Such an approach will assist in providing information-based and well scoped assessments for informed decision making on potential alternatives for side flow treatment.

The recommendations developed in this report are built on findings from literature reviews performed to identify existing measures and methodologies and their application to food waste valorisation and management published in the REFRESH reports “Methodology for evaluating environmental sustainability” (Unger et al., 2016a) and “Methodology for evaluating LCC” (de Menna et al., 2016). These reviews highlight that while there are several standards and guidance documents, these may not reach practitioners performing LCA and LCCs. There is a need to bridge this gap for assessors who might have a deep knowledge of systems they are assessing but are not in depth method experts in LCA or LCC. This is taken into account by:

- Highlighting some of the most challenging methodological aspects identified from the literature review
- Providing food waste specific examples
- Using REFRESH situations to elaborate on method choices
- Encouraging the practitioner to ask the important questions and thus help to scope LCA and LCCs better

The recommendations presented in this report will serve as a base for other outputs of the REFRESH project, where simplified guidance tools with respect to environmental performance and cost for businesses will be developed to explore the benefits of valorisation. The recommendation will also be a part of the CoE (Community of Experts) within the REFRESH project. As such, it will provide stakeholders and policy makers with guidance regarding assessing the environmental and cost dimensions for a given intervention aimed to reduce wastage of food.

Finally, the work carried out will contribute to facilitating the application of LCA and LCC to studies focused on side flows from the food supply chain, and also to the research field on the combination of LCA and LCC.

## 2.2 Approach

This report “Generic strategy for LCA and LCC - Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain” provides recommendations on how to scope an LCA, an LCC or a combined LCA and LCC, with focus on side flows.

The audience for the recommendations given in this report is LCA/LCC practitioners who have working knowledge in and applying LCA and LCC in their field of expertise but who are not methodology experts.

The research builds on existing guidance, in particular for LCA on the International Reference Life Cycle Data System(ILCD) handbook (EC, 2010) and

for LCC on the framework devised by Hunkeler et al. (2008) and Swarr et al. (2011), which are further developed with the aim to cater for food waste and by-product related questions. This report specifically addresses the (i) challenges arising when scoping food waste and by-product valorisation and food waste and by-product prevention assessments and (ii) combining of both LCA and LCC assessments.

The formulated recommendations give guidance on methodological aspects where additional clarity is needed by providing explanations, concrete examples and recommendations to support the user. The recommendations specifically address key challenges identified in the REFRESH reports “Methodology for evaluating environmental sustainability” (Unger et al. 2016a) and “Methodology for evaluating LCC” (de Menna et al., 2016) by specifically responding to:

- Does the question being asked result in an attributional or consequential model?
- What is a suitable functional unit (FU) and system boundary (SB) in relation to the research question(s)?
- How to deal with multi-functionality (allocation/system expansion)?
- What environmental burden/economic costs does a side flow from the food chain have?
- How to identify replaced products, and on what basis?
- Which are the most important environmental indicators to focus on? Climate impact is common, but standards require many aspects to be explored. What is relevant but also feasible?
- Which cost items should be inventoried?

All recommendations given are **based on state-of-the-art LCA and LCC research**. Where different opinion occurs in the literature and scientific debate on some issues, the related standpoints are detailed in the recommendations section provided in this report.

The recommendations focus primarily on change-oriented studies of food waste interventions.

The developed guide builds on existing standards and LCA/LCC literature, and provides guidance to the assessor on how to overcome specific methodological challenges, through the use of decision trees and by giving examples. The document is focusing on the scoping stage of an LCA and LCC assessing **side flows from the food supply chain** (FSC) as defined in section 2.3. Changes in equipment and energy use, lead times, process optimisation, energy optimisation within the FSC which are not influencing the raw material use per unit driving product are out of scope.

The guide distinguishes between footprint studies and intervention studies (described further in section 4.1):

**Footprint studies** provide general information on the impact associated with a given or future product or service by giving a “snap shot” of the system.

This corresponds to what the ILCD guide (2010, p.3) describes as an accounting study: "Purely descriptive documentation of the system under analysis (e.g. a product, sector or country), without being interested in any potential consequences on other parts of the economy". This type of study is an attributional study.

Footprint studies of waste flows are covered in a general manner to adequately link the recommendations given to current LCA and LCC frameworks as the ILCD handbook and the guidance on product environmental footprints – PEF (EC, 2013) which focus on the driving product of a system rather than waste flows. General guidance on footprint studies of valorised side flows and waste management systems is provided in section 4.1.2.

**Intervention studies** are studies that explore effects of interventions to a system by assessing the impact due to a *change*; thus a comparison of two, or more, well-defined scenarios is performed. In the ILCD guide (2010, p.3) this is referred to as studies for "Micro-level decision support" and "Meso/macro-level decision support". This type of study is a consequential study, although on a small scale attributional data may be used (further explained in section 4.1.1).

General guidance for these types of studies is provided in section 4.1.3 and examples of intervention studies are given in Annex A.

The difference between a **footprint study** and an **intervention study** is explained further in section 4.1.1.

For life cycle costing aspects, the guide focuses on environmental LCC (E-LCC), following the categorization proposed by Hunkeler et al. (2008). Further details on the general scoping of an LCC study are provided below (section 4.2).

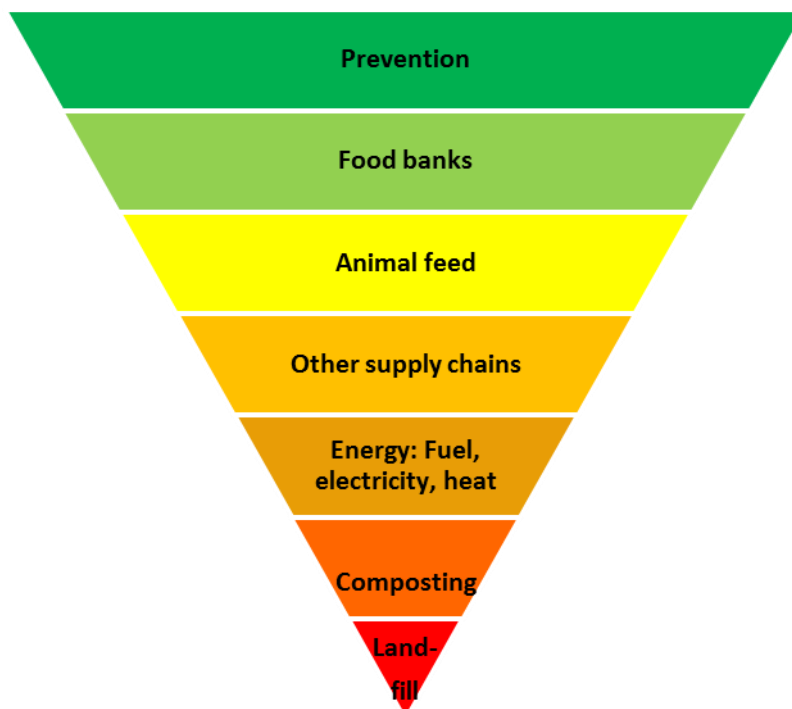
The report applies to all levels in the waste hierarchy<sup>1</sup>, shown in Figure 1 adapted to the FUSIONS definition (Östergren, 2016). The hierarchy states the order of preference for handling of side flows, however, the EC directive on waste specifically encourages (EC, 2008, Directive on waste, paragraph 4): "*When applying the waste hierarchy referred to in paragraph 1, Member States shall take measures to encourage the options that deliver the best overall environmental outcome. This may require specific waste streams departing from the hierarchy where this is justified by life-cycle thinking on the overall impacts of the generation and management of such waste*". This report focuses on the latter point, the life cycle methodology to understand the overall impacts of different interventions and allows comparing them, whether within a hierarchy level or across. In addition, it provides recommendations for combining it with the economic dimension, and thus providing additional value.

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<sup>1</sup> See for example:

[http://ec.europa.eu/environment/waste/publications/pdf/Making\\_Sust\\_Consumption.pdf](http://ec.europa.eu/environment/waste/publications/pdf/Making_Sust_Consumption.pdf)

**Figure 1: The scope of this report covers all levels in the waste hierarchy**



The recommendations in the following chapters will help the reader to:

1. Establish what "REFRESH situation" a system describes
2. Establish whether the study is a footprint or intervention study
3. Tackle methodological choices in the LCA and LCC study
4. Give guidance on how to combine LCA and LCC assessments

Table 1 gives an overview of the scope of the report, as well as direction to relevant sections in the report for definitions and guidance.

**Table 1: Overview of what is in and out of scope of guidance in this report**

| Type of study   | In scope | Out of scope   | Section in report  |
|---|----------|--|--|
| Does the aim include the assessment of environmental impacts and/or costs attributed to a mass flow from the <b>food supply chain (FSC)</b> ? | Yes      | Only mass flows from <b>FSCs</b> are covered; mass flows from other systems are out of scope | <b>See section 2.3</b> for definition of the FSC   |
| Does the study aim at assessing the utilization of <b>a side flow</b> , or the prevention of a side flow?                                     | Yes      | Studies on <b>driving products</b> from FSCs are out of scope                                | <b>See section 2.3</b> for definition of driving products and <b>side flows</b> , and <b>section 3</b> for distinction between different situations for side flows ( <b>REFRESH situations</b> ) |
| If cost is assessed: Does an E-LCC approach fit the purpose of the study?   | Yes      | Conventional LCC (C-LCC) and Societal LCC (S-LCC) are out of scope                           | <b>See section 4.2</b> for definition of C-LCC, <b>E-LCC</b> and S-LCC   |
| Does the study aim at assessing a <b>footprint</b> ?  | Yes      |  | <b>See chapter 5</b> for summarised recommendations and <b>4.1.2</b> for background on footprint studies   |
| Does the study aim at assessing the effect of an <b>intervention /change</b> ?  | Yes      |  | <b>See chapter 5</b> for summarised recommendations and <b>section 4.1.3</b> for background on intervention studies and examples in Annex A  |

## 2.3 Definitions used in this report

In the REFRESH project the FUSIONS definition of food waste has been agreed upon (Figure 17 in Annex B), however the methodology in this report is developed to be generic and rather relate to the function of the flow to be assessed in the stated problem than pre-set definitions. Based on this, the following definitions are applied in the report.

**Food** is defined in accordance with article 2 in the EC regulation on the principles and requirements of food law (EC, 2002) where food means any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be eaten by humans. 'Food' includes drink, chewing gum and any substance, including water, intentionally incorporated into food during its manufacture, preparation or treatment.

The **food supply chain** (FSC) is considered to start when the food is ready for harvest, slaughter or caught in the net/on the hook and is considered to have left the food chain as it is consumed/used (see Figure 17 in Annex B).

According to the FUSIONS definition of food waste, only flows from the food supply chain that are not valorised as animal feed, biobased materials or through biochemical processing are considered food waste. In this report, however, a broader definition is used including all flows leaving the FSC that the stakeholder generating it **wants to minimise** (i.e. not the driving products, see further down), and refer to them as **side flows from the food supply chain**.

A **side flow from the food supply chain** is a material flow of food and inedible parts of food from the FSC of the driving product, including wasted driving product, and also final disposal of inedible and edible parts of unconsumed food product after use, e.g. plate leftovers. Quality does not play a role in defining a side flow. The stakeholder in the FSC producing this flow tries to have as little as possible of it, "the less, the better" applies for this flow. Henceforth in the report it is referred to by the shorter term 'side flow'.

This document focuses on side flows and not on driving products.

Examples of side flows and of their utilisation are:

- A wasted driving product (bread, carrots) or product mixture (e.g. mixed vegetable waste from a retailer) from the FSC
- A side flow from the FSC being used in a new or novel application in the FSC and thus replacing another product, e.g. the use of fibres from carrot peel instead of starch in sausages
- The side flow can be an existing flow or a future flow (not existing for the moment, e.g. when planning future operations)
- Food donations since it leaves the regular food supply chain and are not the reason why the FSC is put in place
- A marked down product competing with full prize products is seen as economic valorisation and thus the marked down product flow is handled as a side flow

Any side flows *not* coming from the food supply chain are out of scope; some examples are:

- Bio-based products such as fuel maize
- Crops grown for the purpose of animal feed, e.g. soy
- Apples and fruits grown not destined for human consumption, e.g. for "decoration"

- Products not yet having entered the food supply chain (wild fish or wild animals that potentially could be caught, pre-harvest crops not being mature to harvest due to pests, etc.)

**Driving product:** The product(s) or material(s) that is/are at least partly responsible that a FSC is in place. If there were no need for this product, certain processes in the FSC would not take place. Driving products can also include non-food products. The stakeholder in the FSC producing this product wants to produce it: “the more, the better” applies for this flow.

Jointly produced products (e.g. milk, cream and butter) are all driving products, as long as “the more, the better” applies for the product. Valorisation of side flows may generate new products that are jointly produced with the driving product, i.e. a side flow may become a driving product after valorisation. Furthermore, changes in the market place might mean that a certain output flow changes from being a side flow to a driving product, and vice versa.

### 3 REFRESH situations

The purpose of the REFRESH Situation is to support scoping of Life Cycle Assessments and Life Cycle Costing (LCC). The REFRESH situations should be seen as a framework that helps describing more accurately and consistently the wider system where an assessment takes place and thus for instance helps in defining the case specific system boundaries, or whether allocation of upstream burden to the side flow should be done, or not. **The REFRESH situations themselves are just a categorisation, not methods and REFRESH situations are independent of who looks at it, generator, valoriser or authorities.**

There are four defined REFRESH situations (RS): prevention of side flow (RS 1), side flow valorisation (RS 2), valorisation as part of waste management (RS 3) and end of life treatment (RS 4). These have been described previously in a REFRESH report (Unger et al, 2016a) and also in Unger *et al.* (2016b).

They have in common that:

- they can take place at any point/process in the life cycle;
- they can take place within the remit of any stakeholder (including consumers) and they are independent from the perspective, i.e. the producer of side streams or receiver;
- more than one REFRESH situation can occur at the same life cycle stage, e.g. part of a side flow is valorised at source, part becomes input to a waste management system and is then in turn valorised;
- more than one REFRESH situation can occur at different life cycle stages within a life cycle under investigation;
- a side flow can change from one RS to another if the system around it changes (see later for examples);
- all final destinations of the side flow can be accommodated.

#### 3.1 Prevention of side flow (RS 1)

Waste prevention, which is the highest priority of the waste hierarchy (see Figure 1), is defined as the prevention of side flow through avoidance, reduction, and reuse, but excluding off site recycling. The Waste Framework Directive (EC, 2008) especially in Article 3, clause 12-13, states that prevention means taking measures before a substance, material or product has become waste, which reduce: (a) the quantity of waste, including through the re-use of products or the extension of the life span of products; (b) the adverse impact of the generated waste on the environment and human health; (c) the content of harmful substances in materials and products (Zorpas and Lasaridi, 2013).

As this report's scope is wider than waste as defined above, this REFRESH situation is called prevention of side flow but is routed in the above described waste prevention measures. The authors propose that prevention is only an



option if the raw material is not fully utilised for the desired purpose without changes in product specifications (e.g. quality grading, packaging size or composition) and product formulation. If there was never wastage of resources in the first place, there cannot be prevention, in other words, one cannot claim preventions by designing a process or the whole food supply chain well and resource efficiently. Depending on where in the life cycle the prevention takes place, more or fewer processes in the life cycle will be affected. If a new technology raises harvest efficiency (i.e. less crop lost), then this will only affect the agricultural stage; if food waste is prevented at the consumer level, then the prevention will show benefits for the whole life cycle up to that stage. While prevention is generally seen as reducing environmental impacts, there might also be trade-offs. For instance, if consumers are reducing their own food waste, food demand could decrease. However, if less is needed there might be poorer economies of scale, actions for prevention might result in economic or environmental burden (e.g. energy for better preservation), which need considerations.

In terms of assessing different interventions, it is probably mostly relevant to explore interventions that aim to prevent side flows, i.e. moving from RS 2, 3 or 4 to RS 1. However, it is also possible to evaluate interventions that start from RS 1 and moves to RS 2, 3 and 4. An example of this would be a process facility that for some reason wants to evaluate consequences of increasing a side flow, perhaps due to economic reasons, i.e. starting from a small side flow (RS 1), and going to a larger side flow (RS 2, 3 or 4 depending on treatment of this increased flow).

Measures taken for prevention of side flow include: **redesign** and **optimisation of processes, new technology, re-work of material, behavioural change** (e.g. other management routines). An example of behavioural change would be if consumers use up their purchased food in time, so they do not have to throw away spoilt food. Another example would be retailers changing their purchasing routines so that the items ordered are better matched to what is sold (less wastage). In the last example it is important to check if the change in routine actually leads to less wastage, and not just changes the location where the wastage occurs (e.g. transferred from retailer to supplier).

#### **Box 1: Additional examples of RS 1**

**Household:** Better planning of shopping and cooking leads to that less food is wasted; correct storage temperature which prolongs the shelf life; smaller packing size leads to less waste since the food is used before it turns bad; smarter packing solutions preserves and protects the food better and less food is wasted; smart date marking takes into account the history of the product and informs the consumer how long it can be stored.

**Retail:** Improved stock management so that less products turn bad/pass use-by-date; better handling of vegetable and fruits leads to less waste; coordination of campaigns leads to less waste; new legislation restricting last-minute order cancellations; relaxation of cosmetic standards for fruit and veg.

**Restaurants:** Smaller portions lead to less plate waste; improved working process leads to less kitchen waste.

**Food Processor:** Better peeling technology; improved production planning; smarter change overs for liquid food with less mixed products; well-trained personnel cutting meat; wrongly packed products are re-packed and sold instead of being discarded.

**Transport and Storage:** Improved routing to avoid damages; choice of best transportation; new storage technology improves the quality; new lorries keep the temperature optimal for the different types of food; smart packaging protects the food from physical damage (e.g. fruits and eggs) may lead to less returns and waste due to damages during handling. The measures may also reduce waste at the consumer (see above).

**Primary production:** New and more efficient harvest technology leaving less vegetables on the ground; Improved trimming technology of vegetables.

### 3.2 Side flow valorisation (RS 2)

In side flow valorisation the outputs of the valorisation replace a marketable product or service. It can take place at any point in the life cycle, including the consumer stage (which itself does not produce a marketable output linked to the existing product chain but still can produce material outputs, e.g. carrot peelings which can be valorised as animal food and replace some commercial animal feed).

The key difference between side flow valorisation and valorisation as part of waste management is that it utilises, in general, side flows for which the origin is known, which are uncontaminated, high quality material flow, and therefore may allow usage within the food supply chain. In this situation there is **a clear link between the stakeholder where the output flow originates and the benefit from valorisation**. In other words, the stakeholder gains from putting the material flow into a specific route, e.g. a type of treatment. These treatment technologies can be identical to treatment technologies in waste management, e.g. anaerobic digestion. However, the stakeholder who benefits from the value from the product (energy) is different. In contrast to 'valorisation as part of waste management', described in the next section, in side flow valorisation the stakeholder takes the decision on further fate of a material while having the potential value gained in mind. This value can be material, economic, social, reputational or other.

It is possible that a side flow changes from one RS to another if the system in which it is produced in changes, e.g. if a new market is available for a side flow that previously did not exist or was not accessible (→ change in economic value). This can even lead to a side flow becoming a driving product (probably alongside other driving products), i.e. while before the generator wanted to have less of this flow, the circumstances change in such way that the generator would like to have more of this product. For example a potato packer who sends potatoes which cannot be sold as they are too small to a municipal biogas facility (RS 3). However, the potato packer can identify restaurants which would like to use these

small potatoes as delicacy potatoes. Depending on the price and agreement reached this would represent an intervention moving from RS 3 (see next point) to RS 2 (if the 'less is better' statement still holds, while some benefit is derived for the potato packer), or even from RS 3 to driving product, if the 'less is better' statement does not apply. This might be the case if the agreement and price achieved is beneficial enough to the potato packer that it is part of his product portfolio. In the last case, moving from RS 2 to driving product, the framework in this report can still be used, it can be treated as a move from RS 3 to RS 2.

Examples of measures taken for side flow valorisation could be: consumer plate leftovers used to feed the consumer's pet dog (if this means that less pet food is purchased in the household), animal feed production, biobased material and biochemical processing, fermentation or bio-energy production. The value from the side flows or services can be part of the business model, for instance if a manufacturer uses food processing waste as input into an anaerobic digester and the energy generated substitutes purchased energy from the market. The anaerobic digester might be on site as part of the stakeholder's operation or off site, run by a third party that provides either the energy back to the stakeholder or other forms of value, e.g. monetary.

In summary, in RS 2 **the generator** of the side flow gains some form of tangible value from the side flow, this can be economical, reputational or other.

## Box 2: Additional examples of RS 2

**Household:** Leftovers are used to prepare food to the pet in the household and substitutes pet food from the shop; home composting (if compost is produced and replaces compost bought at the shop).

**Retail:** Meals are prepared out of food that is approaching best before date but still perfect for eating, food is given away for charity which benefits the brand image of the retailer as being socially responsible; marked down prices of food close to best before date.

**Restaurants:** Prepared meals not served in school canteens are sold to employees and parents (if allowed).

**Food Processor:** Biogas production that substitutes bought energy. Biogas production at site being sold. Re-cycling (on site or off-site) that benefits the generator, e.g. trimmed fruits are sold and further processed to juice, the ends of a smoked ham which have been sliced are sold for pizza topping by the generator, the circles cut out of the centre of the big round crisp breads are sold as small culinary bread; sorted out small potatoes that are not accepted by the consumers are sold to restaurants as culinary potatoes by the generator. On-site feed production (which benefits the food processor economically or socially); advertising campaigns of food that is not sold as planned; not utilised side flows are sold to a feed producer.

**Transport and Storage:** A fruit storage facility sells fruits that are too ripe to sell to retailer to food processors for producing purees.

**Primary production:** Biogas production that is used on farm and substitutes bought energy, biogas production at site that is sold, feed production (the feed is sold or replaces purchased feed).

### 3.3 Valorisation as part of waste management (RS 3)

Valorisation as part of RS 3 can occur at any point in the life cycle. The material flow may be mixed with other materials for further treatment. The driving motivation of these processes is the disposal. However, the disposal is undertaken while at the same time generating some value for someone other than the generator of the side flow. Thus, it is important that the side flow generator wanted to dispose of the material at some point. This means that there is no tangible value attached to the side flow from the generator's point of view, which explains why he wants to get rid of it. Only at a later stage or for another stakeholder in the life cycle, was the notion to extract some value from the side flow introduced. However, in some cases, lack of traceability and risk of potential contamination might explain why the value gained from the side flow can be lower and less material specific than the original materials. Common valuable outputs from such treatment are energy or compost, but also animal feed.

A side flow in RS 3 may be accompanied by a loss of traceability or an increase in contaminations but not necessarily.

Measures for valorisation as part of waste management include any valorisation which gives a marketable product after the material has once been considered of no value to the generator, e.g. animal feed production, commercial composting, plough in if for purpose of soil enhancement, commercial anaerobic digestion, co-generation / incineration with energy recovery.

#### Box 3: Additional examples of RS 3

**Household:** Leftovers are sorted out and collected in a separate bin for composting by the municipality.

**Retail:** Unsold bread and vegetables are given away for feed production. Food that is approaching best before date but still perfect for eating are given away for charity without any gain for the retailer. Unsold bread and vegetables are given away to a feed processor

**Restaurants:** Prepared meals not served in school canteens are picked up by charity organisations.

**Food Processor, Transport and Storage:** Food side flows are given away or someone is paid for taking care of the un-utilised side flows for valorising it e.g. biogas production, heat production (incineration), feed or other products. Food is given away for charity without any tangible gains for the food processor.

**Primary production:** Food on the field is given away for charity (so called 'gleaning') without any tangible gains for the farmer.

The distinction between RS 2 and RS 3 is only dependent on the value of the side flow for the actor **generating** it (and not on the value for the actor receiving it), which is shown in Table 2.

**Table 2: Distinction between RS 2 and RS 3**

|  | RS 2               | RS 3          |
|--|--------------------|---------------|
| Generator of the side flow   | Stakeholder 1      |               |
| Receiver of the side flow  | Stakeholder 1 or 2 |               |
| Does the output flow have some value (economical, reputational, etc.) for Stakeholder 1? | Yes                | No            |
| Which stakeholder benefits from the value of the side flow?                              | Stakeholder 1      | Stakeholder 2 |

### 3.4 End-of-life treatment (RS 4)

The purpose of this situation is to handle material, and reduce its quantity and stability for final disposal. The sole purpose or function of this activity is the disposal of the waste. No value (economical, functional or emotional) is attributed to the material. Treatment technologies are not designed to maximize any valuable outputs but to reduce emissions. For instance, a landfill is not designed to optimise methane production, quite the contrary, even if landfill gas is collected.

