Methodology for evaluating LCC

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Glossary

The definitions of the terms in the glossary have been taken from: A) ISO standard for life cycle assessment (ISO 2006); B) Hunkeler et al. (2008); C) PEF guide (EC 2013); D) Ciroth et al. (2011).

Allocation[A]	The partitioning of input or output flows of a process or a product system between the product system under study and one or more other product systems.
Co-product[A]	Any of two or more products coming from the same unit process or product system.
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.
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.
Cradle to gate[C]	A partial product supply chain, from the extraction of raw materials (Cradle) up to the manufacturer's "gate". The distribution, storage, use stage and end of life stages of the supply chain are omitted.
Cradle to grave[C]	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.
Cut-off (criteria)[A]	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.
Discounting[B]	Converting future costs (and revenues or value) to equivalent (net) costs at a common point in time (e.g. present year).
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.
Environmental impact[C]	Any change to the environment, whether adverse of beneficial, that wholly or partially results from an organisation's activities, products or services (EMAS regulation)
Environmental Life Cycle	An assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the

Costing[B]	actors in the product life cycle (e.g., supplier, manufacturer, user or consumer, or end of life actor) with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future. Environmental LCC has to be accompanied by a life cycle assessment and is a consistent pillar of sustainability.
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
Functional unit[A]	Quantified performance of a product system for use as a reference unit (comment: in the PEF guide the term "unit of analysis" is used)
Life cycle[A]	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal
Life cycle assessment[A]	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle
Life cycle impact assessment[A]	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
Life Cycle Sustainability Assessment[D]	It evaluates environmental, social and economic impacts and benefits in a life cycle perspective. It integrates LCA with LCC and S-LCA (Social Life Cycle Assessment)
Process[A]	Set of interrelated or interacting activities that transforms inputs into outputs
Product[A]	Any goods or service
Product system[A]	A collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.
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[C] Definition of aspects included or excluded from the study. For example, for a "cradle to grave" 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. It may be graphically represented through a system boundary diagram.

Transfer (payments)[B] 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[B] 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.

List of abbreviations

ASTM American Society for Testing and Materials International

C-LCC Conventional Life Cycle Costing

E-LCC Environmental Life Cycle Costing

EP&L Environmental Profit and Loss

EVA Economic Value Added

FAO Food and Agriculture Organization of the United Nations

FLW Food Losses and Waste

FU Functional Unit

FUSIONS Food Use for Social Innovation by Optimising Waste Prevention Strategies

GDP Gross Domestic Product

GHG Greenhouse gas emissions

GWP Global Warming Potential

HACCP Hazard Analysis and Critical Control Points

IRR	Internal Rate of Return
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCSA	Life Cycle Sustainability Assessment
NGO	Non-Governmental Organization
NPV	Net Present Value
OECD	Organization for Economic Cooperation and Development
PERT	Program Evaluation and Review Technique
REFRESH	Resource Efficient Food and dRink for the Entire Supply cHain
S-LCC	Societal Life Cycle Costing
SETAC	Society of Environmental Toxicology and Chemistry
UCO	Used Cooking Oil

1 Executive summary

This report reviews measures and methodologies for the evaluation of the life cycle cost dimension of food waste. It aims at contributing to REFRESH sub-task 5.1.3 that will provide recommendations for the development of a standardized system approach for integrating the life cycle cost and the environmental dimension of different measures regarding food waste (prevention, valorisation and waste management options). To analyse the major methodological challenges, four REFRESH situations focusing on food waste have been defined and described: prevention at source, co-product valorisation, valorisation as part of waste management, and end of life treatment. The most relevant documents (books, standards, scientific papers, reports, and others) were reviewed to analyse:

Relevant definitions of Life Cycle Costing, with a focus on most recent approaches;

Cases of application on food systems and food waste prevention, disposal, management, valorisation;

Commonly used/recommended method for key aspects;

Areas of challenge/improvement.