Examples of measures for end of life treatment include: incineration without energy recovery, landfilling with and without gas recovery, wastewater treatment (a consumer pouring spoilt milk down the drain or left over product washed out during line change over), discard to land and sea (e.g. from fisheries), and ploughing in (for the sole purpose of disposing of the material).

#### Box 4: Additional examples of RS 4

**Household:** Food left-overs disposed of in the mixed wastage fraction, and sent to municipal incineration plant without energy recovery.

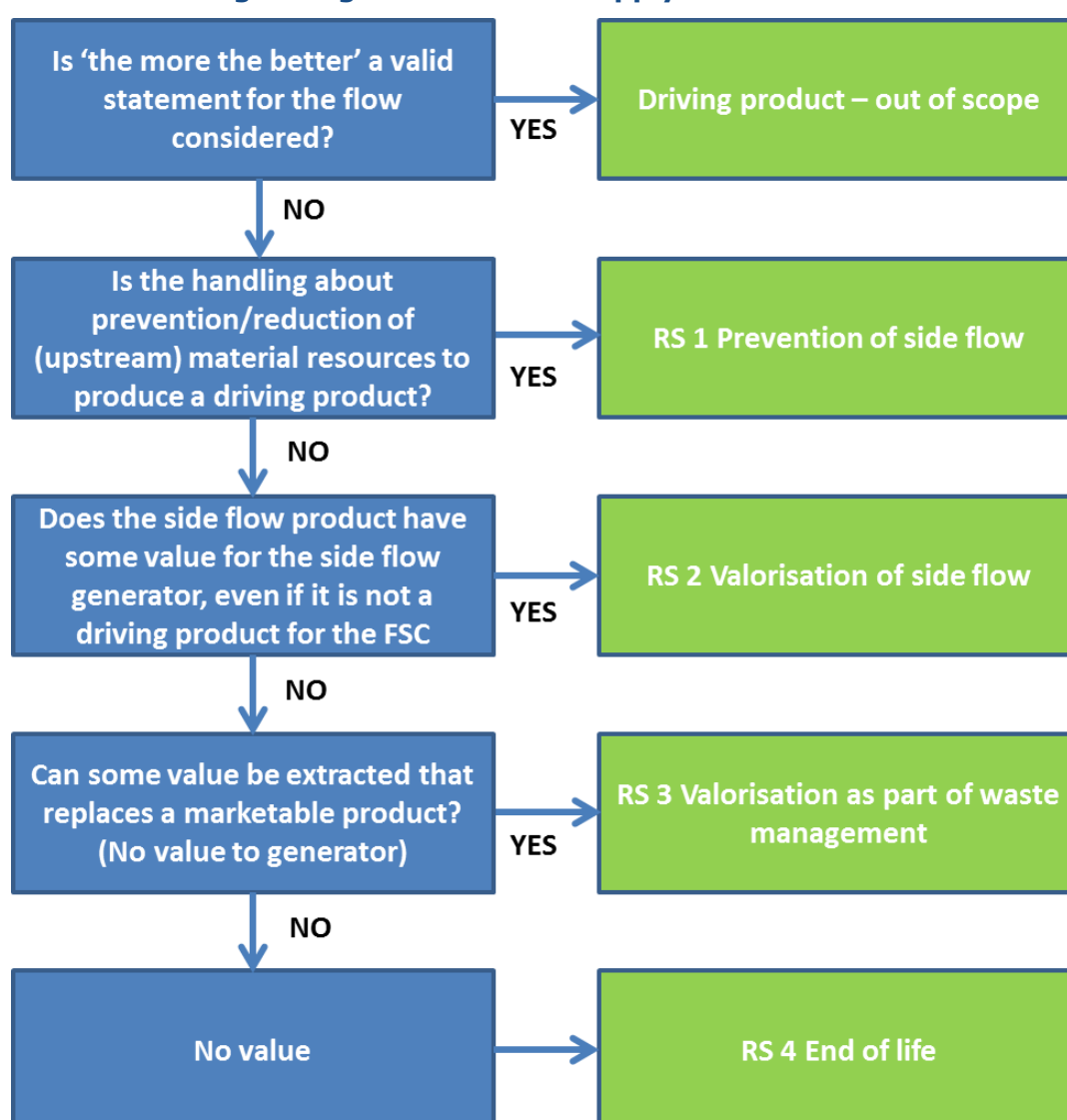
**Retail:** Food that has passed the sell-by-date is sent to municipal composting facility and compost is spread on land to put it somewhere but does not replace another marketable product and does not provide any other service of relevance to a stakeholder.

**Primary production:** Discarded fish thrown out from the fishing vessel into the sea.

### 3.5 Decision tree for determining REFRESH situation

The purpose of this decision tree is to help practitioners determine in which REFRESH situation the proposed food side flow study falls under. Each situation is characterised by specific methodological characteristics, which are detailed below. The questions need to be answered in the order they are given. If there are several output flows and scenarios that are considered in an assessment each of them has to be looked at separately and the different resulting system boundaries combined to allow a comparison. The decision tree is presented in Figure 2.

**Figure 2: Decision tree for determining the REFRESH situation for side flows. Only mass flows originating from the food supply chain are considered**



**It is important to note that the same type of side flow, depending on the circumstances of the specific food supply chain, might fall into different REFRESH situations.**

## Guidance on the decision tree

- 1) Determine if the mass flow in scope is a 'side flow from the food supply chain'

### **Is 'the more, the better' a valid statement for the flow considered?**

Is the flow part of the product portfolio of this specific FSC (food, material or other)? Are the FSC design and its processes aimed at generating as much of the flow as possible – the more, the better? Some supply chains produce both, food and non-food products, or some products can be used both for food and non-food purposes, e.g. vegetable oils. In such cases, even if the flow is not food, the supply chain is designed to optimize the products as part of the product portfolio. For example, the press cakes from vegetable oil generation might be sold as feed and thus considered as a part of the product portfolio since the market demand decides the production mix of driving product and other co-products. If the statement 'more is better' applies then: YES.

If, however, the company prefers to have as little as possible of the side flow and just tries to get some value/benefit out of the side flow then the answer is: NO. Note that it is in some cases not feasible to reduce the side flow to zero, but this does not mean it is a product. Some companies could even plan overproduction also because they know that a certain share of the product will be not sold due to several causes. Nevertheless, as long as the less the better applies it is a side flow.

**YES → under the current situation, the flow is considered a product rather than a 'side flow from the food supply chain' and thus is out of scope of this report**

### **NO – It is a REFRESH Situation**

- 2) Determine which REFRESH situation applies

### **Is the current handling about prevention/reduction of (upstream) material resources to produce a driving product?**

Is it a comparison (before and after) of a change in processing or management in the FSC, which leads to a change in amount of a specific side flow (which is not a driving product)? Is the side flow not a driving (desired) product and the 'the more the better' statement does not apply? The change does not alter the function of the driving product of the FSC but leads to a changed resource efficiency in producing it, e.g. a certain amount of driving product can be made with less material input? In this case the answer is YES. The amount of food waste which is changed/avoided can occur at any stage of the supply chain including the end of the supply chain, i.e. at the end of life of the product.

Process changes that lead to improved energy efficiency but no change in material efficiency is not a REFRESH 'prevention of side flows' as wasted energy does not change any side flows, although the need to produce less energy will lead to less material resources being used for energy production. Such energy efficiency studies are out of scope of REFRESH situations.



**YES → Refresh situation 1 Prevention of side flow**

**NO – Go to next question**

**Does the side flow product have some value for the side flow generator, even if it is not a driving product for the FSC?**

Does the side flow have some value for the stakeholder generating it? Value means economic, social, environmental, image, emotional etc. Is there a clear link between the stakeholder generating the side flow and its further processing? Does the generator initiate the valorisation/further treatment of the output flow? Does the valorised product replace marketable products?

**YES → Refresh Situation 2 Side flow valorisation**

**NO – Go to next question**

In some cases when a completely new product is the result of the valorisation process the marketable product may be hard to define or may be found in a completely different segment and further research may be required, but the RS 2 still applies in these cases.

Food donations fall into RS2 if a stakeholder takes the conscious decision to donate the food, e.g. a retailer making it part of its corporate social responsibility. Although the retailer will try to reduce the generation of unsold products, there will still be some reputational/image benefit if they communicate about their food donation. If someone wants to dispose of unwanted food and does not care who gets it then the answer is NO (see RS 3). An example of the latter is the case when people with fruit trees in their garden put out a box with ripe fruits on the pavement for everyone to take. There is a clear desire to get rid of the excess fruit, and the fruit tree owner might not know the final user of the fruit.

If, however, e.g. a city administration plants fruit trees for the purpose to make them accessible to city dwellers, then this is not valorisation but the production of fruits is the driving product and thus not a RS.

**Disposal/getting rid of the side flow is the driving force but some value can be extracted that replaces a marketable product? The generator of the side flow does not gain any value from valorisation.**

**YES, RS 3 valorisation as part of waste management**

In RS 3 the generator of the side flow typically hands over the material to another stakeholder (e.g. in the waste management sector) and does not get compensated from providing the material. However, the side flow has some value which is extracted and which replaces a product on the market. The existence of an accessible market where the gained product can be sold to is essential. If there is no accessible market, then RS4 applies, even if there is a market for that type of product somewhere else.

Typical products from RS 3 are energy or compost, but also animal feed or even redesigned products such as new valorised products.



**NO – no value is derived from the waste; Go to RS 4**

**RS 4 End of life treatment**

This situation includes all waste treatments that only aim at treating the side flow, and the purpose of the treatment is not to create any value. For instance, burning of waste or spreading on land could be considered in RS4 if there is no benefit gained, i.e. the purpose is not to improve soil quality or similar.

## 4 Generic LCA and LCC of side flows – method recommendations

This section provides recommendations first on LCA, then on LCC, and finally on how to combine them. All recommendations are summarised in chapter 5 .

### 4.1 LCA modelling framework

The framework of LCA consists of four stages: goal and scope, inventory, impact assessment and interpretation. The goal and scope stage determines key aspects of the study. According to the ISO standard 14044 (ISO, 2006) the goal and scope clearly needs to state the purpose of the study and the way the study is setup. More specifically, the list below need to be stated and described (list taken from ISO 14044, p.7). The items addressed in this report are written in **bold** text:

Goal of the study:

- The intended application;
- the reasons for carrying out the study
- the intended audience, i.e. whom the results of the study are intended to be communicated;
- whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

Scope of the study:

- the product system to be studied;
- the functions of the product system or, in the case of comparative studies, the systems;
- **the functional unit;**
- **the system boundaries;**
- **allocation procedures;**
- **LCAI methodology and types of impacts;**
- **interpretation to be used;**
- data requirements;
- assumptions;
- value choices and optional elements;
- limitations;
- data quality requirements,
- type of critical review, if any;
- type and format of the report required for the study.

The ISO standard gives further information for each of these items. While it is recommended to follow the ISO standard when describing the goal and scope of the study the purpose of this report is to give some supplementary guidance for some of the items on the list (in bold). These were selected based on the

literature review in Unger et al. (2016), where the main methodological challenges when assessing environmental impact of measures for side flows are: modelling framework for the study (consequential or attributional), functional unit and system boundaries, handling multi-functional processes, when and how to attribute burden to the side flow, how to identify a replaced product, and what environmental impact indicators to focus on.

#### 4.1.1 Determining the modelling framework: attributional or consequential?

##### Background/state of science

LCA methodology distinguishes between two different types of modelling: attributional and consequential LCA. The difference between attributional and consequential studies is important but can be difficult to establish. This section is an overview of the key aspects to consider for attributional and consequential studies for practitioners not familiar in detail with these types of LCA, to 'de-mystify' the topic and to help practitioners ease into it. The scientific debate on these modelling choices has been ongoing for many years, and more detailed discussions can be found in literature (e.g. Zamagni et al. 2012, Earles et al. 2011, Wardenaar et al. 2011, Pelletier et al. 2015, Weidema 2001, 2003, Weidema et al. 2009, 2010, Ekvall et al. 2004).

An attributional LCA (**ALCA**) assesses what is the **impact of a functional unit using data** representing infrastructure and technology in a defined geography and socio-economic conditions within the scope of the study. It is a snap shot of the system (a footprint).

ALCAs can be **stand-alone assessments (What is the impact associated with 1 FU?)** or be used for **comparing** two or more **different systems** producing the same FU. In the latter case **each system** represents a specific infrastructure, technology, geography and socio-economic condition which do not change but are **stable**. An example is: **What is the difference in producing 1 MJ electricity in Austria and Sweden?** Both countries currently produce electricity (ignoring for this example imports and exports) and the FU is the same amount and quality of electricity. No change is introduced to either system.

Another important feature of ALCA is the assumption that **each unit of the FU has the same impact as the previous or next**, independent of scale (1 unit FU has 5 units of impact, 1000 units of FU have 5000 units of impact). This is because data associated with the FU are based on an existing system with a certain capacity which produces one or several FUs and thus the impact of each FU is the same. However, this is the reason why ALCAs are **only of limited use to inform decision making** as they do not assess the impact of any changes to the system(s). However, ALCA can be used to identify, e.g. where hotspots across the life cycle are, i.e. processes which contribute most to the overall impact of a FU and thus inform management where changes might be most effective. It is also possible to estimate what the impact of a FU will be once changes have been made and a new stable system has been established. This

would be the case if the research question is: What is the impact of a system producing a FU compared to what is the impact of **another** system producing the same FU? What ALCA does not assess, is, what the impacts (including wider impacts within the system – not just directly linked to the FU) due to the change will be. This is when CLCA is required.

In consequential LCA (**CLCA**) the focus is on assessing the **effect on one system due to changes** (interventions). It has therefore always a **comparing element**. The research question for a CLCA can be: **What will be the impact of moving from disposing xx t of food waste via route A to valorising them using technology B?** The change in utilisation of a certain amount of food waste is assessed. It takes a forward looking (prospective) viewpoint. The extent (scale) of the intervention is important as it will determine what processes are affected by it, either directly or indirectly (in the background system). The assumption that **each FU has the same associated impact does not apply here**. In CLCA there will be certain **thresholds**, where the impact of one unit might change significantly, e.g., where an existing capacity to valorise food waste using technology B is exhausted and new capacities will have to be built. Therefore, the FU needs to represent this **scale** (unlike ALCA where the FU is often one unit). Moreover, the **time horizon** needs to be stated over which the change will take place. The assessor will have to understand what processes will be affected and to what extent and what the consequences will be. These might be directly linked to the main output of the FU, i.e. if more electricity is needed to use technology B, or indirectly, if putting the new product on the market might lead e.g. to the replacement of other products, changes in consumer behaviour or the need to dispose of a previously not existing product. At the same time, if the current system (before intervention) will not continue to operate as it is now, there might be avoided processes. There is general consensus that these aspects are dealt with system expansion in CLCA. Guiton et al. (2013) give as examples for sources of indirect effects constrained production factors (i.e. capacity related effect), multi-output processes, i.e. processes producing several products and changes in their quantities and the effect of those; and when novel products, services and processes are introduced and thus leading to a change in the respective markets. A **good understanding of the socio-economic** conditions is therefore very important for CLCA as it is the requisite to understand how markets are likely to be affected; further information on this is given in the section on intervention studies (4.1.3).

### **Grey areas between ALCA and CLCA**

The results between two comparing ALCA and a CLCA are different as they assess different questions.

However, if only small changes take place in an CLCA which only affect some processes to a small degree (do not change background processes), then an CLCA can use attributional data as proxy, e.g. changes in electricity demand are small and will not lead to differences in imports or exports of electricity or even building or decommissioning infrastructure. However, if results of CLCA using attributional data (as only a small change is assessed) are scaled up, the results are no longer appropriate as the accumulated effect results in a large change which is not captured in ALCA data. In such cases ALCA and CLCA might look very similar but

their potential to inform decisions is different. For instance, a food waste prevention intervention is realised in one household which leads to fewer products being purchased by the household and to halving the amount of food waste being disposed as part of household waste. If this intervention is done by one household, the effect, while significant on a household level, is unlikely to have any wider consequences. However, if all households within a country would adopt this measure there might be some wider consequences which need to be assessed, e.g. if the frequency of household waste collection changes. These changes are only considered in a CLCA. Another example is an intervention study where a producer wants to understand the consequences of changing raw material in the production of his product; let's say a sausage producer would like to utilise carrot peels as an ingredient in the sausages. If this is on a very small scale, then the processes affected by this change will not affect the market, and attributional data can be used to model the effects. Still, this will not give the same result as if two attributional LCAs were compared (one of the current sausages and one of the new sausages with carrot peel), because in the consequential LCA the current treatment of the carrot peel (e.g. biogas production) will be taken into account but not in the ALCA for this specific question. Basically, different systems are modelled in line with the different types of questions.

Moreover, in order to understand the effects of an intervention, in a CLCA the current system (attributional) needs to be described which is the same as in an ALCA.

Comparing two (or more) systems with ALCA might on occasion give the impression of assessing an intervention if only the processes that are different are assessed (i.e. the research question is what is the difference between the two systems). This might be the case if the research question is e.g.: **What is the difference in producing electricity in Austria and Sweden?** This is an attributional question requiring comparing the two systems that produce electricity. As the interest only lies in the difference between them, some processes, which are in common in both systems can be omitted. For instance, if transmission losses are the same in both countries because the same distances are covered then these can be omitted because they have the same impact in both assessments and thus do not alter the results, i.e. the magnitude of the difference between producing electricity in Austria and Sweden. However, the results of the comparison would be the same if two stand-alone assessments of Austrian and Swedish electricity are done and the difference calculated (assuming the same assumptions and system boundaries). An example of the difference between an ALCA and a CLCA is given in Box 5.

### Box 5: Example of attributional and consequential LCA of milk production (excerpts from Thomassen et al. 2008)

The main goals of this paper by Thomassen et al. (2008) was to demonstrate and compare ALCA and CLCA of an average conventional milk production system in the Netherlands. The comparison was based on four criteria: hotspot identification, comprehensibility, quality and availability of data.

In the ALCA the functional unit was 1 kg of fat and protein corrected milk and the scope cradle to gate. A simplified system was assumed where **milk and animals** (mostly bull calves and culled milking cows) were the only outputs. Economic allocation was used to deal with co-products.

In the CLCA the functional unit was the same but in regard to **an increase in milk production**, which required at least one additional dairy farm (capacity increase). System expansion was used to deal with co-production.

Taking as example system expansion due to additional **beef**, the following was observed. When identifying the environmental burden of meat from dairy cows, the question to be asked was: What will not be purchased by retailers/supermarkets when more meat from dairy cows is provided? It was identified that this increased availability of beef will replace that from foreign dairy cows and pork, as meat from dairy cows is mainly used for minced meat and easy to prepare meat meals. As meat from foreign and domestic dairy cows are constraint by quotas, the marginal meat must come from beef cattle and pigs (most sensitive process). Similarly, calves, mostly bulls, will result in beef production after a growth period at a meat cattle farm, which again will substitute beef and pork production.

Differences were found between ALCA and CLCA in total outcomes where CLCA results were 35-75 % less than the results for ALCA. Major hotspots were the same for all impact categories, whereas, other hotspots differed in contribution, order and type. The main cause of differences is the fact that different systems are modelled.

Guiron et al. (2013) compiled a very useful table in their overview document on consequential LCA listing the main differences between CLCA and ALCA, see Annex C.

### Decision tree for distinguishing the type of study

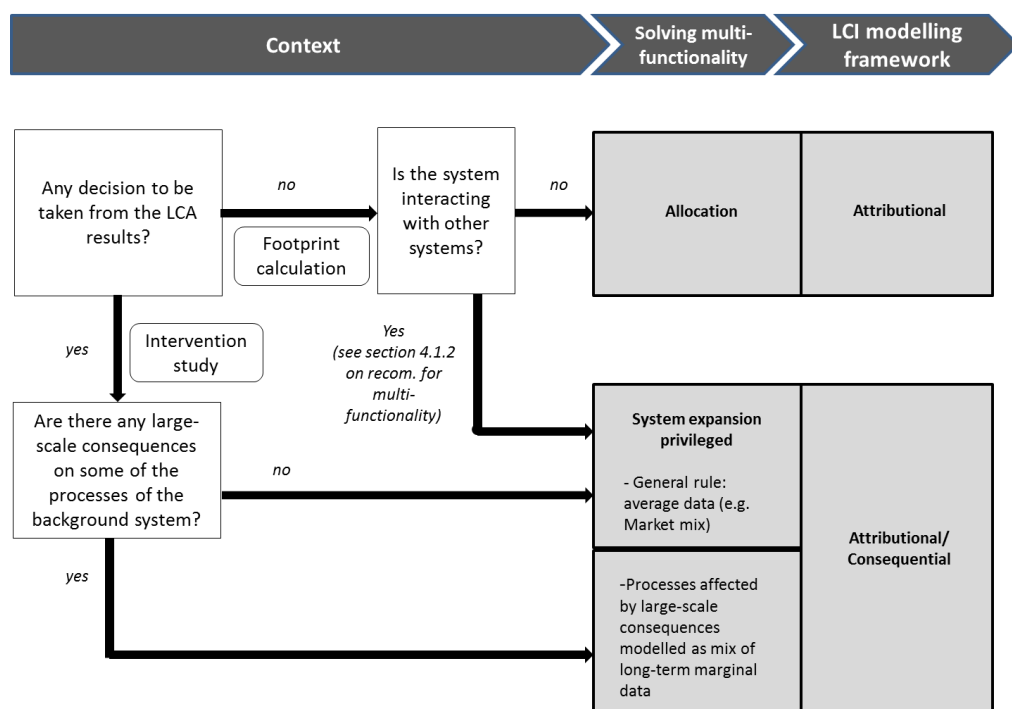
In this document a distinction between two different contexts is employed: footprint (ALCA) and intervention studies (CLCA). Figure 3 shows a decision tree that helps to determine which type of study is appropriate for the posed question, and corresponding LCI modelling framework (consequential or attributional). This tree is an adaption of a figure by Laurent et al. (2014) and is based on the ILCD handbook (EC, 2010). Starting at the top left, it first needs to be established if any decision will be taken based on the LCA results. If no, the study is purely undertaken to understand the environmental impact associated with a product or

service. If so then this is a **footprint study**. The next question is if the system interacts with other systems. If the answer is no, an attributional LCI modelling framework is used. If yes, for example there are multifunctional processes in a system, the recommendation is to use system expansion to handle multi-output processes if feasible, otherwise allocation (see section 4.1.2 on handling multifunctional processes and our recommendations). Furthermore, to use average life cycle inventory (LCI) data (market mix); i.e. to use an **attributional** data modelling framework is recommended. Going back to the top left again, if a decision will be taken from the LCA results (yes to first question in Figure 3), then it is an **intervention study**, looking at effects of a change. In these cases, the next step is to determine whether there are large scale effects on processes in the background system (yes to second question in Figure 3). The modelling should be done with the use of long-term marginal data; i.e. to use a **consequential** data modelling framework. If on the other hand, there are only minor flows in your system, which will not affect any markets (*no* to second question in Figure 3), average market data can be used (as employed in an attributional modelling framework). In the following sections recommendations are provided on method choices for these two types of studies. In Annex A examples are provided highlighting how these recommendations can be employed in side flows studies.

## Recommendation

At the start of an LCA study, it is recommended to use the decision tree in Figure 3 to determine which type of study is undertaken, and to clearly state this in the goal and scope of the study.

**Figure 3: Decision tree for determining type of study (footprint/intervention) and corresponding modelling framework, adapted from the ILCD handbook (EC, 2010) and Laurent *et al.* (2014)**





#### 4.1.2 Footprint studies: Functional unit, system boundaries, handling multi-functionality and data inventory

For footprint studies, an attributional modelling framework is used, see above (Figure 3).

Examples of the kind of questions that are answered by a footprint study:

- What environmental impact potential is linked to the treatment of this waste stream? *(For example, if a company wants to report the impact of the handling of their waste streams)*. Stand-alone study.
- What is the environmental impact potential of this waste treatment compared to another waste treatment? *(For example, if policy makers would like to monitor (track) the potential environmental impact of different waste treatment technologies that are used in different countries)*. Comparison study. Note: not for the purpose of changing from one waste treatment to another, then it is an intervention study.
- What is the environmental impact potential linked to a product, made from a valorised side flow? *(For example, if a stakeholder would like to communicate the environmental performance of his product to the customer)*. Standalone study.
- What is the environmental impact potential linked to a product made from a valorised side flow compared to another product? *(For example, if a retailer would like to communicate the footprint of two different products, one made from a valorised side flow, and one not)*. Comparison study.

Hence, a footprint calculation can be performed in isolation for one product system, but it can also be used for comparing the environmental performance of products or services to each other.

It is also possible to perform a footprint study of the generation of side flows in a FSC; this was done in the project FUSIONS (2016). In this case, the study is focusing on the driving product of the FSC, but highlighting the impact of side flow generation. Since the focus of the FUSIONS study is on the driving product, this type of footprint study is out of scope of this report; for further information see FUSIONS (2016).

### Functional unit – footprint studies

#### Background/state of science

Existing guidance document align with ISO in stating that the functional unit (FU) should be in line with the goal and scope of the study and reflect the function of the product/service being studied. The definition of functional unit according to the ISO standard (ISO, 2006) is: “quantified performance of a product system for use as reference unit”, and the definition of the corresponding reference flow is: “measure of the outputs from the processes in a given product system required to



fulfil the function expressed by the functional unit". Hence, whereas the FU describes the function of the system, the reference flow describes the actual quantitative flow that corresponds to this function. For studies which assess FSC side flows, the literature shows that while it is common to use a mass based FU (Unger et al. 2016), the distinction between FU and reference flow is not always highlighted and the focus is on the quantitative reference flow (often calling it FU), while the 'functional' aspect of FU is sometimes neglected, particularly any service aspect. For instance, if a side flow is valorised in RS 3 this also fulfils the service of appropriately disposing the material, in addition to any value that is gained. It is, moreover, important to include any quality aspects in the FU if this is relevant for the product or service provided. For example, when treating side flows, the composition of the waste can influence the amount of energy that can be generated; hence information on the composition should be provided in the FU in such cases.

### **Recommendation**

The FU in footprint studies should be the quantified performance of the product or service provided. Two types of footprint studies for side flows are identified, for which these corresponding reference flows are recommended:

1. Footprint of product made from a valorised side flow (RS 2 and 3).  
Reference flow: mass-based unit of valorised product (relevant quality aspects provided, e.g. protein content for feed products), or X MJ of energy or fuel product
2. Footprint of waste treatment process of side flows (RS 3 and 4). Reference flow: mass-based unit of treated side flow (information on composition provided). The FU also includes the service of treatment of the waste.

Other FUs may also be used, e.g. value of valorised product. However, it is recommended to use the mass based FU as default, and to use other FUs as a supplementary unit of analysis, in order to increase possibility to compare different studies.

## **System boundaries – footprint studies**

### **Background/state of science**

LCA standards give clear recommendations that system boundaries need to be in line with the goal and scope of the study. For footprint studies, this means that the relevant processes that contribute to the production of the product or provision of the service should be taken into account. It is recommended to draw the processes included in the system boundary in a process flow diagram and preferably also what is left out. A distinction is normally made between the foreground system which includes the processes that are in focus in the study and the background system which includes the supporting processes to the foreground system (energy production etc.).

Case studies which are represented by RS 3 use a boundary starting at the waste generation (gate) and ends either with the valorised product (gate to gate) or after utilisation of the valorised product (gate to grave). Studies of type RS 4

start with the waste generation (gate) and end with the treatment process and any associated emissions (grave). No environmental impact from upstream processes is associated in either of these situations. Further details are also described in the section on 'Handling multi-functionality'. For RS 1, a footprint study is not relevant, since there is no side flow to calculate a footprint of.

## **Recommendation**

Three types of footprint studies for side flows are identified, for which these corresponding system boundaries are recommended:

1. Footprint of product made from a valorised side flow, RS 2. SB: Including a share (by allocation) of the upstream FSC before it becomes a side flow to the end of valorisation chain (at the valorised product – cradle to gate – or until the end of life of the valorised product – cradle to grave).
2. Footprint of product made from a valorised side flow, RS 3. SB: From point of generation of the side flow to a valorised product (gate to gate) or the end of valorisation chain (gate to grave).
3. Footprint of waste treatment process of side flows RS 4. SB: From point of generation of the side flow to end of waste treatment process (gate to grave).

Further, to increase transparency, it is recommended to draw a system diagram showing foreground and background system as well as the most relevant processes not covered, e.g. if the use phase of a product is not included.

## **Handling multi-functionality – footprint studies**

### **Background/state of science**

Based on the decision tree in Figure 3, a footprint study should use allocation when not interacting with other systems (very rare), and otherwise use system expansion as first option. This is also in line with the hierarchy recommended in the ISO standard (ISO, 2006) on how to deal with multi-functionality: 1) avoid allocation by subdivision, 2) expand the system, 3) use allocation. Still, in practice, economic allocation is very often used in LCA studies (e.g. Ayer et al. 2007; Beccali et al. 2010; Van der Voet et al. 2010). Pelletier et al. (2015) argue that whereas in consequential LCA there is a rationale for using system expansion, there is no such rationale in attributional LCA where the aim is to derive the environmental burden associated with a product or system. Furthermore, Pelletier et al. (2015) say that often it is difficult to identify single product systems that provide functionally equivalent products to replace the side flow, making system expansion practically difficult to execute, and may also give a result that poorly represents the product's associated burdens. This is a viewpoint visible in many LCA studies, where allocation is often employed as a

practical way to deal with multi-functionality in attributional LCA studies (like footprint studies). In summary, while ISO (where there is no distinction between ALCA and CLCA is made) recommends system expansion over allocation, there is a strong trend in the scientific debate that allocation is most suitable for ACLA (footprint studies) while system expansion is preferred for CLCA (intervention studies), see section 4.1.3).

One situation when multi-functionality is an issue is in RS 2, where burden from the FSC should be allocated to the side flow (see section on system boundary above). A challenge here is to determine the basis for the allocation (i.e. mass or economic or other). The rationale should be chosen with the goal of the study in mind (Pelletier et al, 2015), and is best decided on a case to case basis, considering the system under study, there is no 'best' allocation method that fits all types of studies (Ardente and Cellura, 2012). Furthermore, a sensitivity analysis should be undertaken to see how the chosen allocation basis affects the results of the study. Still, a common practice is to rely on economic allocation, as explained above. A common argument for economic allocation is that it is the generation of economic value that motivates the production processes. This argument also "corresponds to the rationale for allocation based on social causality and for distributing responsibility for burdens in proportion to benefits conferred (fairness)" as explained by Pelletier et al (2015). When using economic allocation, ILCD (EC 2010, p 265) argues that it is common to apply the allocation at the wrong point by using market price as the basis. Instead the value immediately after the process step should be used.

One argument for using a physical relationship in favour of economic numbers as allocation basis is that it can result in misleading conclusions that cheap products are associated with low environmental burden (Pelletier and Tyedmers, 2011). An example of this is by-catch from blue-finned tuna fisheries, where the by-catch is of very low economic value compared to the tuna. Giving this by-catch a low environmental burden (based on the price) can ill-advisedly motivate using this by-catch with seemingly low environmental burden, instead of using other resources from more sustainable production systems.

However, since the driver for processes is the economic gain, in this report it is recommended to use, in general, economic allocation unless another approach is more appropriate for the specific situation.

Footprint studies on driving products (main product in the production system) are out of scope in this report; for allocation rules in standard footprint calculations we refer to the PEF initiative, see Box 6. Furthermore, footprint studies of RS 1 is not relevant, since for these situations there is no side stream to do a footprint of, see instead the section on intervention studies (section 4.1.3).

## Box 6: EU Initiative on Product Environmental footprint of driving products

Guidance on how to scope this type of study is provided from the EU initiative on Product Environmental footprint (EC, 2013); the aim with the initiative is to provide a common way of measuring environmental performance. The approach is tested in pilot studies for specific product groups between 2013-2016 together with more than 280 volunteering companies and organisations. For food, there are pilots for beer, coffee, dairy, red meat, olive oil, pasta and wine, as well as pet food ([http://ec.europa.eu/environment/eussd/smgp/ef\\_pilots.htm](http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm)). Between June and September 2016 the pilots consult on the draft final product specific rules, so called PEFCRs (product environmental footprint category rules).

With reference to footprint studies of side flows the focus is different than for footprint studies of driving products. A number of product category rules (PCR) and Product Environmental Footprint Category Rules (PEFCR) exist as mentioned above. Consider for example the PEFCR for red meat ([http://ec.europa.eu/environment/eussd/smgp/ef\\_pilots.htm](http://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm)). There the rule is to allocate the burden between all products coming from the slaughter (meat for human consumption, hides to leather industry, products for animal feed applications, waste to biogas etc) based on biophysical allocation (which generates similar results as when mass allocation is applied). So following this rule, valorised side flow products from the red meat FSCs would always carry a burden, independent in what form they are valorised. However, there are two points that need to be considered. Firstly, the PEF guidance is being developed for footprinting of driving products. In contrast, the focus in this report is on side flows leaving the FSC which are not the driving product (or part of the product mix it is designed to produce). Secondly, the recommended allocation by the PEFCR practically can only be applied if there is still a link or connection to the FSC. This can be the case in some situations, but in others, this is not the case. For example, for a waste management operator that receives a waste stream, mixed together with other streams or from different meat producers, it would be extremely difficult to allocate any burden to the mixed waste stream. The recommendation for side flow footprints is therefore to use the **REFRESH situations**, as they differentiate more clearly between different valorisation situations, unless there is rationale for using another allocation basis and if so provide the rationale, and perform sensitivity analysis on the different options. For REFRESH Situation 2, where the generator of the side flow actually benefits in some way from the valorisation of the side flow (there is still a link to the FSC), it is recommended to allocate a burden to this side flow. However, for REFRESH situations 3 and 4, where there is no value to the generator of the side flow, no allocated burden is given to the waste stream. This is also consistent with the approach to have waste come as burden-free input into system boundaries. The differentiation between RS 2 and RS 3 is therefore crucial and needs to be thought through in detail.

### Recommendation

Allocation is recommended in footprint studies (in favour of system expansion). Regarding allocation between driving product and side flow, it is recommended to

employ the REFRESH situations, and only allocating burden to the side flow for RS 2 (and not RS 3 and RS 4 where the side flow should be burden free). Furthermore, it is recommended using economic allocation using the value immediately after the process. If using another allocation basis, this should be clearly motivated. Source of data for the allocation as well as the allocation factors used need to be clearly stated.

## **Data inventory – footprint studies**

### **Background/state of science**

During data collection, information on all processes included in the system boundary is collected and serves as basis for the impact assessment. In footprint calculations, an attributional LCI modelling framework is used, see Figure 3. This means using average data on processes in the background system, e.g. electricity bought from the grid, and diesel used in lorries. For foreground processes primary data should be collected as far as possible. If this is not possible the use of secondary data is required but this needs to be reflected in the interpretation of results and discussed in context of representativeness.

### **Recommendation**

For footprint studies of side flows it is recommended to use average data on processes in the background processes, and specific data for the core processes (foreground) in the system being studied.

### **4.1.3 Intervention studies: Functional unit, system boundary, handling multi-functionality and data inventory**

The purpose of intervention studies is to inform a decision of the consequences associated with a change. Therefore, the scope needs to cover all processes that are affected by the decision (consequential, see Figure 3). This implicitly means one compares one scenario to another and thus the results from an intervention study are always relative compared to footprint studies which are absolute.

In cases when more than one alternative scenario are of interest, each intervention is studied separately and compared to the baseline; a comparison is only possible if the same functional unit is used (otherwise comparison is not feasible).

## **Functional unit – intervention studies**

### **Background/state of science**

As with footprint studies the functional unit (FU) should be in line with the goal and scope of the study and reflect the function of the product/service being studied.

When the intervention involves exploring prevention of side flows (RS 1), the functional unit (FU) needs to include the function of the driving product of the system, since the environmental performance of the driving product will be affected by a preventive action (i.e. less resources will be needed). However, if the scenarios compared involve RS 2, 3 or 4 (and not prevention), the FU can be

expressed as “*Utilisation of a side flow*”, and the system boundary can exclude the upstream processes before the flow was generated.

### Recommendation

Two types of intervention studies are identified, for which these corresponding FUs are recommended:

1. Intervention studies involving a scenario for RS 1 (prevention of side flow), FU: amount of driving product, over specified time period and scale (reference flow: mass-based unit of driving product)
2. Intervention studies only assessing RS 2, 3 and 4 (NOT involving a scenario for RS 1, prevention of side flow), FU: amount of side flow utilised, over specified time period and scale (reference flow: mass-based unit of side flow)

### System boundaries – intervention studies

#### Background/state of science

Existing standards give clear recommendations that system boundaries need to be in line with the goal and scope of the study. For intervention studies, which employ a consequential modelling framework (see Figure 3), this means covering the processes that are affected by a change. Hence, comparing two scenarios the upstream processes should be included in the case when the changes affect the upstream processes. This means the largest system boundaries of any of the scenarios determine the overall system boundaries. In the case of one of the scenarios being compared involving prevention (RS 1), then the upstream processes leading up to the side flow generation must be included, since they are affected by the change. In Figure 4 for example, the left graphic shows the current situation, where a retailer currently sends a side flow to a municipal waste treatment facility, which in turn produces some value from it (system A in the figure, RS 3). The right graphic illustrates the system after a change was introduced, where the purchasing routine was changed and thereby the side flow prevented (system B in the figure, RS 1). Since processes are affected upstream, less resource is needed for the driving product, the system boundary needs to include the upstream processes in the FSC. The resulting environmental effect of moving from RS 3 to RS 1 is derived by adding the ‘new’ processes (system B) and subtracting the ‘old’ processes (system A):  $B-A$ , see Figure 5.

When identifying the processes that should be included in the system boundaries, the processes that actually change should be considered; perhaps some processes are unaffected by preventing some food waste streams, e.g. energy for cooling if same size storage room is still used.

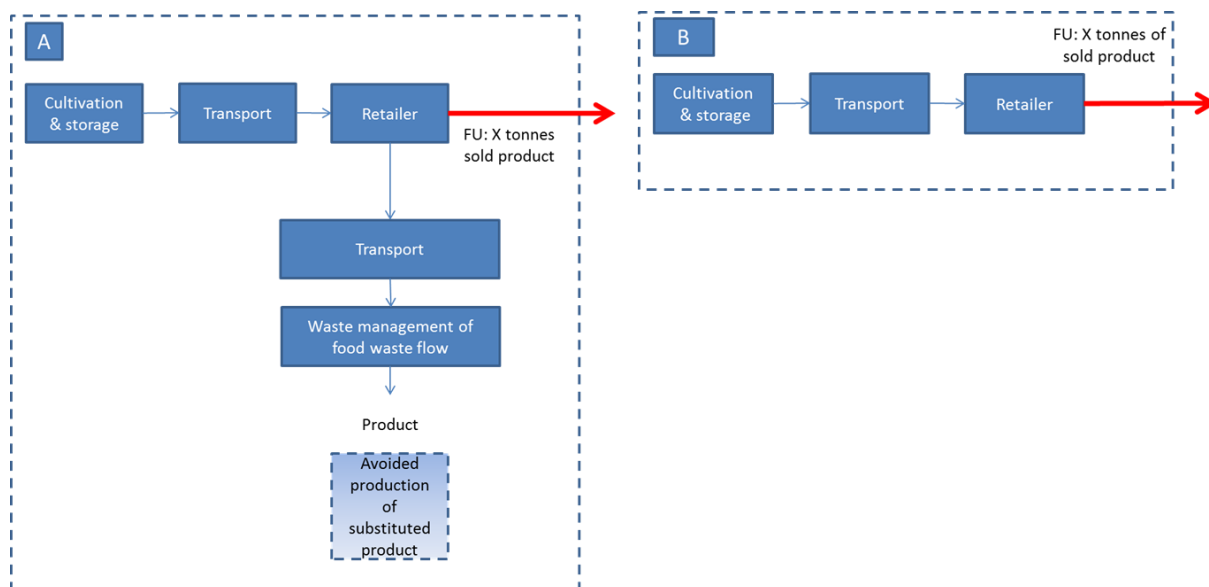
In Figure 6, system boundaries are shown for another example, where the system under investigation is REFRESH situation 3 (system A in the figure); value is derived from the side flow at a facility but there is no value for the generator of the side flow. The study explores effects of valorising the side flow, and giving

value to the generator of the side flow (e.g. the actor treats the flow on site and utilises the energy generated in the facilities of the site) which corresponds to REFRESH situation 2 (system B in the figure). In this case, the upstream processes can be excluded, since they are not affected, there is no change in resource utilisation in the upstream processes. Again, the resulting effect of the change is derived by subtracting the 'old' processes from the 'new':  $B-A$ , see Figure 7.

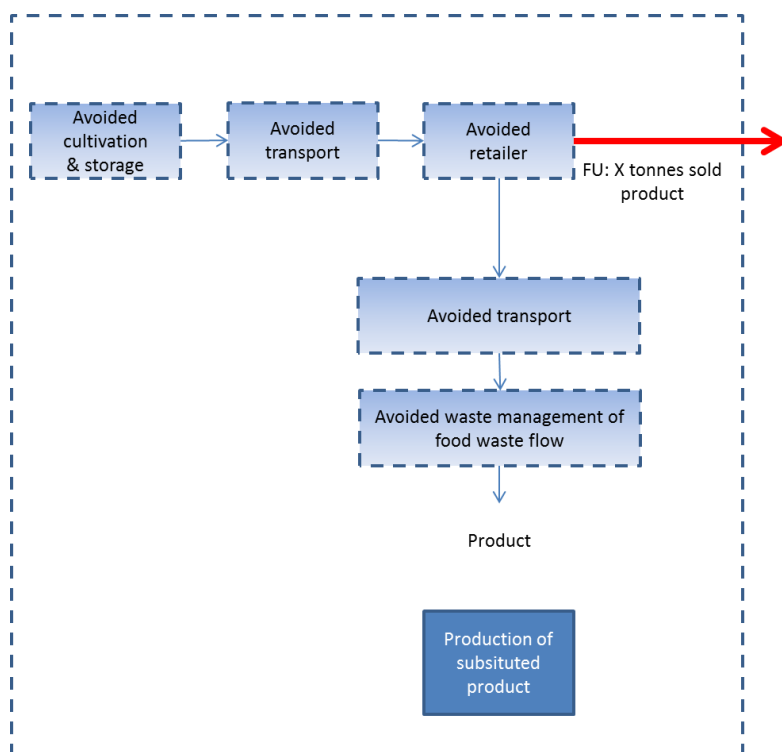
Please note that depending on the presentation of the results, it might be necessary to calculate A and B separately and then from these values to derive the net result. Or, if the focus is only on the net result, it is sufficient to calculate the net effect directly from the resulting system after putting system A and B together (Figure 5 and Figure 7). See also section on impact assessment and interpretation when combining LCA and LCC results (section 4.3).

In the figures, dark blue coloured boxes denote impact, whereas light blue denotes avoided impact (i.e. negative numbers).

**Figure 4: FU and system boundary when at least one of the compared scenarios involves preventing a side flow, example of moving from RS 3 (A) to RS 1 (B)**

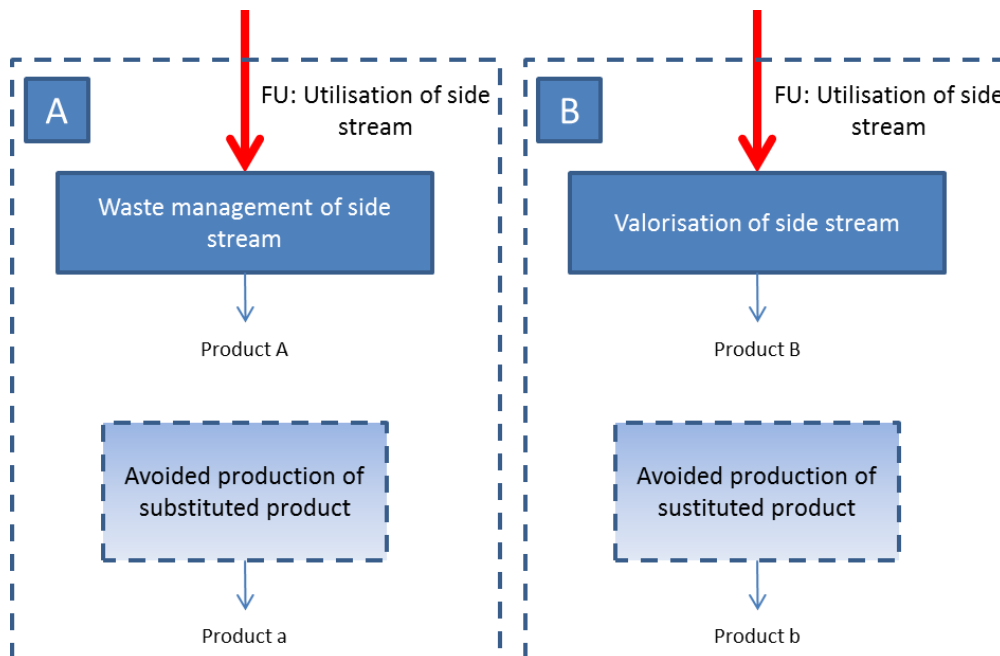


**Figure 5: Resulting system of moving from RS 3 to RS 1 (example)**

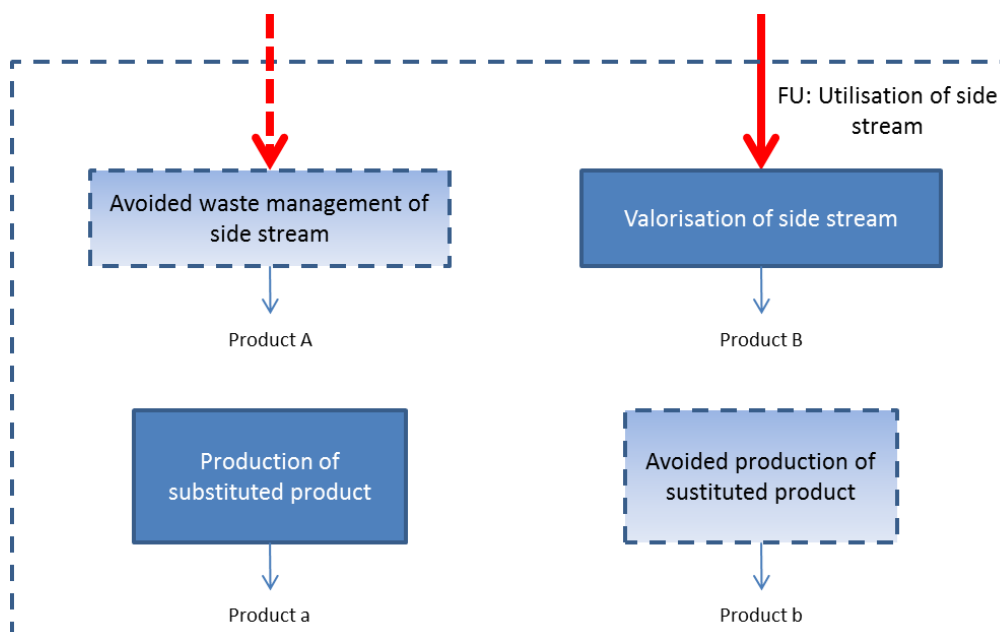




**Figure 6: FU and system boundary when the scenarios compared do not involve preventing side flow**



**Figure 7: Resulting system of moving from RS 3 to RS 2 (example)**



## Recommendation

1. For intervention studies involving a scenario for RS 1 (prevention of side flow), the following SB is recommended: Production of driving product, and where side flow leaves the FSC to treatment of side flow. If treatment/valorisation gives marketable product(s), include these too.

2. For intervention studies only assessing RS 2, 3 and 4 (NOT involving a scenario for RS 1, prevention of side flow), the following SB is recommended: from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include also replaced production (avoided impact)

## Handling multi-functionality – intervention studies (RS 2- RS 3)

### Background/state of science

There is good scientific agreement that an intervention study should use system expansion to deal with multi-functionality. In studies of side flows, this is needed if the type or amount of product yield by the system changes due to the intervention. Then this 'extra' function needs to be handled in the system and it is recommended, in line with the ILCD handbook (Figure 4), to expand the system to include avoided burden of potentially replaced production on the market. A **good understanding of the socio-economic** conditions is very important for intervention studies as it is the requisite to understand how markets are likely to be affected: Is the market for an additional quantity of a product expanding or shrinking? Can the additional product be absorbed or despite potentially having a function this will not be realised as alternative products are e.g. cheaper or there is no access to their markets? Weidema (2003) has provided guidance on how to identify replacement products.