The literature review showed that, amongst several costing approaches, the so called Environmental LCC allows the integration of costing techniques and LCA into a comprehensive assessment. Nevertheless, few examples of application of LCC to food waste were available, most of them focusing on management scenarios for (household) food waste. Only one study encompassed prevention measures. Some of these specific gaps and challenges should be addressed within REFRESH sub-task 5.1.3 and deliverable 5.3. In the specific, further guidance will be provided on:

Identification and characterization of appropriate functional units and system boundaries in accordance with LCA and coherent with the economic relevance of processes;

Specific cost modelling, including categories, cost perspectives and discounting rates;

Inclusion/exclusion criteria for food waste externalities, indirect effects, and trade-offs.

Thus will be carried out by:

Using REFRESH situations to elaborate on method choices;

Including practitioners in LCC scoping;

identifying a set of questions that should be asked when scoping an LCC

Providing food waste specific examples.

1 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.. To this end, a systemic approach has been deemed necessary to analyse potential food waste prevention, valorisation, and management routes, in terms both of environmental and economic impacts. Work Package 5 aims at providing the environmental and cost dimension of these valorisation routes and options by using life cycle assessment (LCA) and life cycle cost (LCC) methodologies. In this perspective the first tasks were to identify existing measures and methodologies and their application to food waste valorisation and management. Task 5.1.2 thus aimed at collecting and analysing the literature on life cycle costing with a focus on practical implementation on food waste, in order to provide input to REFRESH sub-task 5.1.3.

Life cycle costing is a rather consolidated methodology aimed at calculating the overall cost of a product or a service over its life span or life cycle. Despite being used for a long time by both decision-makers and businesses, LCC was standardized only with reference to specific product categories. Several approaches can be found in the literature, mainly differing in terms of perspective, costs included, and potential application. Conventional LCC (C-LCC) techniques are mainly applied in the framework of decisions over products or investments requiring high initial capital, such as buildings, energy systems, transport systems, military equipment, and durable goods in general, with the perspective of the producer or the consumer. Environmental Life Cycle Costing (E-LCC) was developed in order to be compatible with LCA and should assess costs occurred during the life cycle of products, services, and technologies, directly covered by one or more actors. Besides, other costing methodologies with a larger perspective aim at assessing also the overall direct and indirect costs covered by the society. This is the case of Societal Life Cycle Costing, Cost-Benefit Analysis and Full-Cost Accounting.

Despite a variety of applications, LCC was rarely used in the evaluation of food systems and food waste management or valorisation. Few studies, mainly from academic publications, assessed costs deriving from food waste with a life cycle perspective. Thus, the following report aims at presenting results from the literature review to a larger readership than academic and business LCC practitioner. Information were collected and analysed in order to derive basic recommendations and take outs that can be useful for relevant stakeholders dealing with food waste prevention, valorisation, and management.

The second chapter of the report presents the methodology of the systematic literature review, with a description of each step followed to identify sources, collect relevant information, analyse and discuss the main results. The third chapter discusses the more general aspects of the review, such as some historical background and a description of the different LCC approaches. The fourth presents the REFRESH situations: this section is the same as in D5.1. The fifth presents: an overview of LCC application to food systems and food waste management, disposal, or valorisation; a discussion of the specific aspects identified in the methodology of the review. Information of this chapter is based on the literature review. The final chapter summarizes results from the literature review and highlights the main take outs for next tasks of Work Package 5.

2 Methodology of the review

A systematic literature review was carried out to collect information on both theoretical and methodological aspects of the evaluation of food waste cost dimension. In order to ensure consistency between task 5.1.2 and task 5.1.1 as preparatory work for task 5.1.3, a similar methodology was followed, envisaging 5 steps:

i) Scope definition

Coherently with the general aim of the Work Package 5 and the specific objectives of the Task 5.1.2, the review aimed at identifying:

Relevant definitions of Life Cycle Costing, with a focus on most recent approaches;

Cases of application on food systems and food waste prevention, disposal, management, valorisation;

Commonly used/recommended method for key aspects;

Areas of challenge/improvement.

ii) Literature identification

Relevant documents were identified by searching scientific databases, internet search engines, and existing knowledge. The following keywords were used in the literature search: "LCC", "life cycle costing", "food waste". Additional documents were identified also during the review (e.g. because they were referenced to in a reviewed document) and added to the whole corpus. Collected documents were categorized according to the source typology:

Books from international publishers;

International standards and policy guidelines;

Papers published in academic journals with a focus on life cycle cost of food waste and valorisation;

Reports from International Organizations and past European projects;

Grey literature;

Business sustainability reporting tools.