Weidema (2003) states that for a thorough understanding of a specific product substitution, information is required on:

#### 1. The **extent of the studied substitution**, where:

- small, short-term substitutions affect only capacity utilisation, but not capacity itself,
- small, long-term substitutions affect also capital investment (installation of new machinery or phasing out of old machinery),
- large substitutions affect also the determining parameters for the overall technology development, i.e. the constraints on the possible technologies, the market segment affected, as determined by the obligatory product properties (i.e. properties that a product "must have" for a customer in that segment to accept the products as comparable and thus substitutable).

2. **Product availability**, i.e. whether the market situation actually allows a choice between the products to be made (markets and/or production technologies may be constrained by market failures, declining markets, regulations, or shortages in supply of raw materials or other necessary production factors).

3. The **positioning properties of the products** ("nice to have"), as well as price and information, which influences the degree to which a potential product substitution will actually be realised.

Furthermore, in the same study (Weidema, 2003) a decision tree is given helping the assessor identify processes (and markets) that are affected by the intervention. This has been adapted in Figure 8.

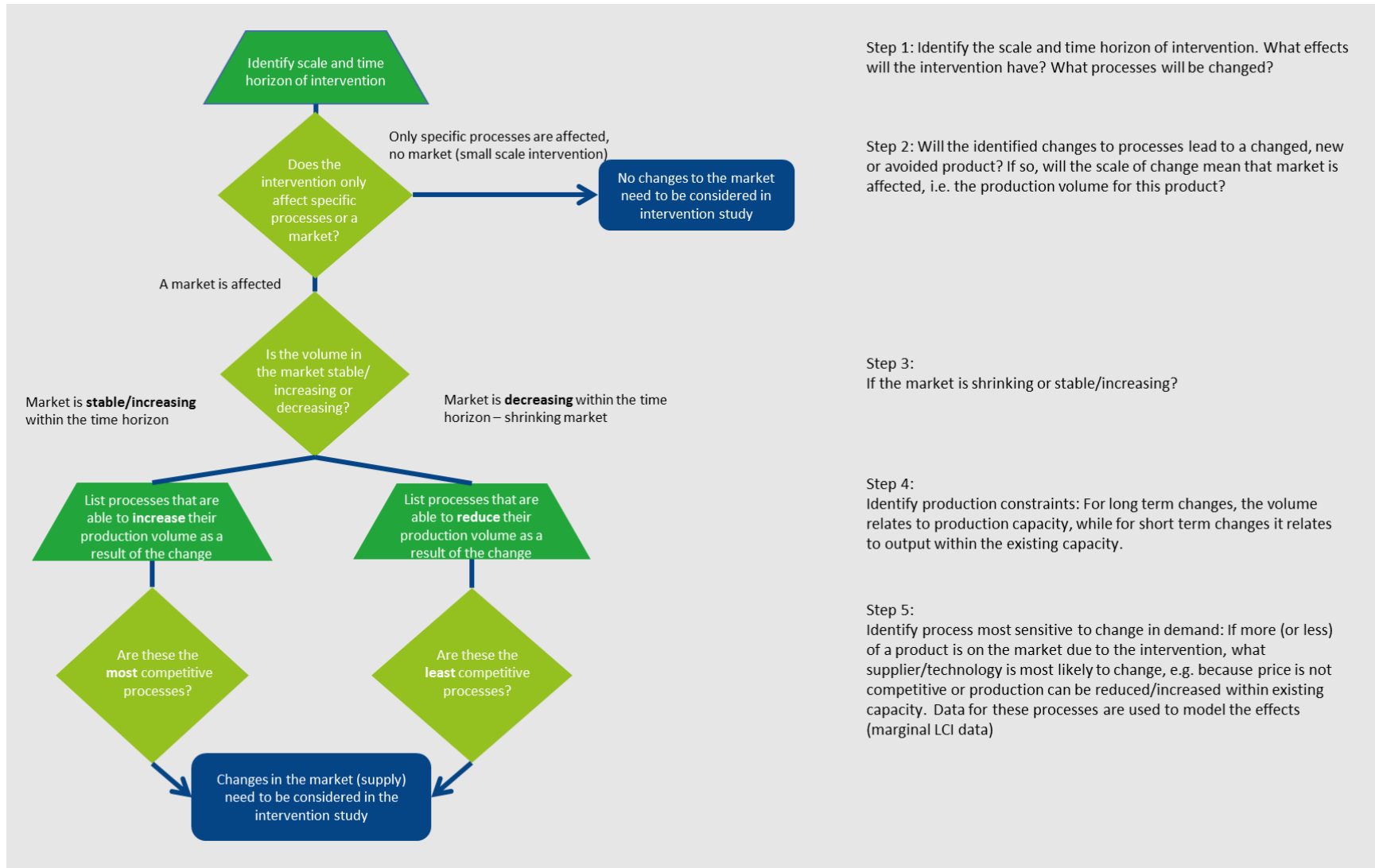
Selecting substituting products can sometimes be difficult, below some considerations. A new product can be created at RS 2-3, e.g. a composting site might have an innovation to produce not just compost but maybe an insulation material out of compost. This would be a new product to the market. However, the function is not new, so there are other products already delivering the function and thus can be substitute products. Still, careful consideration is needed on what replaces the theoretical new product considering that the new product may only appeal to a certain type of people. On the other hand a newly valorised by-product might be very appealing to consumers and economic profitable and for that reason creates a new demand and market, for example a new super food like Goji berries or chia seeds. There might not have been a market for this type of product before, but due to fashion, marketing and research resulting in health claims it becomes a driving product.

If a completely new function is created, it is possible there is no replacement product. In this case it does not substitute anything but expands the market. The benefit is thus the avoided disposal (if it was not produced before), or solely of economical nature and no product is substituted. In such cases it is recommended that no substituting product is used, however sensitivity analysis should be carried out taking into account hypothetical market situations.

## **Recommendation**

For handling multi-functionality in intervention studies, it is recommended using system expansion and including avoided burden of potentially substituted products on the market. It is also recommended using the guidance from Weidema (2003) as shown in Figure 8 to help identify the substituted product (production technology).

**Figure 8: Decision tree outlining the 5-step procedure for identifying the processes affected by a change in demand for a specific intermediate product (adapted from Weidema 2003)**



## **Data inventory – intervention studies**

### **Background/state of science**

In the data collection phase, data for all processes included in the system boundary from the goal and scope, are collected and serve as the basis for the impact assessment. In intervention studies, a consequential LCI modelling framework is used, see Figure 3. Depending on the scale of the system, different data are used to model the processes in the background system. The decision tree in Figure 8 helps to understand if the changes affect markets or not; if yes, then these market changes need to be considered in the model by using marginal data for these processes (the figure also helps you to identify these marginal processes).

### **Recommendation**

It is recommended using specific data for the processes in the foreground system being studied, and to use the decision tree in Figure 8 for determining if the changes affect markets or not; if yes then marginal data should be used to model these processes that are affected; if not then average data can be used for background processes in the system.

#### **4.1.4 Cut-off principle in footprint and intervention studies**

Within the chosen system boundaries of the study some processes are often not taken into account, they are cut-off.

### **Recommendation**

The criteria used for excluding some processes should be clearly declared in the study. It is recommended to take into account all processes that contribute significantly to the environmental impact. Existing studies on the same system are useful indicators as to what processes contribute to what extent to the overall impact. In order to be transparent, it is recommended to draw a process flow diagram of the system boundaries, and to highlight clearly and motivate if possible which processes are included and excluded (cut-off) respectively in the study.

#### **4.1.5 Impact assessment in footprint and intervention studies**

As described in the literature in Unger et al. (2016a), in food waste LCAs, mid-point level indicators are mostly used (e.g. global warming potential, eutrophication potential etc) as opposed to end-point indicators (i.e. damage to human health, damage to ecosystem diversity and resource scarcity). Environmental impact categories are usually selected regarding the purpose of the environmental assessment and to some extent the availability of data (i.e. certain impacts are not assessed due to missing data). Climate change is by far the most commonly analysed environmental impact category in food LCAs.

Indeed, this indicator is mentioned in every literature review source except in water footprint assessments. Food production stands for a significant share of global emissions contributing to climate change, eutrophication, acidification and eco-toxicity (from use of pesticides), and in food LCAs is it common to include at least the first three of these. Most standards follow ISO 14044 (the exception being the single issue standards such as the carbon footprint standard) and recommend having a multi-impact approach in order to have a complete overview of environmental impacts.

### **Recommendation**

It is recommended following the guidance from the ILCD Handbook, regarding impact assessment, including their suggested environmental impact assessment methods for deriving the impacts. Regarding the selection of the environmental impact categories, this study recommends, that unless specifically stated in the research question, to have a multi-impact approach in order to have a broader understanding of environmental impacts and to be able to identify trade-offs. However, if data availability is limited, it is suggested to follow recommendations given in Table 3, which is based on the literature review in Unger et al. (2016a) and on the literature review described in the EU FUSIONS report (FUSIONS, 2015).

**Table 3: Recommendations on selection of impact categories**

| Impact categories   | Type of analysis |                 |  |   |
|---|------------------|-----------------|--|---|
|   | Carbon footprint | Water footprint | LCA  |   |
|   |                  |                 | No agricultural processes within system boundary | Agricultural processes within system boundary |
| <b>Climate Change/<br/>Global warming potential (GWP)</b> | Required         | NA              | Required   | Required                                      |
| <b>Resource Depletion – water</b>                         | NA               | Required        | Highly recommended                               | Highly recommended                            |
| <b>Resource Depletion – mineral, fossil</b>               | NA               | NA              | Highly recommended                               | Highly recommended                            |
| <b>Eutrophication – aquatic</b>                           | NA               | NA              | Highly recommended                               | Highly recommended                            |
| <b>Eutrophication – terrestrial</b>                       | NA               | NA              | Optional   | Highly recommended                            |
| <b>Acidification</b>                                      | NA               | NA              | Optional   | Highly recommended                            |
| <b>Land Transformation</b>                                | NA               | NA              | Optional   | Highly recommended                            |
| <b>Ecotoxicity for aquatic fresh water</b>                | NA               | NA              | Optional   | Optional                                      |
| <b>Ozone Depletion</b>                                    | NA               | NA              | Optional   | Optional                                      |
| <b>Human Toxicity - cancer effects</b>                    | NA               | NA              | Optional   | Optional                                      |
| <b>Human Toxicity – non-cancer effects</b>                | NA               | NA              | Optional   | Optional                                      |
| <b>Particulate Matter/Respiratory Inorganics</b>          | NA               | NA              | Optional   | Optional                                      |
| <b>Ionising Radiation – human health effects</b>          | NA               | NA              | Optional   | Optional                                      |
| <b>Photochemical Ozone Formation</b>                      | NA               | NA              | Optional   | Optional                                      |

#### 4.1.6 Interpretation in footprint and intervention studies

The last stage of an LCA is the interpretation of results. This, together with the 'goal and scope' setting are the stages where the quality of a study shows. It is recommended to be very clear about what are the results of the impact assessment and what is the interpretation of results, these should not be mixed. All activities in the interpretation stage need to be linked back to the research question and put into context of the goal and scope.

There are three activities in an interpretation based on the ILCD General guidance for LCA, detailed guidance (EC, 2010, p286):

- (1) **Identification of significant issues** (i.e. the key processes, parameters, assumptions and elementary flows), including the main contributors to the Life Cycle Impact Assessment results, as well as the main choices that have the potential to influence the precision of the final results of the LCA.
- (2) **Evaluation of these issues** with regard to their sensitivity or influence on the overall results of the LCA. This includes completeness, sensitivity and consistency with which the significant issues have been handled.
- (3) The results of the evaluation are used to formulate **conclusions and recommendations**.

In the conclusions the results are put in a wider context. It is helpful to highlight trade-offs across impacts and life cycle stages. Also, it is useful to say how far results are transferable to other situations, e.g. can a general conclusion be drawn to the whole industry, or if the study is specific because of certain aspects which need to be stated. It is also recommended to compare with results of other, similar studies and the differences explained.

#### Recommendation

It is recommended to include the three activities listed above in the interpretation stage of the study. In particular, to do a sensitivity analysis for parameters that have a large influence on the results and potential conclusions of the study.

## 4.2 LCC modelling framework

Life cycle costing is a consolidated methodology that allows the calculation of all costs generated during the life cycle of a product or a service. Three different LCC approaches were defined by Hunkeler et al. (2008): Conventional, Environmental, and Societal LCC. They distinguish in terms of costs and stakeholders included in the assessment, system boundaries, possible integration with LCA. A more detailed analysis of the differences between these approaches can be found in Hunkeler et al. (2008) and De Menna et al. (2016). As highlighted in De Menna et al. (2016), despite several applications, LCC was only recently used to assess food waste management or valorisation, as an integrated tool with LCA. Based on the literature review carried out in De Menna et al. (2016), this section provides the reader with guidance on the general scoping of a side flow LCC study. A first paragraph is aimed at identifying the appropriate LCC approach



through a decision tree (see If the answer is 'no', the costing dimension can be assessed separately. If only costs are assessed, in particular internal costs the assessor have to pay, then a Conventional LCC (C-LCC) is suggested. This approach is rather established and mainly focuses on investment, operating, and maintenance costs emerging during the life span of a product. Disposal costs are included only as long as they are sustained by the assessor. Thus, C-LCC is not usually carried out in integration with LCA, but it could be used when system boundaries are cradle to gate and only one actor is covering for all costs. Considering the objective of REFRESH Task 5.1.3 of developing a system approach for integrating LCA and LCC in the evaluation of food waste streams, C-LCC is not within the scope of the report. The reader can refer to De Menna et al. (2016) for further information and sources.

If the answer to Q1 is 'yes', then environmental and costing dimensions are part of the same assessment, adopting different approaches according to the stakeholders included and the type of integration with LCA (see Q2). The assessor should decide whether to include costs for all the stakeholders that may be affected by the analysed system also through externalities, including society, governments, etc. In such perspective, a Societal LCC (S-LCC) approach should be adopted. In S-LCC, costs affecting every stakeholder, both directly and indirectly through externalities (e.g. environmental impacts), are assessed. In fact, as argued by Martinez-Sanchez et al. (2016), an S-LCC encompasses all externalities that can be monetised. Therefore, the integration with a complementary LCA support the S-LCC in identifying and quantifying relevant externalities to be then monetised. A standard approach for the monetisation of externalities is currently still under development (ISO 14008). In general, further research is needed to identify methodologies for the evaluation of several emissions in an S-LCC context. Therefore, S-LCC is thus not included in the scope of the report.

Figure 9). Further guidance on specific methodological aspects of side flow LCC modelling is provided in a second paragraph. Explanatory applications of this modelling framework are then presented in Annex A.

#### **4.2.1 Determine the type of LCC**

The first crossroad when scoping an LCC study is related to the overall aim of the assessment, which influences the more suitable costing approach (see If the answer is 'no', the costing dimension can be assessed separately. If only costs are assessed, in particular internal costs the assessor have to pay, then a Conventional LCC (C-LCC) is suggested. This approach is rather established and mainly focuses on investment, operating, and maintenance costs emerging during the life span of a product. Disposal costs are included only as long as they are sustained by the assessor. Thus, C-LCC is not usually carried out in integration with LCA, but it could be used when system boundaries are cradle to gate and only one actor is covering for all costs. Considering the objective of REFRESH Task 5.1.3 of developing a system approach for integrating LCA and LCC in the evaluation of food waste streams, C-LCC is not within the scope of the report. The reader can refer to De Menna et al. (2016) for further information and sources.

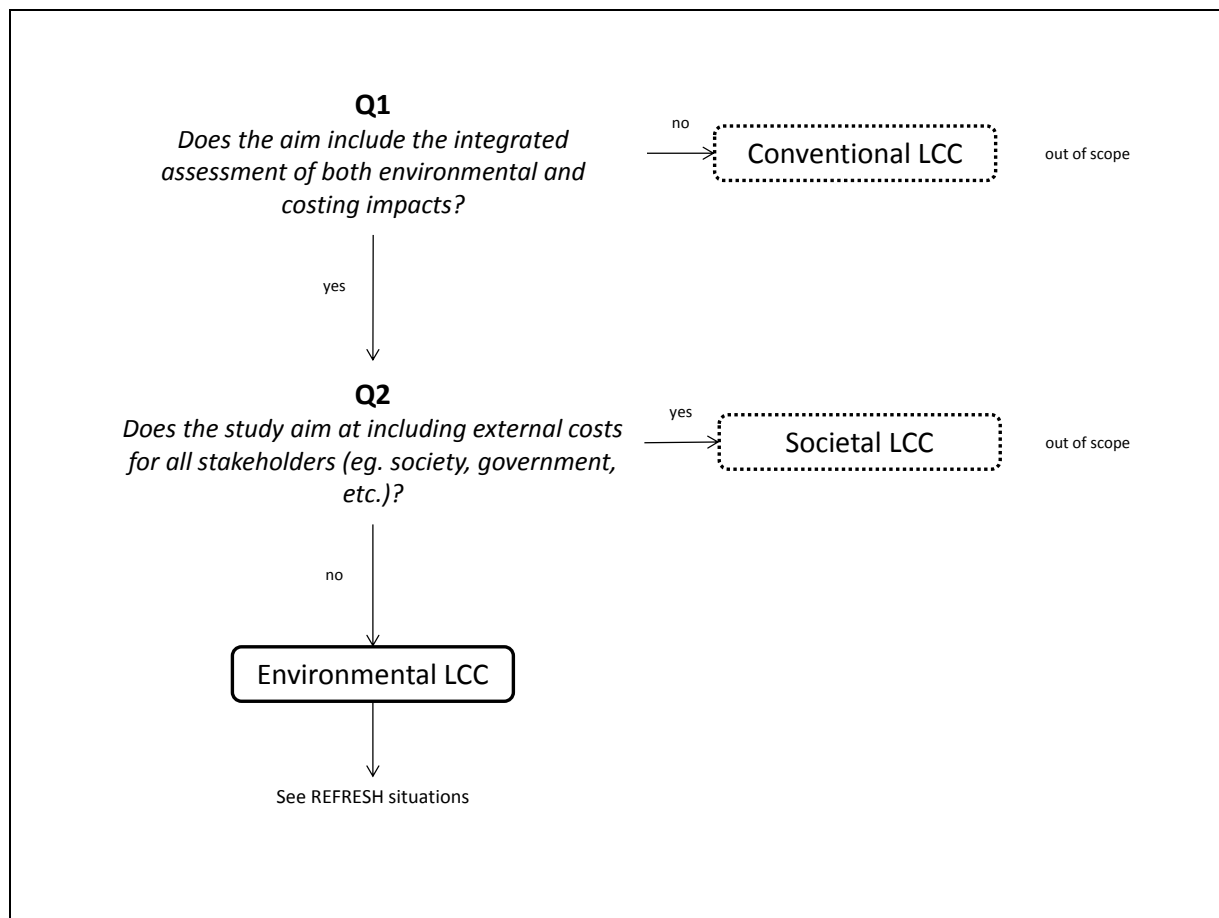
If the answer to Q1 is 'yes', then environmental and costing dimensions are part of the same assessment, adopting different approaches according to the stakeholders included and the type of integration with LCA (see Q2). The assessor should decide whether to include costs for all the stakeholders that may be affected by the analysed system also through externalities, including society, governments, etc. In such perspective, a Societal LCC (S-LCC) approach should be adopted. In S-LCC, costs affecting every stakeholder, both directly and indirectly through externalities (e.g. environmental impacts), are assessed. In fact, as argued by Martinez-Sanchez et al. (2016), an S-LCC encompasses all externalities that can be monetised. Therefore, the integration with a complementary LCA support the S-LCC in identifying and quantifying relevant externalities to be then monetised. A standard approach for the monetisation of externalities is currently still under development (ISO 14008). In general, further research is needed to identify methodologies for the evaluation of several emissions in an S-LCC context. Therefore, S-LCC is thus not included in the scope of the report.

Figure 9). In the specific, it is important to identify whether to integrate or not environmental and costing aspects within the same study (Q1). Depending on the answer a certain LCC approach is recommended.

If the answer is 'no', the costing dimension can be assessed separately. If only costs are assessed, in particular internal costs the assessor have to pay, then a Conventional LCC (C-LCC) is suggested. This approach is rather established and mainly focuses on investment, operating, and maintenance costs emerging during the life span of a product. Disposal costs are included only as long as they are sustained by the assessor. Thus, C-LCC is not usually carried out in integration with LCA, but it could be used when system boundaries are cradle to gate and only one actor is covering for all costs. Considering the objective of REFRESH Task 5.1.3 of developing a system approach for integrating LCA and LCC in the evaluation of food waste streams, C-LCC is not within the scope of the report. The reader can refer to De Menna et al. (2016) for further information and sources.

If the answer to Q1 is 'yes', then environmental and costing dimensions are part of the same assessment, adopting different approaches according to the stakeholders included and the type of integration with LCA (see Q2). The assessor should decide whether to include costs for all the stakeholders that may be affected by the analysed system also through externalities, including society, governments, etc. In such perspective, a Societal LCC (S-LCC) approach should be adopted. In S-LCC, costs affecting every stakeholder, both directly and indirectly through externalities (e.g. environmental impacts), are assessed. In fact, as argued by Martinez-Sanchez et al. (2016), an S-LCC encompasses all externalities that can be monetised. Therefore, the integration with a complementary LCA support the S-LCC in identifying and quantifying relevant externalities to be then monetised. A standard approach for the monetisation of externalities is currently still under development (ISO 14008). In general, further research is needed to identify methodologies for the evaluation of several emissions in an S-LCC context. Therefore, S-LCC is thus not included in the scope of the report.

**Figure 9: General scoping of LCC**



If the assessor wants to limit the analysis to relevant stakeholders of the analysed system that are directly sustaining costs (e.g. different actors of the supply chain), then the recommended approach is the Environmental LCC (E-LCC), accompanied by a complementary LCA assessing the environmental dimension. As defined by Hunkeler et al. (2008, p. xxvii) E-LCC is an LCC approach that “summarizes all costs associated with the life cycle of a product [including] those involved at the end of life; these costs must relate to real money flows. Externalities that are expected to be internalised [...] must also be included”. Thus, E-LCC must not be considered a weighting method (i.e. translating environmental externalities into monetary value as in S-LCC) but a costing method that can be integrated with LCA (i.e. having same functional unit and system boundaries). E-LCC covers external costs already internalised (e.g. taxes), and those that are expected to be internalised in the future (e.g. the future introduction of a CO<sub>2</sub> tax or a tax on fats that will internalise external costs). E-LCC can serve several purposes. Typologies of goal and scope of an E-LCC provided by Hunkeler et al (2008) and reviewed in De Menna et al. (2016) include:

- Assessment of total costs for an actor: similarly to a C-LCC a business can use an E-LCC for the evaluation of costs related to different food waste scenarios and derive insights for both internal firm management and investment plans;

- Evaluation of competitiveness: in order to evaluate the potential marketability of a product (e.g. bioplastic from food waste), a firm can use an E-LCC approach to assess both its cost and benefits and those that will be incurred by consumers during the use/ownership of a product;
- Identification of trade-offs or win-win solutions: coupled with an LCA, an E-LCC can help businesses to identify the least expensive environmental measure or the breakeven between costs and environmental impacts;
- Estimation of value added and supply chain effects: differences in terms of value added or cost distribution along the supply chain can be estimated with an E-LCC approach.

This method is covered by the report as far as side flows valorisation and management is regarded. Thus, it is within the scope of the report and further guidance is provided in the following sections.

## **Recommendation**

Considering the aim of this part of REFRESH of providing integrated LCA and LCC tools for the analysis of food waste routes, Environmental LCC is recommended and thus the type of LCC covered in this guidance. For general guidance on E-LCC of food waste routes, the assessor can rely on the following paragraphs, and then, have more practical examples of E-LCC and LCA application based on the REFRESH situation of his study within Annex A.

### **4.2.2 E-LCC modelling**

#### **General modelling: attributional vs. consequential**

##### **Background/state of science**

Since an E-LCC approach is always recommended when assessing costs with an LCA, the distinction between attributional and consequential LCA has to be addressed, due to its meaningful effects on the costing modelling.

This distinction was rarely addressed by the literature, with the notable exception of Wood and Hertwich (2013). These authors argued that an E-LCC would be relevant only in attributional studies, since its focus on cost minimization and its microeconomic perspective prevent it from appropriately assessing larger economic impacts (i.e. in a consequential study) (Wood & Hertwich 2013). In this aspect, they agree with some authors that question E-LCC relevance for the assessment of the economic pillar of sustainability (Jørgensen et al. 2010; Jørgensen et al. 2013; Gluch & Baumann 2004). Notwithstanding, they also maintain that an E-LCC could eventually capture larger economic effects if integrated within a Life Cycle Sustainability Assessment and using other indicators such as value added, imports, productivity of capital and labour, etc. (Hannouf and Assefa, 2016; Klöpffer and Ciroth, 2011; Wood and Hertwich, 2013).

However it is worth noting that the LCC microeconomic perspective proves useful in determining e.g. savings in the use or end-of-life phase of “green” products or

services with high purchasing prices (Klöpffer & Ciroth 2011). Furthermore, Hunkeler et al. (2008) highlighted how E-LCC can provide the estimation of cost distribution and of value added along the supply chain.

## Recommendation

From a theoretical point of view, a fully integrated LCA-LCC of food waste should assess the environmental and cost dimensions with a consistent modelling framework. This means that the assessor should coherently distinguish here between an “attributional E-LCC” and a “consequential E-LCC”. The first is mainly focused on current cost figures and *can* eventually include an estimation of economic impact (e.g. value added). The second has a larger perspective as it *includes*, besides costs, also estimation of economic consequences (e.g. value added, including effects on markets).

An “attributional E-LCC” is recommended for footprint studies: its main aim is to derive a cost figure or comparison of food waste specific situation(s), for 1 or more actor.

A “consequential E-LCC” is recommended for intervention studies: its main aim is to assess economic consequences of changes in the system, both in terms of costs and value added.

## Functional Unit

### Background/state of science

When conducting an E-LCC, goal and scope definition includes the identification of a functional unit. Based on recommendations provided by SETAC (Hunkeler et al. 2008), in case of parallel assessment, both LCA and E-LCC need to have the same functional unit to ensure consistency. This is a relevant distinction between E-LCC and other costing techniques used in management, as it implies that all relevant budget items need to be allocated on a process/product base (see following sections on indirect costs allocation). This is especially the case when several products are produced by the same firm and/or within the same plant.

In literature (De Menna et al. 2016) mass-based FUs were largely used in food waste, waste and food studies, sometimes related to specific products (e.g. 1 person meal) or functions (e.g. monthly plant operation). However, some FUs were related to area (e.g. orchards), volumes, or energy.

## Recommendation

Since in our approach LCA and E-LCC are integrated, functional unit should be identified in accordance with LCA. Therefore, the distinction between footprint and intervention studies described in 4.1 has consequences also for E-LCC. In particular:

1. The functional unit (FU) in footprint studies should be the quantified performance of the product or service provided:

- a. Footprint of product made from a valorised side flow (RS 2 and 3). Reference flow: mass-based unit of valorised product (relevant quality aspects provided, e.g. protein content for feed products), or X MJ if energy or fuel product
  - b. Footprint of waste treatment process of side flows (RS 3 and 4). Reference flow: mass-based unit of treated side flow (information on composition provided). The FU also includes the service of treatment of the waste.
2. Two types of intervention studies are identified, for which these corresponding FUs are recommended:
  - a. Intervention studies involving a scenario for RS 1 (prevention of side flow), FU: amount of driving product, over specified time period and scale (reference flow: mass-based unit of driving product)
  - b. Intervention studies only assessing RS 2, 3 and 4 (NOT involving a scenario for RS 1, prevention of side flow), FU: amount of side flow utilised, over specified time period and scale (reference flow: mass-based unit of side flow)

## System Boundaries

### Background/state of science

As for functional unit, in an E-LCC, system boundaries should be consistent (i.e. including the same stages or processes) with LCA (Hunkeler et al. 2008). Thus, E-LCC can include the assessment of several upward (e.g. food supply stages) and downward (food waste collection, valorisation, management) processes that are usually assessed separately in traditional costing techniques.

In reviewed literature (De Menna et al. 2016), there is a distinction between cradle-to-gate and cradle-to-grave types of boundaries (see Table 4).

**Table 4: System boundaries typology and consequences for E-LCC**

|                    | Cradle-to-gate  | Cradle-to-grave                 |
|--------------------|---|---------------------------------|
| Processes included | All included up to farm/plant/retail                    | All included up to use/disposal |
| Upward costs       | Can be assessed fully or through market price of inputs |                                 |
| Downward costs     | Can be excluded   | Included                        |
| Perspective        | Single actor possible/common                            | Multi actor possible/common     |

The choice of specific system boundaries, and related features, influences data collection extensiveness and results analysis. In particular, with cradle to gate boundaries and the use of market prices for inputs, the assessment would require

less (or no) data from stakeholders other than the assessor, but wouldn't allow measuring costs distribution among the supply chain and only a single actor perspective would be possible. In this case, the E-LCC is rather similar to a C-LCC. The same would happen with a cradle to grave analysis carried out by the latest stakeholder (e.g. consumer) using market prices for inputs. On the opposite, if a cradle to grave boundary was used and full upward/downward costs assessed, data collection would be more detailed and expensive but it would allow assessing costs and their distribution in a multi-actor perspective.

Hunkeler et al. (2008) suggested that system expansion is not incompatible with E-LCC and system boundaries are often expanded in the literature when dealing with multifunctionality (De Menna et al. 2016). Thus, although no explicit mention was found in the literature on attributional and consequential modelling, it is possible to apply system expansion in the latter case taking into account all those processes that may be affected (e.g. substitution of market products, avoided costs, benefits and revenues).

### **Recommendation**

System boundaries for E-LCC should be chosen coherently with LCA and according to the distinction between footprint and intervention studies described in 4.1 and the specific REFRESH situation described in 3.2. Costing recommendations are provided for each type of study.

In footprint studies:

1. Footprint of product made from a valorised side flow, RS 2. SB: Including a share of the upstream FSC (by allocation of costs or by market price of side flow) before it becomes a side flow, to the end of valorisation chain (at the valorised product – cradle to gate – or until the end of life of the valorised product – cradle to grave).
2. Footprint of product made from a valorised side flow, RS 3. SB: From point of generation of the side flow to a valorised product (gate to gate) or the end of valorisation chain (gate to grave); no price should be paid to acquire the side flow (e.g. by waste management company), but costs for collection and transport are to be included.
3. Footprint of waste treatment process of side flows RS 4. SB: From point of generation of the side flow to end of waste treatment process (gate to grave); no price should be paid to acquire the food waste flow (e.g. by waste management company), but costs for collection and transport are to be included.

In intervention studies:

1. Intervention studies involving a scenario for RS 1 (prevention of side flow), SB: all costs from the production of driving product, and then from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include this also as avoided impact (see impact assessment below).



2. Intervention studies NOT involving a scenario for RS 1 (prevention at source), i.e. only scenarios for RS 2, 3 and 4, SB: all costs from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include also replaced production (avoided impact: see impact assessment below); please note that when moving towards a RS 2 scenario, potential benefits for side flow generator (avoided disposal taxes and revenues from side flow) should be included as well in the system expansion, as avoided costs.

## **Handling multi-functionality**

### **Background/state of science**

Multifunctionality (e.g. multioutput processes) represents a challenge also for E-LCC. As observed by Hunkeler et al. (2008), whenever possible, costs should be attributed among the different coproducts using cost allocation based on market prices, sale shares, etc.

LCA-type substitution can be however carried out by subtracting the cost of an equivalent production process in case of system expansion. Indeed, as emerged in De Menna et al. (2016), in the literature, system expansion is usually adopted in case of multifunctionality. Substitution is carried out using revenues of coproducts or market prices of substitute products as avoided costs. However, no distinction was made between attributional and consequential modelling.

### **Recommendation**

As mentioned in 4.1, the model from Laurent et al. (2014) was adapted based on the ILCD handbook (EC, 2010), regarding how to handle multi-functionality and the use of attributional or consequential modelling.

Thus, in case of footprint studies with an allocation from the driving product (RS 2), burden is usually transferred from side flow generator to valorisation chain in cost terms. When dealing with multioutput processes, costs should be attributed to the functional unit through economic allocation (using the value immediately after the process). It is recommended to use the same criterion as in the LCA. Different choices should be motivated and checked for sensitivity.

Whenever consequential modelling is used (intervention studies) in the E-LCC, system expansion and substitution should be performed. If available, revenues from co-products with market value can be considered as avoided costs. Market price of substitute products identified using the guidance from Weidema (2003) in section 4.1.3 can be considered as an alternative. In both case, avoided cost figures should be provided in a transparent and clear way (i.e. separate cost category).



## Cut-off principle

### Background/state of science

Since E-LCC focuses on costs, a cut-off principle (i.e. environmental vs. economic relevance) should be chosen to define what cost-generating processes to include or exclude from the assessment (Hunkeler et al. 2008). Selected cut-off option should be the same for each scenario, to ensure consistent comparisons.

In reviewed studies (De Menna et al. 2016), three options emerged:

- Option A: only costs directly related to LCA inventory items are considered (e.g. raw materials, energy, etc.); the E-LCC results will outline potential differences from inputs and other physical flows; data collection is simpler and integrated with LCA.
- Option B: also costs indirectly derived from the LCA inventory are considered (e.g. labour and capital for processes inventoried, etc.); the E-LCC results will provide an overview of financial and budget costs (i.e. the alternative scenario is more labour/capital intensive although more resource efficient); more data are required and may need to be allocated (see allocation of costs).
- Option C: further processes not included in the LCA inventory are considered (e.g. R&D, marketing, etc.) based on their financial relevance despite their environmental irrelevance; more data are required and may need to be allocated.

It must be noted that externalities (e.g. external costs deriving from CO<sub>2</sub> emissions) that are anticipated to be internalised can be included regardless of the cut-off option chosen, since they are related to LCA inventory items.

### Recommendation

Once FUs and SBs are identified, a choice must be made in terms of cut-off principle. Regardless of the modelling framework, all 3 options are available and the choice depends on the E-LCC purpose:

- The assessor should use option A if more interested in costs associated e.g. with resource efficiency or if these are the only relevant differences among comparison.
- Option B, instead, is more appropriate when the interest is also on financial aspects and if other indicators are estimated.
- Option C is the best choice for very detailed analysis, including cost figures with little environmental relevance, but can be very problematic if applied to several stages.

## Cost categories

### Background/state of science

Coherently with chosen goal and cut-off principle, cost items should be inventoried. Then a categorisation model should be selected and applied to group cost items within larger typologies (Hunkeler et al. 2008).

Within foreground processes included in the system, cost items related to physical and possibly financial flows are listed and quantified. For background processes (e.g. production and distribution of consumed electricity), it is possible to avoid cost modelling by using market prices/costs of related flows (Hunkeler et al. 2008).

Appropriate categories can then be created to group cost items by:

- Economic typology;
- Life cycle stage;
- Type of activity;
- Detailed cost typology.

These typologies are not mutually exclusive and can be used in sequence (Hunkeler et al. 2008). An example is provided in Table 5.

**Table 5: Example of typology for cost categories used in E-LCC**

| Life cycle stage | Activity   | Cost item   |
|------------------|------------|---|
| Retail           | Marketing  | Labour: €/h/FU<br>Commercials: _ €/radio airing/FU      |
|                  | Materials  | Refrigerators: €/refrigerated food/FU                   |
|                  | Operation  | Electricity: €/kWh/FU<br>Labour: €/h/FU                 |
| Consumption      | Purchase   | Fuel (or other transport): €/l/FU<br>Food: €/kg/FU      |
|                  | Use        | Cooking gas: €/m <sup>3</sup> /FU<br>Waste tax: €/kg/FU |
| End of life      | Collection | Fuel: €/l/FU<br>Labor: €/h/FU                           |
|                  | Disposal   | Fertilizer from composting : - €/kg/FU                  |

While certain categories are overarching, others can be valid for more than one life cycle phase/process, thus allowing summing up similar costs in the product system. Obviously, the level of aggregation directly influences possible impact indicators and results analysis.

### **Recommendation**

As for cut-off, the appropriate cost model should be tailored on the specific aims of the assessor in terms of focus of the analysis and perspective. For example, system boundaries and included costs limit possible categorisations. In case of cradle to gate boundaries with upward costs as market price of inputs, a life cycle stage categorisation may be relevant only for systems with long life span and different phases (e.g. permanent crops).

We recommend defining cost categories by following this short guidance:

1. Identify relevant typology of costs (internal, avoided, revenues, external, etc.), if any, and specifically those that shouldn't be aggregated (e.g. avoided costs); consider that these types are transversal to other categories.
2. List life cycle stages, if distribution of costs/value added among the supply chain is a focus of analysis.
3. If more detail is needed or desired, list main activities/processes composing each life cycle stage.
4. Within each stage and/or activity, list all cost items (also by typology, if relevant)

While for footprint studies, all combinations are possible (with related consequences), in intervention studies we recommend to adopt at least a cost categorisation by typology (e.g. internal, external, avoided, revenue), specific cost item (e.g. labour, capital, materials, energy, etc.), and, if appropriate, life cycle stage. Only with these categories it would be possible to separately estimate external impacts, value added, benefits/costs ratios, etc.

## **Indirect costs allocation**

### **Background/state of science**

Since in E-LCC, cost breakdown is at a unit process level, items such as indirect expenses, administrative costs, overheads, and other similar fixed costs need to be allocated (Hunkeler et al. 2008).

In the literature reviewed (De Menna et al. 2016), fixed rates or usage rate of a plant were used in those studies allocating management, overhead, or fixed costs.

### **Recommendation**

Choice should be based on data availability and focus of the study. In general, if SBs and cut-off require the inclusion of indirect costs (i.e. including processes and

costs common to several products), a specific rate (from economic to physical allocation) must be preferred over an assumed fixed rate. In any case, a sensitivity analysis should be carried out to check the chosen rate.

## **Discounting**

### **Background/state of science**

Future cash flows (costs, revenues, benefits) can have a different economic value than present ones. Thus, in E-LCC a discount rate can be applied. Final results instead should not be discounted, so to be consistent with LCA. In fact, discounting a final result would imply that the final figure has a declining importance over the years (Hunkeler et al. 2008).

In reviewed studies (De Menna et al. 2016), only some authors explicitly used discounting. The actualization was carried out using several rates, from assumed or official interest rates, to cost of capital including inflation and others.

### **Recommendation**

If only present cash flows are included/relevant, then no discounting is needed. This can be the case when an environmental cut-off is chosen and/or the system studied has a relatively short duration (e.g. fresh food products).

Whenever the studied system is characterized by a long life time (e.g. an orchard) or if future cash flows are relevant for the assessment (e.g. long term savings vs. short term investment), discounted cash flows should be used. This would allow assessing in how many years an investment will reach the break even. Similarly, when studying a FW reduction intervention that requires 10 years to realize, costs and benefits should be evaluated according to the time they are happening: present investment is 100% of its cost, future sales will be at 100 - x% of their value. If a discount rate must be used, in general it is recommended to use real/official rates. In footprint studies, it is possible to use specific internal rates (e.g. cost of capital for a firm), especially when only one cost bearer is included. In intervention studies, it is recommended to apply official interest rates and to include inflation. Any discounting rate used needs to be clearly stated and documented.

## **Externalities**

### **Background/state of science**

Environmental impacts of food on natural resources and ecosystems have associated costs and benefits. Some of these are partially reflected in market prices (i.e.: the cost of energy or water use), but many are not. Externalities are quantifiable cost or benefit that occurs when the actions of organizations and individuals have an effect on people other than them. They must be expressed in monetary terms (Martinez-Sanchez et al. 2015). An E-LCC can include externalities that may become real money flows in the decision relevant-future.

However, if an externality assessed within LCA (e.g. CO<sub>2</sub>) is also included into monetary terms in the parallel E-LCC (e.g. through an anticipated carbon tax) there is a risk of double counting in case LCA and E-LCC results are scored and summed. In the specific, if its cost impact were considered in an integrated impact assessment, i.e. through a single score, then the impact of that externality would be overestimated. This risk should thus be avoided (Hunkeler et al. 2008).

Several externalities can be included in an E-LCC, both environmental and social ones. Some examples from reviewed studies (De Menna et al., 2016) are:

- External costs/benefits from emissions (CO<sub>2</sub>, fertilizers, pesticides);
- External costs from disamenities (e.g. land opportunity cost from landfilling);
- External costs/benefits from indirect income effects (e.g. food waste prevention from consumers frees income for other expenses).

### **Recommendation**

First, decision over the inclusion of such externalities depends on the goal and scope of the assessment. As suggested by Hunkeler et al. (2008), externalities that are likely becoming internal costs in the future should be included in the financial part of the study, but must be highlighted separately from other types of costs (see cost categories). Then, as recommended by Hunkeler et al. (2008), when results from LCA and E-LCC are integrated and summed (e.g. converted into a single score), double counting needs to be avoided by considering the externality(ies) only in environmental or costing terms.

In both modelling framework, externalities can be included. Economic externalities are more consistent within intervention studies. For example, indirect income effects potentially generated by food waste prevention could be accounted for in an intervention study, depending on the scale of the change.

## **Cost bearers**

### **Background/state of science**

Since E-LCC may include more than one actor of the supply chain, costs can occur to different cost bearers. When all costs for all actors are accounted for, then it is possible to group costs according to various perspectives that may not overlap with life cycle stages (Hunkeler et al. 2008). In reviewed studies (De Menna et al. 2016), most authors adopted a single actor or a full chain perspective. Few studies included the grouping of costs by related bearers.

### **Recommendation**

Since costs associated with a side flow can be shifted from one stakeholder to the other by policies as well as market dynamics, we recommend adopting a multi-actor perspective whenever possible and whenever the assessor aims at evaluating the distribution of costs and profits across the supply chain.

After cost inventory and categorization, costs should be attributed to different cost bearers (if relevant). First, list all actors that are covering costs in the life cycle of the analysed system. Then, identify whether life cycle stages and bearers overlaps, i.e. checking if all cost items within a stage are covered by the same actor. If yes, then each stage is also representing an actor perspective, and vice versa. If not, it is recommended to group cost items (or categories) according to the actor that is paying for them. An example of this situation is the WEEE (waste electrical and electronic equipment) directive, which allocates costs for collection and disassembly/recycling to producers (Hunkeler et al. 2008).

Usual cost bearers in a food waste study may be:

- Side flow generator (farmers, processors, retailers, consumers, etc.);
- Side flow current or perspective valorisers/users (waste management companies, bioenergy or bioplastic producers, food banks, etc.);
- Government/society (in case of transfers as taxes but also subsidies or education measures, and externalities).

## **Impact assessment**

### **Background/state of science**

In E-LCC different tools may be used to assess costs and economic impact, i.e. revenues, cost hotspots, correlations, breakeven points, etc. (Hunkeler et al. 2008). Several studies assessed Net Present Value (NPV) and Internal Rate of Return (IRR). Some included other tools such as cost-to-benefit ratios, while only in one case value added was estimated (De Menna et al. 2016).

In general, no distinction between attributional and consequential modelling was observed. As mentioned, LCC is characterized by a microeconomic perspective. Its objective is generally to reduce costs or generate savings over the life cycle. Notwithstanding society aims at maximizing value added. Thus, on one hand in a broader context, savings from cost minimization (e.g. from food waste prevention) could generate beneficial economic impacts (e.g. expenditure on other goods and services, other investments, etc.). On the other hand, an E-LCC could still provide estimates of broader economic impacts, through calculation of value added. Hunkeler et al. (2008, p. 10) reports that value added is composed of labor costs, capital costs, and profits. Thus it can be calculated as “the difference between the sales of products and the purchases of products or materials by a firm [...] disregarding possible revenues from co-products”.

In case of system expansion and large scale, however, this economic impact could encompass the indirect effect on the market (e.g. substitution of product), potentially generating trade-offs.

## Recommendation

If the main aim of the E-LCC is on internal financial/budget aspects and there is only one cost bearer, it is recommended to assess cost hotspot, Net Present Value (NPV) and Internal Rate of Return (IRR).

If the main aim is to assess effects on the supply chain, then impact assessment should focus on distribution of costs among life cycle stages and/or cost bearers.

Other assessment may focus on: cost/benefit ratios, profits, and value added.

In case of footprint studies, these methods are all available options and can be combined to derive several insights. As mentioned, SBs, cut-off, and categories may affect the possibility to perform one or more of these assessments.

In case of intervention studies, the focus being on potential systemic consequences, it is recommended to include an evaluation of value added generated by the system, as a proxy of economic consequences.

As mentioned for SBs, if the analysed system produces marketable product(s), effects on replaced production can be included in the impact assessment as avoided value added, using market price of replaced products as a proxy. However, since these economic consequences are not certain, it is recommended to report this figure only separately, to not subtract it from the generated value added, and to discuss it in results interpretation.

## Sensitivity analysis

### Background/state of science

Likewise, sensitivity analysis should be carried out in this phase of an E-LCC study to further discuss results and highlight potential criticism in methods, value choices, data, and variables (Hunkeler et al. 2008, De Menna et al. 2016).

### Recommendation

Regardless of the modelling framework, a sensitivity analysis is recommended within results interpretation. Several parameters and data can be tested for sensitivity, in particular:

- Discount rates;
- Period of analysis;
- Cost data based on assumptions;
- Expected variations in prices and economic contingencies;
- Other value choices.

## 4.3 Combining LCA and E-LCC

In this section methodological choices requiring special attention when combining LCA and E-LCC are highlighted.

### Functional unit and system boundaries

In the goal and scope definition phase of an integrated LCA and E-LCC, both FUs and SBs must be the same. For FUs the choice is quite straightforward, since the analysed function is the same. However, for SBs some inconsistency may occur. In fact, in some intervention studies, changes may affect processes only in environmental or cost terms. For example, a change from a RS 3 to RS 2 (intervention study), will cause no physical changes in upstream processes (no change in resource use or emissions), but there might be a change in costs or revenues. Thus, in this case the upstream processes can be left outside the system boundary in the LCA, but the E-LCC assessment should take into account these effects. As a consequence, the expanded system boundary for the E-LCC also include these changes (e.g. revenues from selling to valoriser, changes in administration costs, licenses and similar) in the upstream processes as avoided costs, while in the LCA these are not considered.

### Recommendation

It is recommended to use the same FU when combining LCA and E-LCC, and also the same SB. However, expanded system boundaries can present some differences when exploring intervention studies that compare RS 2 to other situations, but the LCA and E-LCC can still be combined.

### Cut-off principle(s)

Similarly, we recommended using cut-off for LCA and E-LCC in a consistent manner, coherently with what suggested by Hunkeler et al. (2008). This means that some processes can be included or excluded from the LCA or E-LCC respectively, based on their environmental or cost relevance. In particular, while options A and B for E-LCC cut-off are based on the LCA inventory, option C may result in the inclusion of processes generating relevant costs but not relevant environmental impacts (see page 56 for description of A,B,C). The opposite situation could occur as well but it should be quite unusual. It is recommended to clearly state the cut-off principles for both the assessments and to properly justify them in the goal and scope phase. It is reasonable that even though a consistent cut-off principle is employed for both the LCA and the LCC (to include the processes that contribute most to environmental impact and cost, respectively), that processes omitted will be different, since some processes generate cost but not environmental impact, and vice versa.

### Recommendation

It is recommended to use cut-off criteria for the LCA that are based on environmental relevance, and for the LCC are based on cost relevance. This means that different processes might be excluded in the LCA results compared to



the LCC results, and vice versa, but the results of the two studies can still be considered consistent as long as the same FU and SB are used.

## Combined results interpretation

### Background/state of science

After separately assessing LCA and E-LCC results with related methods, an integrated LCA and E-LCC should enable an analysis of these results in a combined and comparable manner. As highlighted in the literature review (De Menna et al 2016), the most common ways to combine LCA and E-LCC can be categorised into three options.

#### *Portfolio presentation of impacts*

Different scenarios analysed are represented on a table or on a graph showing selected impact categories for LCA and costs for LC stages/scenarios. Usually in a portfolio neither normalization nor weighting is conducted. Table 6 represents an example of a simple portfolio presentation of results for an assessment of a single system, e.g. in a footprint study. Three indicators are reported with the related unit measure and amount.