Single sources were thus inventoried in a detailed overview that can be found in the Appendix (Table 11).

iii) Methodological aspects covered

Life Cycle Costing literature presents two key differences to Life Cycle Assessment: firstly, the application to food waste is a rather recent niche; secondly, there are no overarching standard but only product-specific guidelines. Therefore, publications were collected with reference to: LCC general approaches; LCC application to food systems; LCC application to waste and food waste management; food waste costing studies without a proper LCC methodology, but deemed relevant for the scope of the review. Apart from the general theme of the source (LCC, LCC food, LCC (food) waste) and the approach (conventional, environmental, societal, other costing methodologies), when performing the review, the following methodological aspects were covered:

Functional unit and system boundaries;

Cost categories, allocation and discounting;

Externalities: inclusion and methods for accounting;

Impact evaluation and sensitivity analysis;

Others.

These methodological aspects are developed in the section of the sixth chapter of this report. Starting from the identified topics, a review template form was built and used to collate information from each source. Completed templates can be found in the Appendix (**Table 12**).

iv) Analysis of information

Review templates allowed for cross reading of specific methodological aspects, e.g. if and how functional unit is used by different LCC approaches or studies. The different methodological aspects were analysed during the literature review in order to provide an overview and examples of application.

v) Recommendation and outlook

As last step, findings from the *analysis of information* were combined and inter-dependencies highlighted. Additional comments were provided in regard to what methodology aspects need to be further addressed in Task 5.1.3. According to the project plan the life cycle environmental and costing dimensions are only combined in task 5.3, however, it was important for the task members to seek close alignment and inter-disciplinary so to identify communalities and differences and provide some initial observations from this early interaction.

3 What is Life Cycle Costing

The idea of calculating the impact of products and services in terms of costs in a life span or life cycle perspective[1] is rather old. In the literature review, three main approaches were identified (see **Figure 1**). The so called **Conventional Life Cycle Costing** (C-LCC) techniques are rather well-established both in the

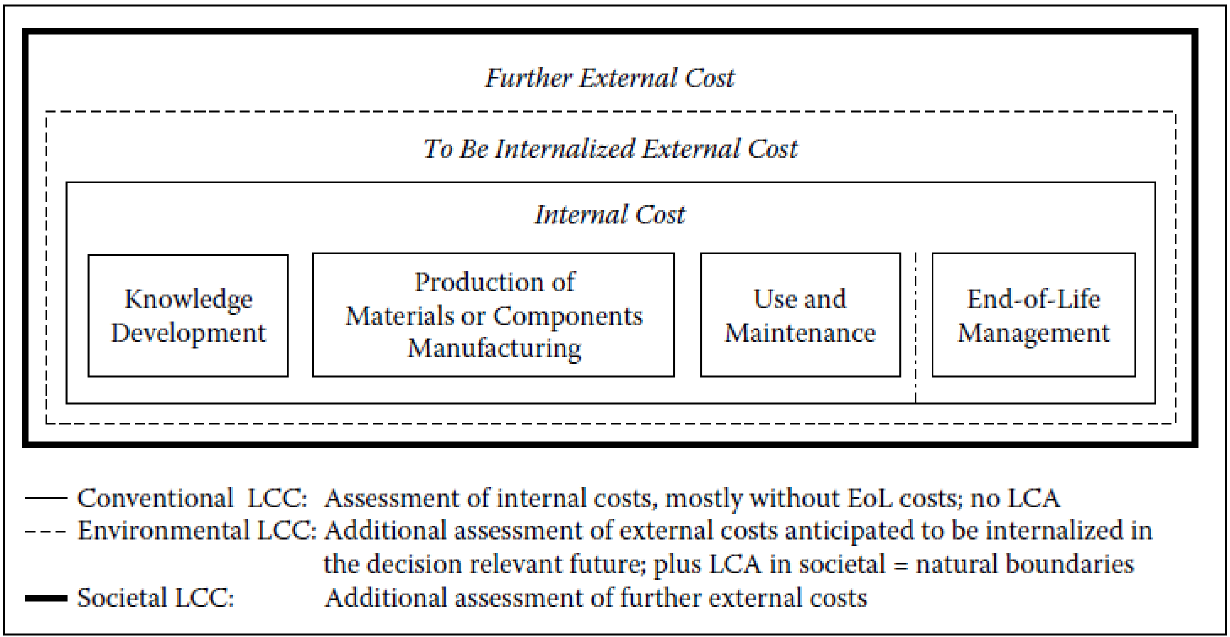
[1] The temporal (life span) and the product system (life cycle) costing perspectives may be overlapping or different depending on the actor(s) included in the analysis as cost bearers.