**Table 6: Example of portfolio presentation**

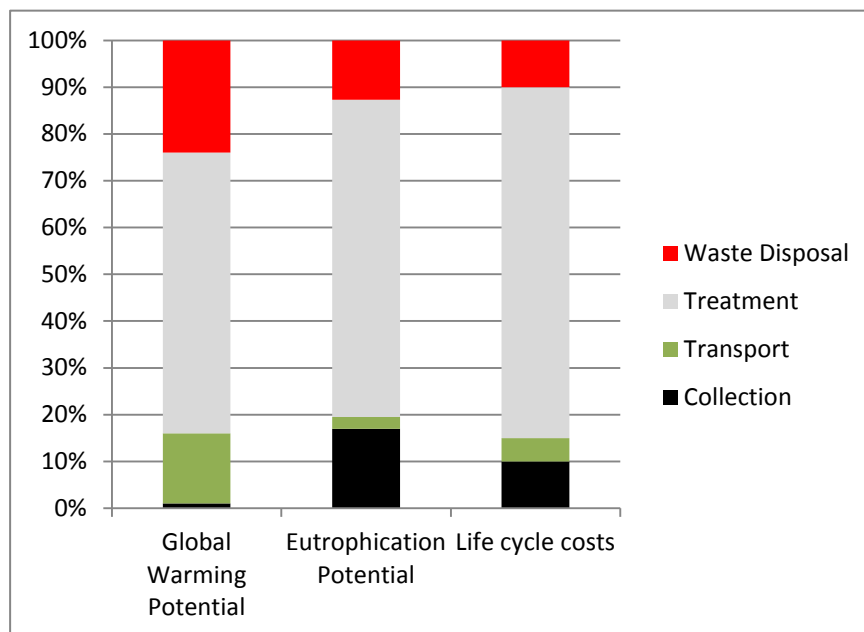
| Indicator                | Unit measure             | Amount |
|--------------------------|--------------------------|--------|
| Global Warming Potential | kg CO <sub>2</sub> eq/kg | 0.12   |
| Life cycle costs         | €/kg                     | 0.16   |
| Cumulative Energy Demand | MJ/kg                    | 3.01   |

Obviously, in an intervention study, the result column may show the net effect of moving from one RS to another, and possibly resulting in negative amounts. When exploring and comparing more footprints or interventions, absolute results for each scenario can also be shown, by adding further columns.

In this type of portfolio, it is important to be careful not to apply an unintentional weighting, by showing all results in one table, where option A performs better in 8 environmental impact categories and option B only in one showing costs. This has to be avoided also in the discussion and interpretation of results reported.

A portfolio presentation can also be used to show the percentage of life cycle stage contribution per each indicator, as in Figure 10. While in this case absolute values are not reported, it is a useful way of showing the respective relevance of hotspots per each impact category.

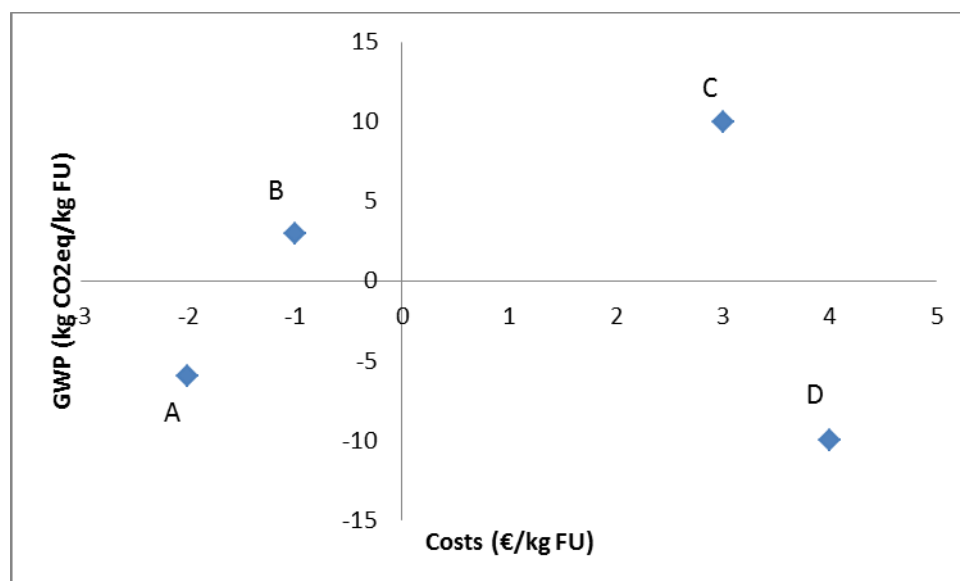
**Figure 10: Example of percentage based portfolio presentation with life cycle stage contribution**



### *Plotting of impacts*

In addition to portfolios, selected LCA and LCC scores can be plotted on a graph to rank alternative scenarios, identify win-win solutions or trade-offs, measure the elasticity between environmental impacts and costs/profits.

**Figure 11: Example of plotting of impacts (footprints)**



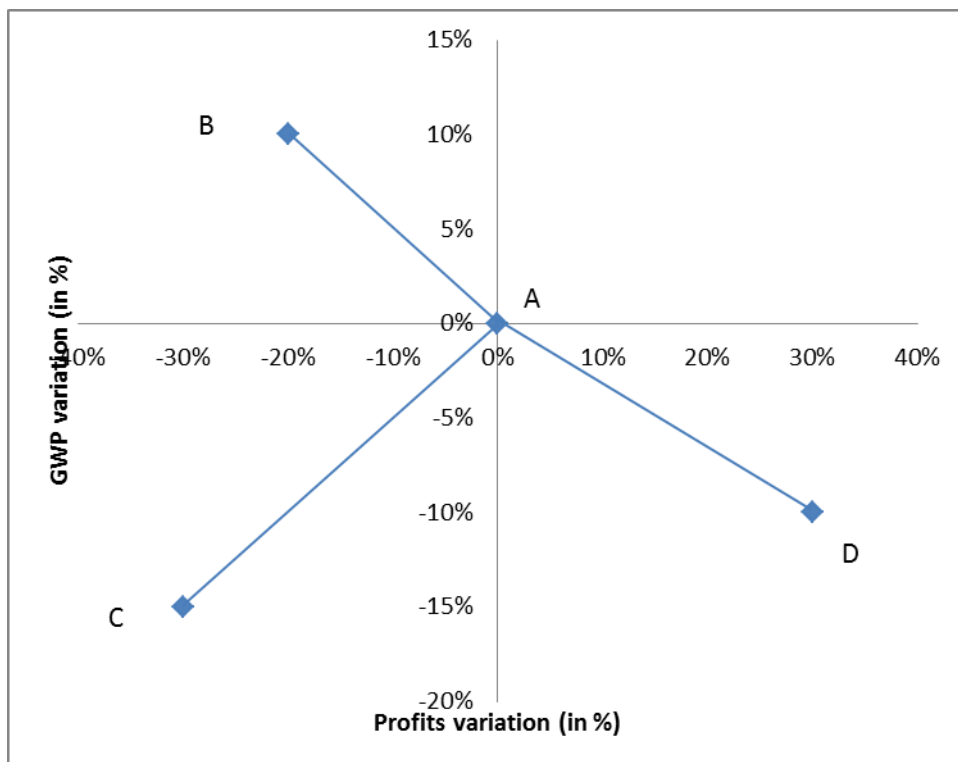
In a comparison between footprints (see Figure 11), a plot graph could simply represent a different way of presenting a portfolio of two impacts. The graph

helps to rapidly identify what is both economically and environmentally sustainable (e.g. A) and vice versa (e.g. C).

This kind of plot graph can be also used to show variations deriving from a sensitivity analysis on a parameter influencing one or both the indicators. Since LCA and E-LCC may have several indicators, plot graphs can present several combinations. Figure 12 gives another example of a plot graph in case of a comparison between interventions. In this figure, GWP and profits percentage variations are shown when moving from one situation (A) to three others (B, C and D respectively).

In this case, it shows how much profit would be lost to reach a certain GWP reduction. For example in D, 30% more profit can be achieved while reducing GWP by 10%, and so on. Please note that lines are not suggesting a linear relation, but are only a graphical mean to connect dots. Also in this case several indicators from both environmental and costing assessment can and should be used in combination to identify trade-offs and win-win solutions. When plotting results in this way, the impact of both the starting point and the end point must be calculated and shown in the figure, whereas in the example provided in Table 6, only the net effect of one intervention is shown (in the case of intervention studies).

**Figure 12: Example of plotting of impacts (interventions)**



## Normalization

Normalisation is an operation that puts the impacts of a system in relation to the impact of another context, e.g. impacts globally, per country etc. This is an optional step in the ISO standard. When performing normalisation for all the impact categories assessed in the study, it is possible to see which impact categories the system contributes most and least to. It is then in the next step possible to also aggregate the results from different impacts together by applying weighting, which is also an optional step in the ISO standard. Results from LCA and LCC assessment may be normalized to be able to compare across different impacts. Table 7 represents an example of how to combine LCC and LCA indicators into a single score. In this case, absolute scores for each scenario and each indicator are transformed into relative factors, by dividing the factor with the factor from the scenario that has the highest factor (i.e. no external basic has been used). No weighting has been applied, i.e. the relative factors are kept separate and not added together. This allows the assessor to identify the scenario(s) that minimizes the overall impact (B).

**Table 7: Example of normalization**

| Indicators | A  | B  | C  | Relative factors     | A    | B    | C    |
|------------|----|----|----|----------------------|------|------|------|
| GWP        | 10 | 6  | 5  | Environmental factor | 1,00 | 0,60 | 0,50 |
| LCC        | 10 | 12 | 18 | Costing factor       | 0,56 | 0,67 | 1,00 |

While portfolios and plots are quite common in LCA and LCC studies in the literature, normalization is not used very often. Furthermore, weighting factors used for grouped results usually requires value choices, thus limiting reliable comparisons of final scores.

On a more general note, it should be emphasised that LCA and E-LCC provide objective numbers and does only respond to the environmental and cost dimensions. Reduction of food loss and waste also has important social (e.g. availability of food) and political dimensions that need to be considered together with the results obtains from LCA and E-LCC. Once the full picture is created, generic KPIs can be formulated as a second step.

## Recommendation

It is recommended using portfolio presentations to show complete results of both LCA and E-LCC results in a common table, and to visualise selected impacts in a graph. As a second step, it is recommended plotting selected indicators (e.g. GWP and cost or NPV or value added) to show eventual win-win or trade-offs between the environmental and cost dimension.

## 5 Recommended stepwise procedure

In addition to following the ISO standard on LCA, it is recommended to go through the following steps when performing an LCA, an LCC, or a combined LCA and LCC study, focusing on side flows:

1. Phrase the question of your study; what is the purpose of the study?
2. Establish if the flow being investigated in the study is a side flow (if not, then this is outside the scope of this report), and which REFRESH situation is applicable, by using the decision tree in Figure 3. For several situations (scenarios) run through the decision tree for each situation.
3. Establish whether your study is a footprint or intervention study, by using the decision tree in Figure 4.
4. If cost is assessed, use Figure 7 to establish if E-LCC is suitable for the study; if yes, this guide can be applied.
5. Utilise Table 8 and 9 for recommendations on methodological choices in the LCA/LCC study.
6. For intervention studies, see also Annex A for applied method recommendations in example studies.

**Table 8: Recommendations on selected method issues for footprint studies**

|                                     | LCA   | LCC  | Combined LCA and LCC   |
|-------------------------------------|---|--|--|
| <b>Functional unit (FU)</b>         | <ol style="list-style-type: none"> <li>1. Footprint of product made from a valorised side flow (RS 2 and 3). Reference flow: mass-based unit of valorised product (relevant quality aspects provided, e.g. protein content for feed products), or X MJ if energy or fuel product</li> <li>2. Footprint of waste treatment process of side flows (RS 3 and 4). Reference flow: mass-based unit of treated side flow (information on composition provided). The FU also includes the service of treatment of the waste.</li> </ol>  |  |  |
| <b>System boundary (SB)</b>         | <ol style="list-style-type: none"> <li>1. Footprint of product made from a valorised side flow, RS 2. SB: Including a share (by allocation) of the upstream FSC before it becomes a side flow to the end of valorisation chain (at the valorised product – cradle to gate – or until the end of life of the valorised product – cradle to grave).</li> <li>2. Footprint of product made from a valorised side flow, RS 3. SB: From point of generation of the side flow to a valorised product (gate to gate) or the end of valorisation chain (gate to grave)</li> <li>3. Footprint of waste treatment process of side flows, RS 4. SB: From point of generation of the side flow to end of waste treatment process (gate to grave)</li> </ol> <p>Draw a system diagram showing foreground and background system as well as the most relevant processes not covered, e.g. if the use phase of a product is not included.</p> |  | The same FU should be used when combining LCA and E-LCC, and also the same SB. |
| <b>Handling multi-functionality</b> | <p>Regarding allocation between driving product and side flow, it is recommended employing the REFRESH situations, and only allocating burden to the side flow for RS 2 (and not RS 3 and RS 4 where the side flow should be burden free). Use economic allocation with the value immediately after the process. If using another allocation basis, this should be clearly motivated. Source of data for the allocation as well as the allocation factors used need to be clearly stated.</p>   |  |  |
| <b>Cut-off principle</b>            | Take into account all processes that contribute significantly to the environmental impact. Existing studies on the same system are useful indicators  | <p>See section 4.2.2 for description of A, B and C</p> <ul style="list-style-type: none"> <li>• Use A if more interested in costs</li> </ul> | Use cut-off criteria that for the LCA are based on <u>environmental</u>        |

|                            |   |   |   |
|----------------------------|---|---|---|
|                            | <p>as to what processes contribute to what extent to the overall impact.</p> <p>Draw a process flow diagram and highlight clearly which processes are included and excluded (cut-off) in the study.</p>   | <p>associated e.g. with resource efficiency or if these are the only relevant differences between compared scenarios.</p> <ul style="list-style-type: none"> <li>• Use B if interested also on financial aspects and if other indicators are estimated.</li> <li>• Use C for detailed analysis, including cost figures with little environmental relevance.</li> </ul> <p>Draw a process flow diagram and highlight clearly which processes are included and excluded (cut-off) in the study.</p> | <p>relevance, and for the LCC are based on <u>cost</u> relevance. This means that different processes might be excluded in the LCA results compared to the LCC results, and vice versa, but the results of the two studies can still be considered consistent as long as the same FU and SB are used.</p> |
| <b>Data inventory</b>      | <p>Use average data on processes in the background processes, and specific data for the core processes (foreground) in the system being studied.</p>  |   |   |
| <b>Cost categorisation</b> | <ol style="list-style-type: none"> <li>1. Identify relevant typology of costs (internal, avoided, revenues, external, etc.), if any, and specifically those that shouldn't be aggregated (e.g. avoided costs); consider that these types are transversal to other categories.</li> <li>2. List life cycle stages, if distribution of costs/value added among the supply chain is a focus of analysis.</li> <li>3. If more detail is needed or desired, list main activities/processes composing each life cycle stage.</li> <li>4. Within each stage and/or activity, list all cost items (also by typology, if relevant)</li> </ol> <p>Adopt at least a cost categorisation by typology (e.g. internal, external, avoided, revenue), specific cost item (e.g. labour, capital, materials, energy, etc.), and, if</p> |   |   |

|                                 |  |   |
|---------------------------------|--|---|
|                                 | appropriate, life cycle stage. Only with these categories will it be possible to separately estimate external impacts, value added, benefits/costs ratios, etc.  |   |
| <b>Indirect cost allocation</b> | Choice should be based on data availability and focus of the study. In general, if SBs and cut-off require the inclusion of indirect costs (i.e. including processes and costs common to several products), a specific rate (from economic to physical allocation) must be preferred over an assumed fixed rate.   |   |
| <b>Discounting</b>              | If only present cash flows are included/relevant, then no discounting is needed. Whenever the studied system is characterized by a long life time (e.g. orchard) or if future cash flows are relevant for the assessment (e.g. long term savings vs. short term investment), discounted cash flows should be used.   |   |
| <b>Externalities</b>            | Externalities that are likely becoming internal costs in the future should be included in the financial part of the study, but must be highlighted separately from other types of costs.   | If results from LCA and E-LCC are aggregated into one score, double counting needs to be avoided. |
| <b>Cost bearers</b>             | <p>Since food waste costs can be shifted from one stakeholder to the other, adopt a multi-actor perspective whenever possible. Usual cost bearers in a food waste study may be:</p> <ul style="list-style-type: none"> <li>• Side flow generator (farmers, processors, retailers, consumers, etc.)</li> <li>• Side flow current or perspective managers/users (waste management companies, bioenergy or bioplastic producers, food banks, etc.)</li> </ul> |   |



|                          |  |  |   |
|--------------------------|--|--|---|
|                          |  | Government/society (in case of transfers and externalities)  |   |
|                          |  | <p>If the main aim of the E-LCC is on internal financial/budget aspects and there is only one cost bearer, it is recommended to assess cost hotspot, Net Present Value (NPV) and Internal Rate of Return (IRR).</p> <p>If the main aim is to assess effects on the supply chain (and several cost bearers), then impact assessment should focus on distribution of costs among life cycle stages and/or cost bearers.</p> <p>Other assessment may focus on: cost/benefit ratios, profits, and value added.</p> |   |
| <b>Impact assessment</b> | Table 3 gives recommended impact categories.   |  |   |
| <b>Interpretation</b>    | <ol style="list-style-type: none"> <li>1. Identify significant issues (i.e. the key processes, parameters, assumptions and elementary flows), as well as the main choices that have the potential to influence the precision of the final results of the LCA/LCC.</li> <li>2. Evaluate these issues with regard to their sensitivity or influence on the overall results of the LCA/LCC. This includes completeness, sensitivity and consistency with which the significant issues have been handled.</li> <li>3. Use the results of the evaluation to formulate conclusions and recommendations.</li> </ol> <p>Suggested parameters to test for sensitivity, if relevant:</p> <ul style="list-style-type: none"> <li>• E-LCC: Discount rates, period of analysis, cost data based on assumptions, expected variations in prices and economic contingencies; other value choices.</li> <li>• LCA: allocation factors, LCI data with high level of uncertainty, choice of substituted product, other value choices</li> </ul> |  | <p>Use portfolio presentations (see section 4.3) to show complete results of both LCA and E-LCC results in a common table, and visualise selected impacts in a graph. As a second step, plot selected indicators (e.g. GWP and cost or NPV or value added) to show eventual win-win or trade-offs between the environmental and cost dimension.</p> |

**Table 9: Recommendations on selected method issues for intervention studies**

|                              | LCA  | LCC   | Combined LCA and LCC  |
|------------------------------|--|---|---|
| Functional unit (FU)         | <div>1. Intervention studies involving a scenario for RS 1, FU: amount of driving product, over specified time period and scale (reference flow: mass-based unit of driving product)</div> <div>2. Intervention studies NOT involving RS 1, FU: amount of side flow utilised, over specified time period and scale (reference flow: mass-based unit of side flow)</div>  |   | <div>The same FU should be used when combining LCA and E-LCC, and also the same SB. However, expanded system boundaries can present some differences when exploring intervention studies that compare RS 2 to another RS (the economic benefit for the side flow generator is included in the RS 2 scenario for the E-LCC, but this actor is not included in the LCA since no physical changes occur there), but the LCA and E-LCC can still be combined.</div> |
| System boundary (SB)         | <div>1. Intervention studies involving a scenario for RS 1, SB: all impacts/costs from the production of driving product, and then from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include this also as avoided impact/cost.</div> <div>2. Intervention studies NOT involving RS 1, all impacts/costs from generation of side flow to treatment of side flow, if treatment/valorisation gives marketable product(s), include also replaced production; please note that when moving towards a RS 2 scenario, potential economic benefits for side flow generator should be included as avoided costs.</div> <div>Draw a process flow diagram showing clearly which processes are included, and not, in the study.</div> |   |   |
| Handling multi-functionality | <div>Use system expansion and include avoided burden of potentially substituted products on the market. Use the guidance in Figure 8 to help identify the substituted production technology. For the E-LCC, if available, revenues from co-products with market value can be considered as avoided costs. Market price of substitute products identified using the guidance from Weidema (2003) in section 4.1.3 can be considered as an alternative. Avoided impact and cost should be shown in a transparent way.</div>  |   |   |
| Cut-off principle            | <div>Take into account all processes that contribute significantly to the environmental impact. Existing studies on the same system are useful indicators as to what processes contribute to what extent to</div>  | <div>See section 4.2.2 for description of A, B and C</div> <div><ul style="list-style-type: none"><li>Use A if more interested in costs associated e.g. with resource efficiency or if these are the only relevant differences between compared</li></ul></div> | <div>Use cut-off criteria that for the LCA are based on <u>environmental</u> relevance, and for the LCC are based on cost</div>   |

|                            |  |  |   |
|----------------------------|--|--|---|
|                            | <p>the overall impact.</p> <p>Draw a process flow diagram and highlight clearly which processes are included and excluded (cut-off) in the study.</p>  | <p>scenarios.</p> <ul style="list-style-type: none"> <li>• Use B if interested also on financial aspects and if other indicators are estimated.</li> <li>• Use C for detailed analysis, including cost figures with little environmental relevance.</li> </ul> <p>Draw a process flow diagram and highlight clearly which processes are included and excluded (cut-off) in the study.</p>  | <p>relevance. This means that different processes might be excluded in the LCA results compared to the LCC results, and vice versa, but the results of the two studies can still be considered consistent as long as the same FU and SB are used.</p> |
| <b>Data inventory</b>      | <p>Use specific data for the processes in the foreground system, and use the decision tree in Figure 8 for determining if the changes affect markets or not; if yes then marginal data should be used to model these processes that are affected; if not then average data can be used for background processes in the system.</p> |  |   |
| <b>Cost categorisation</b> |  | <ol style="list-style-type: none"> <li>1. Identify relevant typology of costs (internal, avoided, revenues, external, etc.), if any, and specifically those that shouldn't be aggregated (e.g. avoided costs); consider that these types are transversal to other categories.</li> <li>2. List life cycle stages, if distribution of costs/value added among the supply chain is a focus of analysis.</li> <li>3. If more detail is needed or desired, list main activities/processes composing each life cycle stage.</li> <li>4. Within each stage and/or activity, list all cost items (also by typology, if relevant)</li> </ol> <p>Adopt at least a cost categorisation by typology (e.g. internal, external, avoided, revenue), specific cost item (e.g. labour, capital, materials, energy, etc.), and, if appropriate, life cycle stage. Only with these</p> |   |

|                                 |                                  |   |
|---------------------------------|----------------------------------|---|
|                                 |                                  | categories will it be possible to separately estimate external impacts, value added, benefits/costs ratios, etc.  |
| <b>Indirect cost allocation</b> |                                  | Choice should be based on data availability and focus of the study. In general, if SBs and cut-off require the inclusion of indirect costs (i.e. including processes and costs common to several products), a specific rate (from economic to physical allocation) must be preferred over an assumed fixed rate.  |
| <b>Discounting</b>              |                                  | If only present cash flows are included/relevant, then no discounting is needed. Whenever the studied system is characterized by a long life time (e.g. orchard) or if future cash flows are relevant for the assessment (e.g. long term savings vs. short term investment), discounted cash flows should be used.  |
| <b>Externalities</b>            |                                  | <p>Externalities that are likely becoming internal costs in the future should be included in the financial part of the study, but must be highlighted separately from other types of costs.</p> <p>When results from LCA and E-LCC are integrated, double counting needs to be avoided.</p>   |
| <b>Cost bearers</b>             |                                  | <p>Since food waste costs can be shifted from one stakeholder to the other, adopt a multi-actor perspective whenever possible. Usual cost bearers in a food waste study may be:</p> <ul style="list-style-type: none"> <li>• Side flow generator (farmers, processors, retailers, consumers, etc.)</li> <li>• Side flow current or perspective managers/users (waste management companies, bioenergy or bioplastic producers, food banks, etc.)</li> <li>• Government/society (in case of transfers and externalities)</li> </ul> |
| <b>Impact</b>                   | Table 3 gives recommended impact | If the main aim of the E-LCC is on internal financial/budget aspects and there is only one cost   |

**assessment**

categories.

bearer, assess cost hotspot, Net Present Value (NPV) and Internal Rate of Return (IRR).

If the main aim is to assess effects on the supply chain (and several cost bearers), then focus on distribution of costs among life cycle stages and/or cost bearers.

Other assessment may focus on: cost/benefit ratios, profits, and value added.

Include an evaluation of value added generated by the system, as a proxy of economic consequences.

**Interpretation**

1. Identify significant issues (i.e. the key processes, parameters, assumptions and elementary flows), as well as the main choices that have the potential to influence the precision of the final results of the LCA/LCC.

2. Evaluate these issues with regard to their sensitivity or influence on the overall results of the LCA/LCC. This includes completeness, sensitivity and consistency with which the significant issues have been handled.

3. Use the results of the evaluation to formulate conclusions and recommendations.

Suggested parameters to test for sensitivity, if relevant:

- E-LCC: Discount rates, period of analysis, cost data based on assumptions, expected variations in prices and economic contingencies; other value choices.
- LCA: allocation factors, LCI data with high level of uncertainty, choice of substituted product, other value choices

Use portfolio presentations (see section 4.3) to show complete results of both LCA and E-LCC results in a common table, and visualise selected impacts in a graph. As a second step, plot selected indicators (e.g. GWP and cost or NPV or value added) to show eventual win-win or trade-offs between the environmental and cost dimension.

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## 7 Annex A: Examples of intervention studies

### 7.1 Example case: Moving from RS 3 to RS 1

In this example a retailer wants to evaluate environmental and economic benefits and impacts/costs of changing routine for buying fruits and vegetables and thus avoiding wastage of unsold fruits and vegetables. Currently, 2 tonnes of mixed fruits and vegetables are sent to a large municipal biogas facility every year, which generates biogas and some residuals. The retailer pays a fee for the fruits and vegetables to be collected. The retailer would like to motivate his staff and suppliers in improved purchasing routines that enable them to reduce the amount of fruits and vegetables sent to the biogas facility, while at the same time ensuring that no burden shift takes place by creating more waste in steps before the retailer (e.g. at the supplier, or at the farm).

The retailer is also expecting the introduction of a “food waste carbon tax” that will attribute an extra fee for the disposal of wasted food, calculated on the embedded CO<sub>2</sub>eq emissions of food and based on the carbon emission trading system. Therefore this externality is anticipated to be internalized.

Currently the annual sales of fruits and vegetables are 100 tonnes and based on the current analysis the increase in sales is expected to be small for the next five years. The fruit and vegetable mix is not expected to change either. The specific question being asked by the retailer is: what will be the cost for the retailer and other affected parties? And what will the environmental impact of this change be?

### How to follow the recommended steps?

Here, the aim is to follow the recommended steps in Chapter 5 for the example case study.

#### **Step 1: Phrase the question of the study, identify the audience for the result**

What are the economic costs for the fruit and vegetable supplier, the retailer, the biogas operator in the chain, as well as the main environmental consequences of reducing the fruits and vegetables that are presently sent to municipal waste handling, by changing the buying routines and communicating with the suppliers in a different set-up? The change will be conducted by teaching the staff different routines, as well as by investing in a new planning software programme. The result will be input to the retailer in his/her decision whether to make this change or not (probably along with other factors).

## Step 2: Establish REFRESH situations

Use the decision tree in Figure 2, to establish if in fact the study explores a side flow (and not a driving product), and if YES the corresponding RS for the starting situation and the possible future situation.

### Starting situation:

Is 'the more, the better' valid for the fruits and vegetables? No, the retailer does not want to have more of the discarded fruits and vegetables. Then it is a side flow and a REFRESH situation applies. Which one?

Is the handling of the side flow about prevention/reduction of (upstream) material resources to produce a driving product? The answer here is 'No'. Move on to next question.

Is the side flow product (biogas) of value but not a driving product for the FSC, and does the output flow generator (the retailer) gain value from it? No, the retailer just wants to get rid of the fruits and vegetables, and pays a fee for it to be collected. Move on to next question.

Disposal/getting rid of the side flow is the driving force but some value can be extracted that replaces a marketable product? The generator of the output flow does not gain any value from valorisation. The answer is 'Yes', this corresponds to our case, which means it is considered as a **RS 3** since the biogas production generates some value for the biogas producer.

### Possible future situation:

Is the future handling about prevention/reduction of (upstream) material resources to produce a driving product? Yes, by reducing the amount of fruits and vegetables sent to the biogas facility, the material resources needed (purchased) for each tonne of fruits and vegetables sold from the retailer decreases. This means this situation is a **RS 1**.

**Conclusion: The study will assess the effect of moving from RS 3 to RS 1**

## Step 3: Footprint or intervention study?

Is the study a footprint or intervention study? The use of decision tree presented in Figure 3 is described below.

Is any decision to be taken from the LCA result? Yes, the retailer would like to use the results from the study as input, along with other factors, for taking the decision on whether it is worth investing money into making a change. **This means it is an intervention study.**

Are there any large scale consequences on some of the processes in the background system? The scale of the flow is 2 tonnes per year, which is not expected to influence the operation of the biogas facility in any major way, so the answer is no. This means that in the modelling **system expansion is privileged**

when accounting for 'additional' functions from the system, and **average market data can be used for processes in the background system.**

#### **Step 4: E-LCC appropriate?**

If the answer is 'no', the costing dimension can be assessed separately. If only costs are assessed, in particular internal costs the assessor have to pay, then a Conventional LCC (C-LCC) is suggested. This approach is rather established and mainly focuses on investment, operating, and maintenance costs emerging during the life span of a product. Disposal costs are included only as long as they are sustained by the assessor. Thus, C-LCC is not usually carried out in integration with LCA, but it could be used when system boundaries are cradle to gate and only one actor is covering for all costs. Considering the objective of REFRESH Task 5.1.3 of developing a system approach for integrating LCA and LCC in the evaluation of food waste streams, C-LCC is not within the scope of the report. The reader can refer to De Menna et al. (2016) for further information and sources.

If the answer to Q1 is 'yes', then environmental and costing dimensions are part of the same assessment, adopting different approaches according to the stakeholders included and the type of integration with LCA (see Q2). The assessor should decide whether to include costs for all the stakeholders that may be affected by the analysed system also through externalities, including society, governments, etc. In such perspective, a Societal LCC (S-LCC) approach should be adopted. In S-LCC, costs affecting every stakeholder, both directly and indirectly through externalities (e.g. environmental impacts), are assessed. In fact, as argued by Martinez-Sanchez et al. (2016), an S-LCC encompasses all externalities that can be monetised. Therefore, the integration with a complementary LCA support the S-LCC in identifying and quantifying relevant externalities to be then monetised. A standard approach for the monetisation of externalities is currently still under development (ISO 14008). In general, further research is needed to identify methodologies for the evaluation of several emissions in an S-LCC context. Therefore, S-LCC is thus not included in the scope of the report.

Figure 9 is used to establish whether E-LCC is appropriate to use in the study.

Does the aim include the integrated assessment of environmental and cost? Yes, then the next question is: does the study aim at including external costs for all stakeholders? No, stakeholders indirectly affected through externalities will not be taken into account. In this case the retailer, and the suppliers, and the biogas operator will be considered. But no other external stakeholders to this chain will be included. This means **an E-LCC is appropriate** for the assessment and the guidance in this report can be used.

#### **Step 5: FU, SB, cut-off and handling multi-functionality**

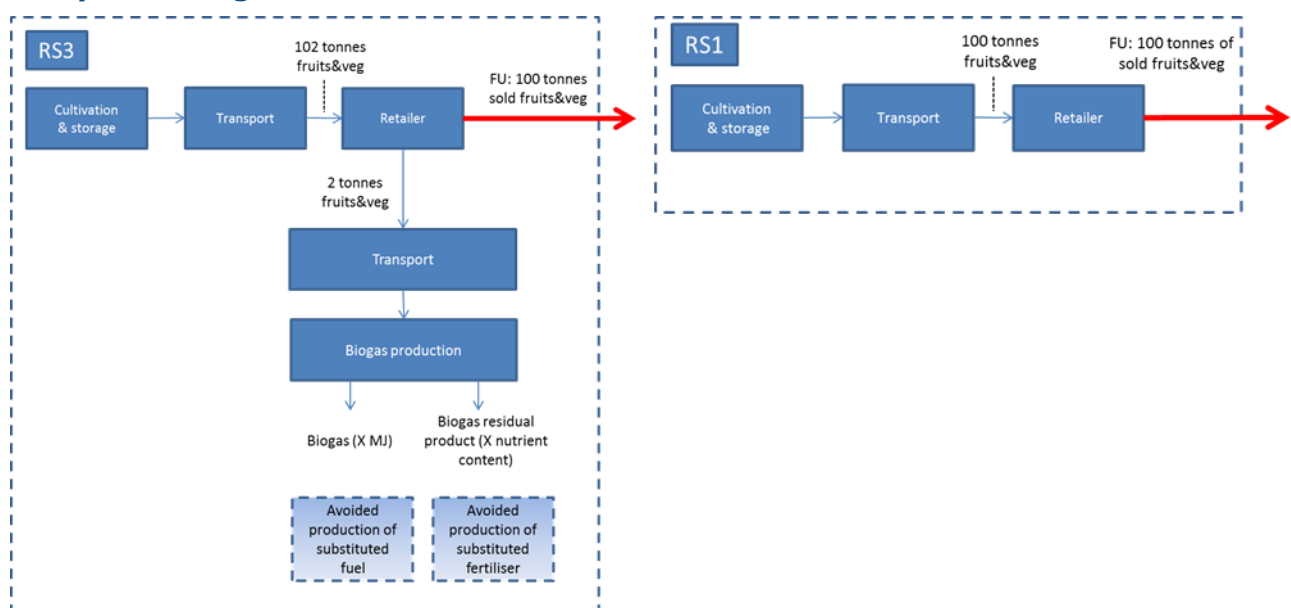
In the goal and scope stage of the study, all the aspects to be included in the goal and scope should be reported (see the list from ISO in section 4.1). However, for simplicity in this example the focus is on FU, SB, cut-off, and handling multi-functionality.

The study explores the effects of moving from RS 3 to RS 1. According to Table 9 the FU should then be the amount of the driving product, over a specified time period and scale. In our case this corresponds to: 100 tonnes of sold fruits and vegetables, over a time period of one year, in the time horizon 2017-2020. The reference flow is 100 tonnes of fruits and vegetables. The composition needs to be given also; what different fruits and vegetables are sold? For this example we assume that the composition is reflected in the composition of the side flow (assume the same). This needs to be taken into account when interpreting the result. The composition is 20% bananas, 20% apples, 20% lettuce, 20% cucumbers and 20% tomatoes on weight basis.

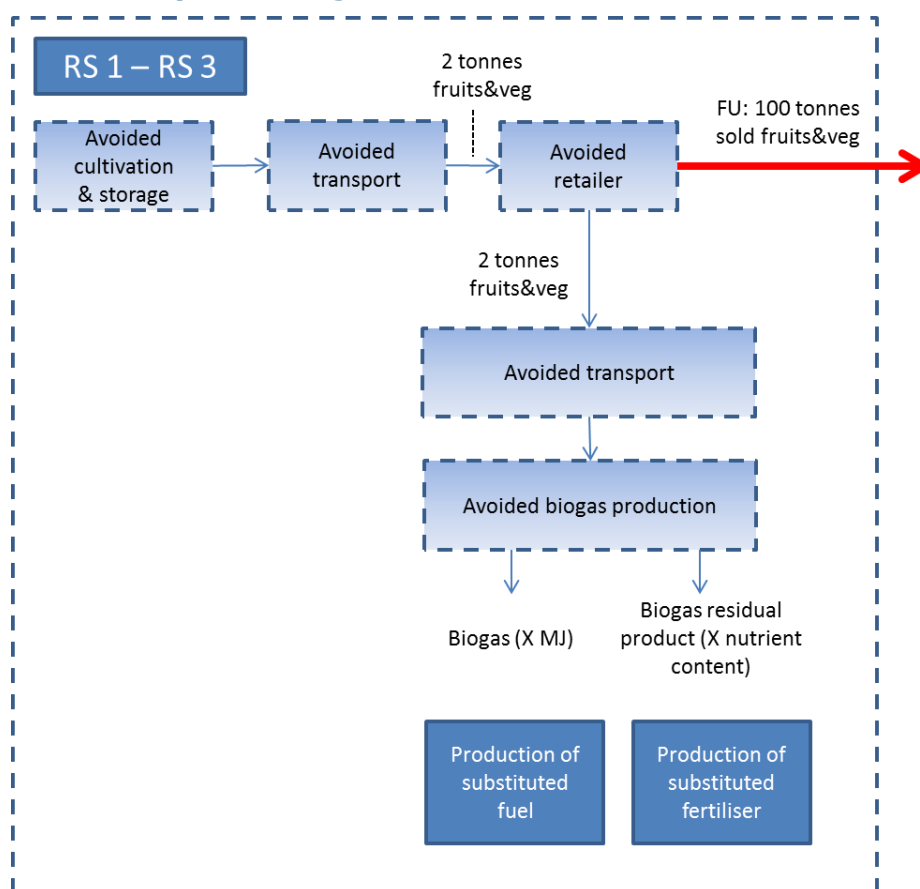
Regarding system boundaries, since one of the scenarios include RS 1, the upstream processes need to be included in the system boundaries. The resulting system is shown in Figure 13 and Figure 14. In the figures, dark blue coloured boxes denote impact, whereas light blue denotes avoided impact (i.e. negative numbers).

The actions taken to avoid the side flow from the retailer might induce more side flows in the process steps upstream (e.g. less fruits and vegetables are purchased from supplier, which might lead to greater wastage at the supplier), this is something that needs to be considered in the study. Will the actions actually lead to a reduced side flow, and not just transfer the flow to previous steps in the chain?

**Figure 13: Process flow diagrams for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 1**



**Figure 14: Resulting process flow diagram for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 1**



System boundaries in the E-LCC are coherent with LCA in terms of life cycle stages considered. Production of inputs for processes (e.g. fuels and chemicals) should be considered through market prices. Costs for cultivation and transport stages can be assessed through market prices of purchased food/service (to both estimate value added and reduction in income for previous stages) or in more detail: the first option is viable if only retailer's costs are changing; the second is mandatory if internal costs for suppliers are changing (e.g. a different purchasing routine may require suppliers to reduce substandard products). Retail costs must be fully inventoried. Downward processes related to biogas can be included in full detail (e.g. inventorying costs related to this stage) or just considering market prices of collection and disposal service. Avoided impacts can be considered either through revenues from electricity and digestate or through market price of identified substituted products.

### Cut-off

In the LCA, processes excluded are: production of seeds and seedlings, transport of personnel, transport of fertilisers, production of equipment, buildings and vehicles, since these processes are expected to have minor environmental impact. This needs to be taken into account when drawing conclusions from the results.

In the E-LCC, since worker training are modified by the intervention and a new planning software is purchased, cut-off should be able to include also costs not directly related to specific LCA flows. Thus we suggest option C (include processes such as software, marketing, trainings that are not included in the LCA inventory but are relevant for costs).

Handling multi-functionality

The system delivers, besides the functional unit of 100 tonnes of fruits and vegetables, also biogas and biogas residuals. These products are expected to replace products on the market with the same functionality. Hence, the biogas replaces natural gas production based on energy content. The biogas residuals replace mineral fertiliser production based on content of nitrogen (N), phosphorous (P) and potassium (K). The decision tree in Figure 8 is used to determine which avoided production should be considered in the LCA. Since the scale of this side flow is quite small, it is not expected to affect any markets, i.e. not the fuel market (biogas product), nor the fertiliser market (nutrient residue from biogas production). Average European data are used for production of the replaced products.

Regarding the avoided production of fruits and vegetables, the volume that is reduced is not expected to influence the fruits and vegetable market. Hence, average market mix data can be used to model the impacts.

Substituted fuel and fertilizer due to biogas production, as well as cost of production of fruits and vegetables, should be considered also in the E-LCC assessment as avoided costs.

Step 6: LCI data

For refrigerated storage at the retailer and production of biogas, primary inventory data are used. For replaced production of fuel and fertiliser, as well as transport and energy production impacts secondary data are used. Table 10 gives examples of inventory data for the LCA.

Cost categories

Guidance in 4.4 should be followed to identify relevant cost categories. Considering the purpose of the study type of costs, life cycle stages, and specific cost items should be needed in the cost model. Table 11 shows an example of cost inventory, including life cycle stages, cost items, and type of cost, based on RS3. It is not meant to be a complete inventory but just to provide a basic idea of what items may be considered, how they may be included, and under what categories.

Table 10: Examples of inventory data for LCA

| Process stage | Inventory data |
|---------------|----------------|
|---------------|----------------|

|   |   |
|---|---|
|   | Input of fertiliser                                   |
| Cultivation of bananas (also for the other fruits and vegetables) | Input of diesel                                       |
|   | Input of pesticides                                   |
|   | Leakage of nutrients (N,P)                            |
|   | Field emissions (N <sub>2</sub> O)                    |
| Transport to retailer   | Transport distances per mode of transport             |
| Retailer  | Input of energy for cooling                           |
| Food waste transport  | Transport distances per mode of transport             |
| Biogas production   | Input of energy for processing                        |
| Avoided production of natural gas                                 | Input of material and energy for fuel production      |
| Avoided production of NPK fertiliser                              | Material and energy for mineral fertiliser production |

**Table 11: Example of cost inventory**

| Life cycle stage        | Cost item                     | Amount   | Unit                       | Type of cost          |
|-------------------------|-------------------------------|----------|----------------------------|-----------------------|
| Cultivation and storage | Fertilizer                    | 35000    | €/tonne/FU                 | Internal cost         |
|                         | Labour                        | 25000    | €/man hours/FU             | Internal cost         |
|                         | Tractor                       | 1000     | €/tonne hours/FU           | Internal cost         |
|                         | Fuel                          | 30000    | €/MJ/FU                    | Internal cost         |
|                         | Land                          | 6000     | €/ha/FU                    | Internal cost         |
|                         | Food sale                     | -102000  | €/tonne/FU                 | Revenue               |
| Food Transport          | Food transported              | 10200    | €/tonne*km/FU              | Market price          |
| Retail                  | Refrigerator                  | 5000     | €/tonne/FU                 | Internal cost         |
|                         | Labour                        | 3000     | €/man hours/FU             | Internal cost         |
|                         | Training                      | 700      | €/man hours/FU             | Internal cost         |
|                         | Overheads                     | 500      | €/turnover share/FU        | Internal cost         |
|                         | Electricity                   | 2000     | €/kWh/FU                   | Internal cost         |
|                         | Software                      | 300      | €/turnover share/FU        | Internal cost         |
|                         | Waste disposal                | 7000     | €/m <sup>2</sup> /FU       | Internal cost         |
|                         | Food waste carbon tax         | 1500     | €/kg CO <sub>2</sub> eq/FU | External cost         |
|                         | Food sale                     | - 150000 | €/FU                       | Revenue               |
| Food waste transport    | Service cost                  | 10       | €/tonne/FU                 | Market price          |
| Biogas production       | Treatment cost                | 100      | €/tonne/FU                 | Market price          |
|                         | Avoided production fuel       | -200     | €/MJ/FU                    | External avoided cost |
|                         | Avoided production fertilizer | -20      | €/tonne/FU                 | External avoided cost |

### Indirect costs allocation

Since the retailer, and possibly also the transport company, is dealing with other products than fruits and vegetables, and cut-off option C is used, then some allocation of indirect costs is needed when they cannot be entirely attributed to the FU. For example, an increase in overheads may arise from the intervention



but these costs need to be attributed to the FU. It is suggested to use a specific factor, such as share of sales/turnover of FU over total.

### Discounting

Discounting can be disregarded, since costs from proposed intervention are likely related to a short time horizon. Normal depreciation can be applied to long term investment costs (e.g. orchards for fruits or biogas plant life time) if upward (cultivation) and downward (biogas production) processes are fully inventoried.

### Externalities

The retailer is expecting the introduction of a "food waste carbon tax". Therefore, in order to properly assess costs and benefits for the future situation, the external cost of embedded CO<sub>2</sub>eq emissions in wasted food must be included. This cost can be included in the inventory (as a separate cost item and typology) and in impact assessment.

### Cost bearers

Relevant actors in the supply chain are:

- Agricultural producers;
- Transport company;
- Retailer;
- Municipal waste management company.

In the starting situation, the retailer is purchasing food and paying for its transport at market prices, thus bearing those costs. Municipal waste management company is bearing all costs and benefits related to food waste disposal.

**Table 12: Example of cost distribution among cost bearers (numbers are not from a real case; revenues are not considered here)**

| Cost bearer             | Amount | Unit |
|-------------------------|--------|------|
| Agricultural producer   | 97000  | €/FU |
| Retailer                | 30200  | €/FU |
| Municipal waste company | 110    | €/FU |

In the future situation, agricultural producers and the transport company are potentially affected by a reduction of revenues, while the municipal waste management company is not anymore a cost bearer of the system.

### Step 7: LCIA

Following the recommendations in Table 3, the following impacts are calculated: GWP, water depletion, depletion of fossil resources, terrestrial and aquatic

eutrophication, acidification and land transformation. In the E-LCC, since the focus is on cost for retailer and other parties, it is recommended to assess costs, and their changes, for the different cost bearers (cost distribution), according to categories and details included. Focus could be on total costs but also NPV could be estimated. If revenues are available (for one or several actors) it is possible to calculate change in profits and value added.

Portfolio of total results and contributions of life cycle stages/cost bearers is presented. A plot graph can also be used to show percentage changes of moving from RS 3 to RS 1 for different indicators, e.g. GWP and total costs, see an example of this in Figure 10. Should the assessor weight and sum LCA and E-LCC scores, it is important to avoid double counting of externalities (see "food waste carbon tax").

## 7.2 Example case: Moving from RS 3 to RS 2

In this example there is a caterer who wants to evaluate environmental impacts and costs of selling catering left overs to a pig feed producer, following a policy change that lifted the related ban. Currently, catering waste was not allowed as feedstock for pig feed production. However, in this example, this ban is assumed to be lifted with the specification that left overs must be treated with heat.

At the end of the example a paragraph shows what changes would be needed in case a policy-maker were conducting the assessment (to explore effects of a change on a big scale).

A caterer is currently sending 1 tonne of catering waste to the municipal biogas facility every year, which generates biogas and some residuals. The caterer pays a fee for catering waste collection. However he would prefer having this waste bought and collected by a feed producer. But the question is: what will be the environmental impact of this change be? The caterer is mainly interested in the effect on climate emissions. And what will be the potential profit for the caterer and other affected parties?

### How to follow the recommended steps?

Here, the aim is to follow the recommended steps in chapter 5 for the example case study.

#### **Step 1: Phrase the question of the study, identify the audience for the result**

What are the profits (and costs) for actors in the chain, as well as the main environmental consequences of upgrading catering waste presently sent to municipal waste handling into animal feed, by selling it to a feed producer? The result will be input to the caterer in his decision whether to make this change or not (probably along with other factors) and how much to charge the feed producer.

#### **Step 2: Establish which REFRESH situation**

Use of decision tree in Figure 2, to establish the corresponding RS for the starting situation and the possible future situation is described below.

##### Starting situation:

Is 'the more, the better' valid for the catering waste? No, then it is a side flow and a REFRESH situation applies. Which one?

Is the assessment about prevention/reduction of (upstream) material resources to produce a driving product? No, move on to next question.

Is the output flow product of value but not a driving product for the FSC, and does the output flow generator gain value from it? No, the caterer just wants to get rid of the catering left overs, and pays a fee for it to be collected; move on to next question.

Disposal/getting rid of the output flow is the driving force but some value can be extracted that replaces a marketable product? The generator of the output flow does not gain any value from valorisation. Yes, this corresponds to our case, which means it is **RS 3**.

#### Possible future situation:

Is the assessment about prevention/reduction of (upstream) material resources to produce a driving product? No, move on to next question.

Is the output flow product of value but not a driving product for the FSC, and does the output flow generator gain value from it? Yes, feed production from catering waste is a valuable product, but not a driving one for the FSC. Furthermore, the caterer would sell it gaining value out of the side flow. This means this situation is a **RS 2**.

***Conclusion: the study will assess the effect of moving from RS 3 to RS 2.***

#### **Step 3: Footprint or intervention study?**

Is the study a footprint or intervention study? Use of decision tree in Figure 3 is described below.

Is any decision to be taken from the LCA result? Yes, the caterer would like to use the results from the study as input, along with other factors, for taking the decision and assessing the potential price of the side flow. **This means it is an intervention study.**

Are there any large scale consequences on some of the processes in the background system? The scale of the flow is 1 tonnes per year, which is not expected to influence the operation of the biogas facility (in RS 3) and of the feed producer (in RS 2) in any major way, so the answer is no. This means that in the modelling **system expansion is privileged** when accounting for 'additional' functions from the system, and **average market data can be used for processes in the background system.**

#### **Step 4: E-LCC appropriate?**

If the answer is 'no', the costing dimension can be assessed separately. If only costs are assessed, in particular internal costs the assessor have to pay, then a Conventional LCC (C-LCC) is suggested. This approach is rather established and mainly focuses on investment, operating, and maintenance costs emerging during the life span of a product. Disposal costs are included only as long as they are sustained by the assessor. Thus, C-LCC is not usually carried out in integration with LCA, but it could be used when system boundaries are cradle to gate and only one actor is covering for all costs. Considering the objective of REFRESH Task 5.1.3 of developing a system approach for integrating LCA and LCC in the evaluation of food waste streams, C-LCC is not within the scope of the report. The reader can refer to De Menna et al. (2016) for further information and sources.