academic literature, in the public sector, and in business accounting. Already in the '30s the US General Accounting Office started to include operating and maintenance costs in public procurement. Later, in the 70s mandatory LCC was included in US public purchase of weapon systems and buildings, and in the same period several European countries started to use it (Hunkeler et al. 2008). Recently, the European Commission (DG enterprise and industry) commissioned a study on the potential contribution of LCC in the sustainable construction sector (Langdon 2007). Therefore, most of LCC techniques were applied in the framework of decisions over products or investments requiring high initial capital, such as buildings, energy systems, transport systems, military equipment, and durable goods in general.

In order to couple LCA with socio-economic impact assessments, a specific SETAC (Society of Environmental Toxicology and Chemistry) working group elaborated a new approach compatible with LCA, the **Environmental Life Cycle Costing** (E-LCC) (Hunkeler et al. 2008). According to their proposal, an E-LCC should assess costs occurred during the life cycle of a product and directly covered by one or more actors in the product life cycle, while conventional LCC usually focuses on real and internal costs covered by the main producer or user (Hunkeler et al. 2008). This means that while conventional LCC mainly focuses on the product, service or investment *life span*, potentially excluding upstream and downstream segments or processes, E-LCC focuses on the life cycle in its LCA-related meaning, thus including all stages from feedstock supply to consumption and/or end of life. Therefore, an E-LCC should have the same product system as LCA, defined by ISO 14040/44 (Swarr et al. 2011). Besides this basic difference, an E-LCC could also include those externalities that will be probably internalized in the decision relevant future, for example CO_2 taxes, and all relevant subsidies and taxes. For these reasons, an E-LCC is thought to be carried out together or after an LCA (Hunkeler et al. 2008). Results can, in fact, be plotted to identify win-win scenarios, compare costs of different environmental measures, analyse cost hotspots along the supply chain, etc. Some results from LCA can also be integrated and monetized as externalities, as long as there is a foreseeable internalization in the relevant future and double counting is avoided (Hunkeler et al. 2008, Swarr et al. 2011). E-LCC was also recently included as economic pillar of the proposed Life Cycle Sustainability Assessment (LCSA) together with environmental LCA and Social LCA (Valdivia et al. 2011).

The SETAC working group also provided a draft definition and some methodological background for the so called **Societal Life Cycle Costing** (S-LCC) (Hunkeler et al. 2008). This approach has a larger perspective and includes all costs covered by anyone in society, whether today or in the long-term future. This means that besides costs assessed by conventional and environmental LCC, also additional social and environmental externalities are considered and converted into monetary terms. Therefore, S-LCC aims at being a stand-alone method, as long as all externalities are monetized (no double counting) and transfer payments (taxes and subsidies) are subtracted. Given that the perspective is encompassing the overall society, this approach can be relevant for policy making to identify larger effects and indirect cost of production systems and alternatives. However, since definitions and methods are not standardized yet, depending on specific choices, S-LCC can be similar to other approaches such as Cost-Benefit Analysis and Full-Cost Accounting (Hunkeler et al. 2008).