If the answer to Q1 is 'yes', then environmental and costing dimensions are part of the same assessment, adopting different approaches according to the stakeholders included and the type of integration with LCA (see Q2). The assessor should decide whether to include costs for all the stakeholders that may be affected by the analysed system also through externalities, including society, governments, etc. In such perspective, a Societal LCC (S-LCC) approach should be adopted. In S-LCC, costs affecting every stakeholder, both directly and indirectly through externalities (e.g. environmental impacts), are assessed. In fact, as argued by Martinez-Sanchez et al. (2016), an S-LCC encompasses all externalities that can be monetised. Therefore, the integration with a complementary LCA support the S-LCC in identifying and quantifying relevant externalities to be then monetised. A standard approach for the monetisation of externalities is currently still under development (ISO 14008). In general, further research is needed to identify methodologies for the evaluation of several emissions in an S-LCC context. Therefore, S-LCC is thus not included in the scope of the report.

Figure 9 is used to establish whether E-LCC is appropriate to use in the study.

Does the aim include the integrated assessment of environmental and cost? Yes, then the next question is: does the study aim at including external costs for all stakeholders? No, stakeholders indirectly affected through externalities will not be taken into account. In this case the caterer, the biogas operator, and the feed producer will be considered. But no other actors external to this chain will be included. This means **an E-LCC is appropriate** for the assessment and the guidance in this report can be used.

### **Step 5: FU, SB, cut-off and handling multi-functionality**

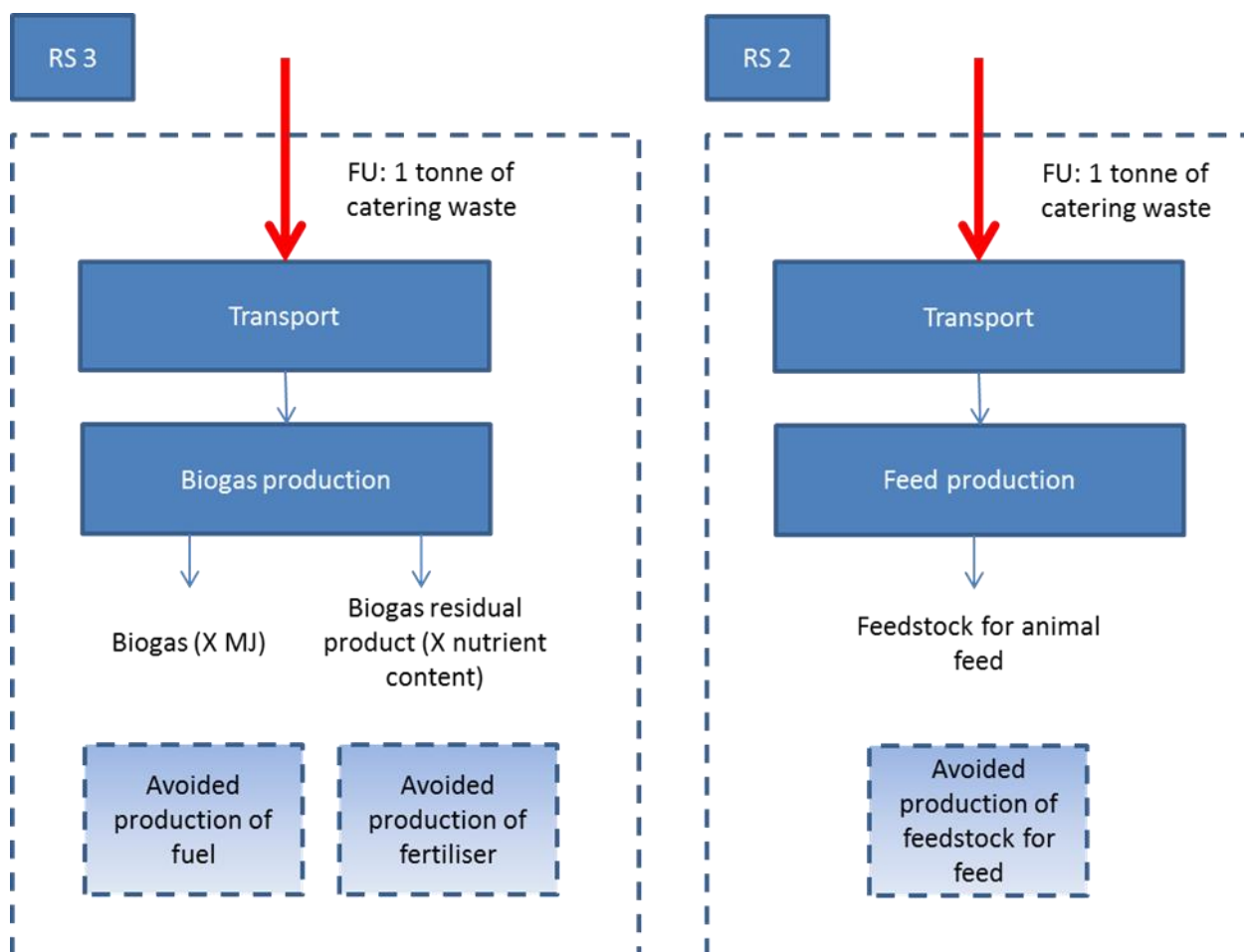
Here, all the aspects to be included in the goal and scope should be reported (see the list from ISO in section). However, for simplicity in this example the focus is one FU, SB, cut-off, and handling multi-functionality.

The recommendation in Table 9 states that the FU should be the amount of side flow utilized, over specified time period and scale, and specified time horizon. In this case, this corresponds to: 1 tonne of catering left-overs, over a time period of one year, in the time horizon 2016-2020. The reference flow is 1 tonne of catering left overs. The composition needs to be given too. For this example it is assumed that the composition is the same as the driving product (catered food). Composition is rather relevant to determine the eventual rate of substitution of replaced products, depending on the specifications for pig food (e.g. calories, protein content, fat, etc.). Therefore, this must be taken into account also when interpreting the result, possibly carrying out a sensitivity analysis on composition parameters.

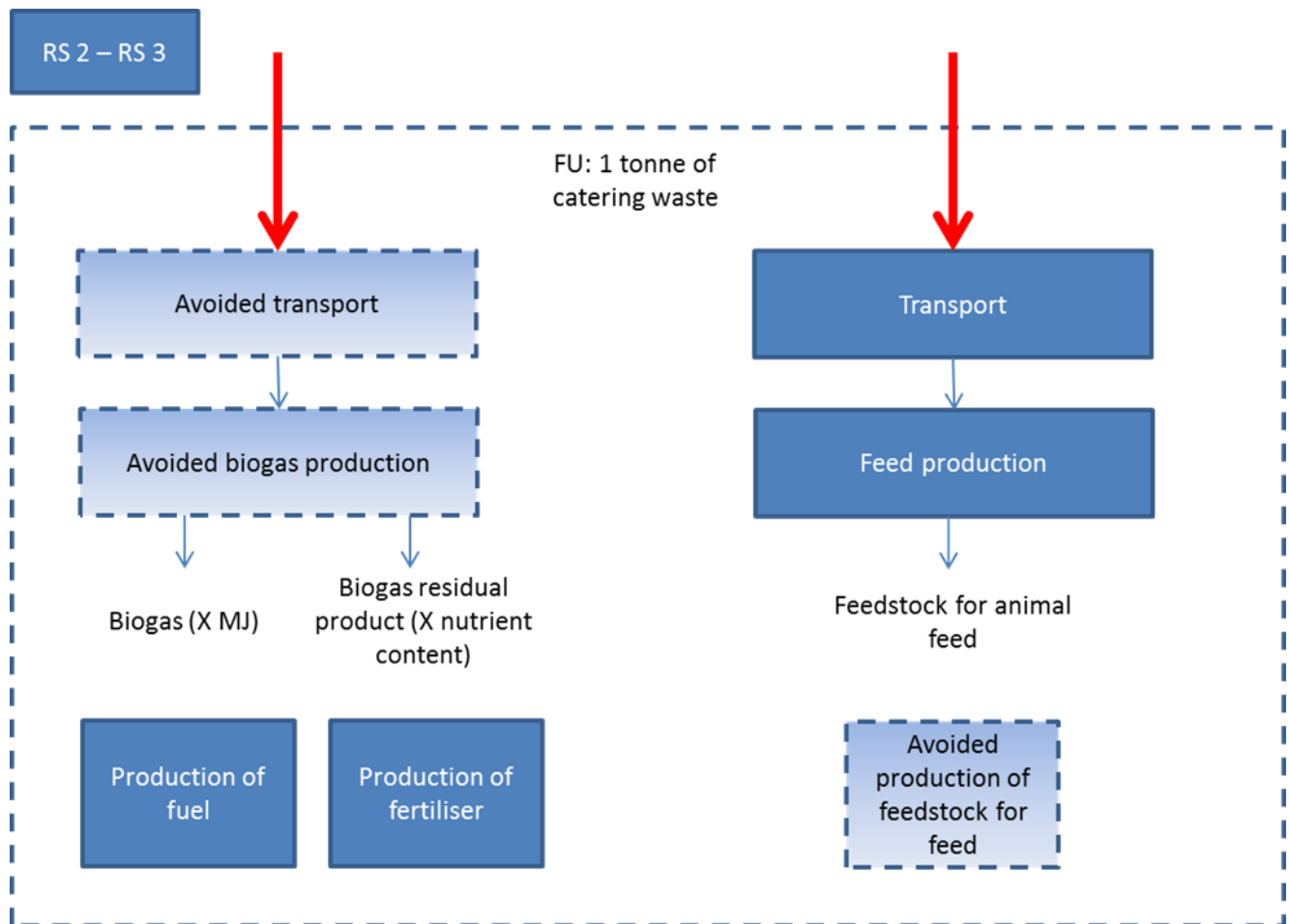
Regarding system boundaries, since no scenario includes RS 1, the upstream processes can be excluded from the system boundaries. The resulting system is shown in Figure 15 and Figure 16.

In the figures, dark blue coloured boxes denote impact, whereas light blue denotes avoided impact (i.e. negative numbers).

**Figure 15: Process flow diagrams for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 2**



**Figure 16: Resulting process flow diagram for LCA and E-LCC, example of intervention study of moving from RS 3 to RS 2**



Processes taken into account in the LCA are: production and combustion of fuel for transport, production of electricity and heat for heat treatment and biogas production, as well as production of energy and auxiliary material for replaced production of fuel, fertiliser and feed.

System boundaries in the E-LCC are coherent with LCA in terms of life cycle stages considered. Production of inputs for processes (e.g. fuels and chemicals) should be considered through market prices. Costs for the caterer should be excluded (out of system boundaries) in the starting situation, while his benefit can be included in the system expansion in the end situation. Costs for collection, transport and biogas production should be assessed fully in the starting situation, as costs for catering waste transformation into feedstock for animal feed in the end situation.

### **Cut-off**

In the LCA, processes not taken into account are travel of personnel, production of buildings and equipment, since these processes are expected to have minor environmental impact. This needs to be taken into account when drawing conclusions from the results.

In the E-LCC, we suggest option B, thus referring on the same processes included in LCA and considering all costs related to LCA inventory flows, both material (e.g. energy and inputs), labour (e.g. working hours), and capital costs.

### Handling multi-functionality

The system delivers, besides the function of taking care of 100 tonnes of catering waste, also biogas, biogas residuals and feed. These products are expected to replace products on the market with the same functionality. Hence, the biogas replaces natural gas production based on energy content. The biogas residuals replace mineral fertiliser production based on content of nitrogen (N), phosphorous (P) and potassium (K). The feed that is replaced is assumed to be average pig feed bought on the European market based on the content of energy, protein and fat. The decision tree in Figure 8 is used to determine which avoided production should be considered in the LCA. Since the scale of this side flow is quite small, it is not expected to affect any markets, i.e. not the fuel market, nor the fertiliser or feed market. Average European data are used for production of the replaced products.

Substituted fuel and fertilizer in RS 3 and substituted feed in RS 2 should be considered also in the E-LCC assessment as avoided costs (revenues for respectively biogas producer and feed producer). In RS2, average market price of feed can be used to determine what would be the potential competitive sale price of left over feed, and the eventual profits for the feed producer.

### Step 6: LCI

For production of biogas and heat treatment of food, primary inventory data are used. For replaced production of fuel and fertiliser, as well as transport impacts secondary data are used. Table 13 gives an example of inventory data focused on GWP.

**Table 13: Example of inventory data for LCA**

| Processes                   | Inventory data                            |
|-----------------------------|---|
| Transport to heat treatment | Transport distances per mode of transport |
| Transport to biogas plant   | Transport distances per mode of transport |
| Heat treatment              | Energy for heat treatment                 |
| Biogas production           | Energy for processing                     |
| Avoided production of fuel  | Material and energy for fuel production   |
| Avoided production of NPK   | Material and energy for fertiliser        |



|                                |   |
|--------------------------------|---|
| fertiliser                     | production, emissions of CO2 and N2O  |
| Avoided production of pig feed | Material and energy for feed production; emissions, emissions of CO2, CH4 and N2O |

## Cost categories

Guidance in 4.4 should be followed to identify relevant cost categories. Considering the purpose of the study, types of costs, life cycle stages, and specific cost items are needed in the cost model. Table 14 shows an example of cost inventory for RS 2.

**Table 14: Example of cost inventory (numbers are not from a real case; revenues are show only for value added calculation)**

| Life cycle stage              | Cost item                   | Amount | Unit           | Type of cost  |
|-------------------------------|-----------------------------|--------|----------------|---|
| Catering left overs transport | Service cost                | 5      | €/tonne*km/FU  | Market price  |
|                               | Catering left over purchase | 30     | €/tonne/FU     | Internal cost for treatment facility<br>External revenue for catering |
| Heat treatment                | Labour                      | 60     | €/man hours/FU | Internal cost   |
|                               | Facility                    | 20     | €/tonnes/FU    | Internal cost   |
|                               | Electricity                 | 100    | €/kWh/FU       | Internal cost   |
|                               | Feed sale                   | -300   | €/tonne/FU     | Avoided cost (revenue)  |

## Indirect costs allocation

Since most actors are dealing with other products than catering waste and cut-off option B is used, some allocation of indirect costs could be needed depending on the accounting method used by involved companies. A specific rate is

recommended, such as share of sales/turnover or share of weight of FU over total.

### **Discounting**

Discounting can be applied, since costs from proposed intervention could occur also in a relatively distant future (e.g. future maintenance/disposal of life span of heat treatment facility). If applied, discounting should be the same in both the starting and the end situation. Otherwise, normal depreciation can be considered.

### **Externalities**

No relevant external costs can be anticipated to be internalized. External economic effect for the caterer can be included in system expansion (e.g. avoided disposal tax and revenue from catering left over sale).

### **Cost bearers**

Relevant actors in the supply chain are:

- Transport company (if any);
- Municipal biogas producer;
- Feed producer;
- Caterer.

In the starting situation, the municipal biogas producer is the relevant cost bearer and the caterer can be included for the disposal tax. In the future situation, the feed producer substitute the municipal biogas producers.

### **Step 7: LCIA**

The focus is on GWP, so only this impact is calculated. In the E-LCC, since the focus is on cost and profits for caterer, feed producers and other parties, it is recommended to assess at least costs for all different cost bearers (cost distribution), according to categories and details included. NPV could be estimated for feed producer. Value added up to catering waste upgrading can be estimated.

Portfolio of total results and contributions of life cycle stages/cost bearers is suggested. A plot graph can be used to show percentage changes of moving from RS3 to RS2 for GWP and different economic indicators.

### **Policy-makers perspective**

This example of assessment could be useful also to a policy-maker which aims at exploring consequences of lifting the ban on catering waste. While a caterer would be more interested in microeconomic consequences, a policy-maker would focus on a meso- or macro-level, thus requiring a change of scale in the FU and some adjustment in the methodology. These changes are provided here below:

- E-LCC appropriate?  
In theory, a policy-maker, especially at a macro-level, could be more interested in a Societal LCC, since also external costs for whole society

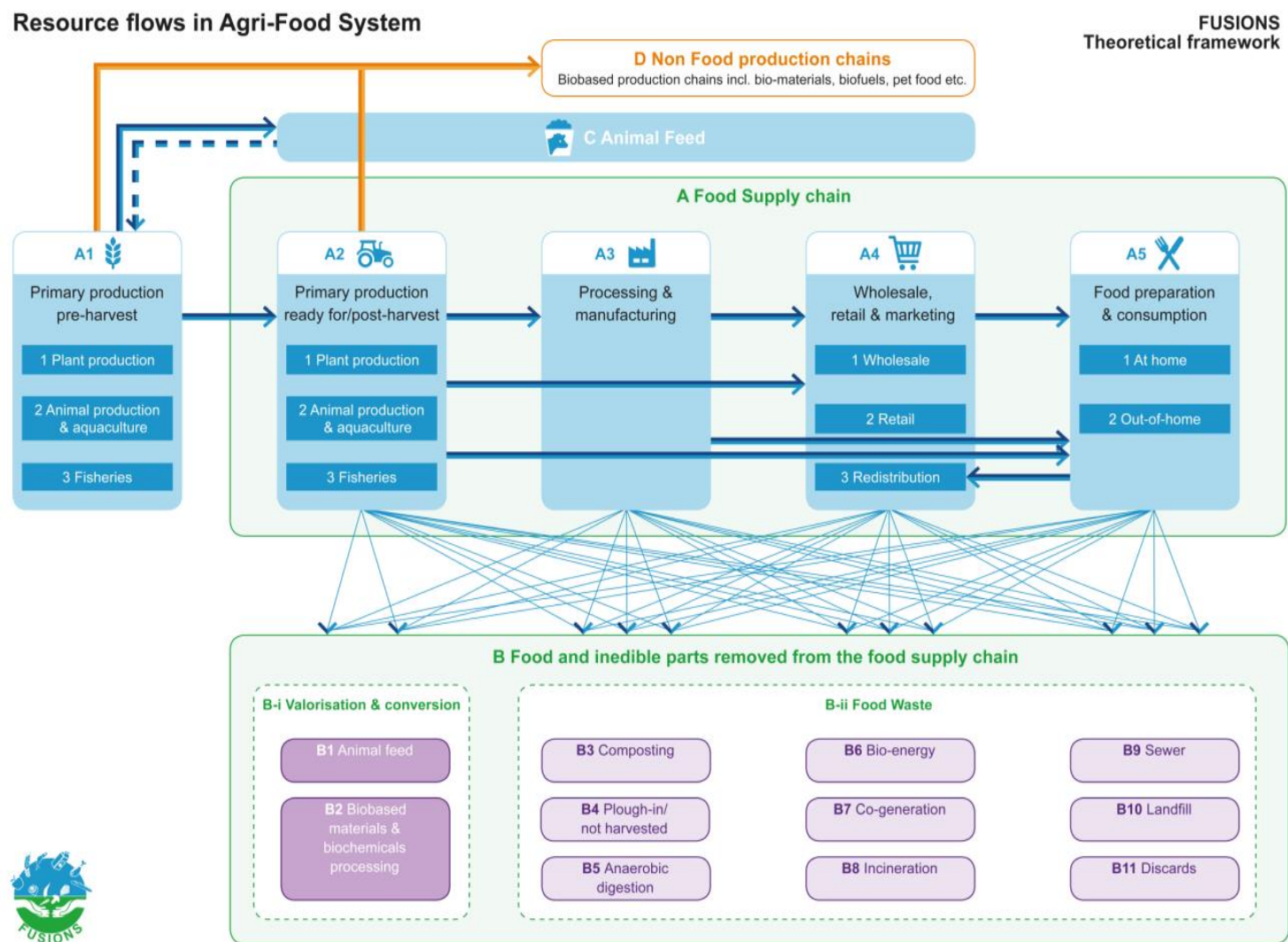
would be included. However, if the policy-maker wants to assess only internal costs for actors in the supply chain, then an E-LCC combined with a LCA can still apply.

- Goal and scope
  - FU, SB and process flow diagram  
The amount of side flow utilized should be adjusted to reflect the proper scale, likely corresponding to a relatively large amount generated in a specific time frame (e.g. one or more years) in a certain geographical area (from municipal to supranational level). Likewise, the composition would probably be very different reflecting the average of several firms, rather than a specific one. As for system boundaries, average cost figures should be used, possibly with some detail for each life cycle stage.
  - Cut-off  
In the E-LCC, cut-off option C should be preferred in this case, (including processes that are not in the LCA inventory but are financially relevant e.g. R&D, marketing, etc.).
  - Handling multi-functionality  
Considering the scale, some effects on market will probably take place, thus changing the substitute products (follow figure 8).
- LCI
  - LCI data  
Considering the scale, some effects on market will probably take place, thus marginal data should be used to model processes that are affected. If the market is stable or increasing for feed, fuel and fertiliser respectively the most competitive processes should be used, and if the market is decreasing then the least competitive processes should be used (see Figure 8).
  - Externalities  
External economic effect must be considered for both the caterer and agricultural producers of substituted feedstock.
- LCIA
  - For the LCA GWP is calculated. In the E-LCC, value added is required to measure the economic effect of the intervention. Estimation can be derived subtracting revenues from sales of feed and purchases of products or materials by firms. Depending on the scale, effects on markets of substitute product should be taken into account as an avoided value added.

## 8 Annex B: Definition of food supply chain

In FUSIONS food waste is considered to be the flows that enter the box B-ii in Figure 17. In this report we use a broader definition and include all flows from the FSC that the stakeholder generate and for which there is a desire to minimize and they are referred to as side flows from the food supply chain. These side flows are part of the flows entering box B in Figure 17 and is independent of destination (Box B-i and Box B-ii).

**Figure 17: Definition of food supply chain from FUSIONS (2014)**



## 9 Annex C: Comparison between CLCA and ALCA

**Table 15: Comparison between consequential and attributional LCA (Guiton et al., 2013)**

|  | Consequential LCA   | Attributional LCA  |
|--|---|--|
| Objective  | Assess the environmental consequences of a change implemented in a system (product, service, socio-economic system) over a time period and at a given time horizon  | Assessment of the environmental performances of a system (product, service, socio-economic system) at a given time horizon under status-quo conditions (no changes considered) |
| Goal   | Support decision making, environmental communication (not yet fully operational), benchmarking  | Reporting, benchmarking, environmental communication (labelling)   |
| Functional Unit  | Actual magnitude of the change (ex. additional 500'000 electric vehicles), over a time period (e.g. 10 years) and at a given time horizon (e.g. 2010-2020).   | Virtual reference unit (e.g. 1 electric vehicle) at a given time horizon (e.g. 2020).  |
| Relationship between the functional unit and the inventory results | Not linearly dependent: if the FU is multiplied by 10, the inventory results are not necessarily tenfold.   | Linear dependence: if the FU is multiplied by 10, the inventory results are always tenfold.  |
| Scope  | Include all the processes affected by the change, even if they are not directly or indirectly required (solicited) by the FU, i.e. are linked to the studied system (product, service, socio-economic system) by a technological cause-effect chain. The processes not affected by the change, even if they are solicited by the FU, are not included | Include all the processes linked to the studied system (product, service, socio-economic system) by a technological cause-effect chain.  |
| Identification of the inventory data (datasets)                    | Simplified approach (Weidema et al. 2009), economic equilibrium models, complex systems   | Based on the product composition, the process flow-sheeting and the chain of suppliers, users,   |

|  |  |   |
|--|--|---|
|  | models (e.g. agent-based)  | and end-of-life processes.  |
| Inventory data sources (datasets)  | The datasets reflect technological and market interactions between the inventory processes following the change, i.e. are marginal data (eventually average marginal data)   | The datasets reflect the average technological interactions between the inventory processes. These are average data at a given time horizon |
| Management of multifunctional processes (which cannot be solved by partitioning) | System expansion / substitution (Allocation methods not to be used)  | Allocation methods<br>Avoided impact approach   |
| Type of LCA impact assessment methods to be used                                 | All  | All   |
| Comparability between LCA studies  | Not strictly mandatory as the C-LCA study is dependent on the socio-economic context and modelling approach adopted. Prospective scenarios for a same study should be comparable as they are considering the same socio-economic context. However, two independent studies carried out to address the same question are probably not comparable. | Mandatory   |
| Reliability of results (uncertainty, sensitivity)                                | Uncertainty and sensitivity analysis   | Uncertainty and sensitivity analysis  |