Figure 1: The 3 types of LCC



Source: Hunkeler et al. 2008

4 REFRESH Situations

To structure the thinking on what the methodological challenges are when evaluating different measures regarding flows from the food chain, relevant REFRESH situations have been defined, described in this section.

5.1 Purpose and link to other activities

To structure the thinking of REFRESH task 5.1.1 and task 5.1.2 in view of task 5.1.3: ‘standard system approach for evaluating the environmental dimension and life cycle cost of food waste’, four REFRESH *situations* are defined which form the skeleton around which the later task of 5.1.3 will be built. The situations try to group different types of circumstances – situations – under which food and food waste will leave the food supply chain and be treated through different routes (destinations). The hypothesis is that similar situations will require similar methodological choices and thus should give a good structure around which to develop a methodology framework. At this stage this merely is a stepping stone to guide the authors thinking and as such will be developed further during task 5.1.3.

These situations are meant to guide in both environmental and cost assessments; hence, the description of the situations are present in both reports: D5.1 and D5.2 which covers methods for cost assessment.

There are many food commodities that are used in the food supply chain, but which might also be used in other types of goods, e.g. vegetables oils might be used in personal care products. There are also many supply chains producing several outputs which feed into different supply chains, e.g. bio-diesel production also produces glycerol, a common ingredient in many food products. It is not helpful if all possible sources and supply chains which feed into the food supply chain are mapped out. REFRESH, therefore, like FUSIONS focuses on flows from the food supply chain and thus the focus for the situations is there.

5.2 Description of REFRESH situations

The following four situations are defined: prevention at source, valorisation maintaining quality, valorisation as part of waste management and end of life treatment.

Important features of these REFRESH situations are:

They can take place at any point/process in the life cycle.

They can take place within the remit of any stakeholder.

More than one situation can occur at the same life cycle stage, e.g. part of an output is valorised at source, and part becomes input to a waste management system and is then in turn valorised.

More than one situation can occur at different life cycle stages within a life cycle under investigation.

All final destinations can be accommodated (hypothesis).

While the presented order of situations has some alignment to the waste hierarchy, all examples given within a situation will not have similar environmental impact.

The situations are described in detail below. How destinations of food waste used in FUSIONS (2015) and Food Loss & Waste Protocol (FLW 2015) align to the four REFRESH situations are provided in **Table 10** in Annex A.

5.2.1 Prevention at source

Waste prevention (see **Table 1**), which is the highest priority of the waste hierarchy, is defined as the prevention of waste at source through avoidance, reduction and reuse, but excluding off site recycling. The Waste Framework Directive 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). Despite the order of priority in the waste hierarchy, only a few studies measure waste prevention in the context of waste management (Laurent et al. 2014).

As an initial thought model, the authors propose that prevention at source can only take place if there has been waste of resources, either by generation of food waste or production of other outputs which were utilized but not as such a desired output (i.e. produced on purpose), otherwise it cannot be prevented. If there was never wastage of resources in the first place, there cannot be prevention. Put differently, not doing the prevention measure would lead to wasted or inefficient use of resources.

Depending on where in the life cycle the prevention takes place, more or fewer processes will be affected. If through a new technology more can be harvested, 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, e.g. if less is needed there might be poorer scale of economy in some instances, or actions for prevention might result in environmental burden (e.g. energy for better preservation), which need considerations.

It is worth keeping any rebound effects, as highlighted by Laurent et al. (2014), in mind when discussing system boundaries later in the project.

Table 1: REFRESH situation: Prevention at source

Prevention at source: the flow is avoided	
Technology routes	**Examples**
- Redesign and optimisation of processes - New technology - Re-work of material - Behavioural change	- Reworks on manufacturing, which was previously discarded as waste, e.g. content of wrongly packaged product is repacked - More efficient change over from one product or flavour to another - Consumers to use up their purchased food in time so they do not have to throw away spoilt food - Retailers marking down the price to sell items close to use-by-date (reduces wastage at retailer, but not necessarily at consumer end)

5.2.2 Co-product valorisation

Co-product valorisation, see **Table 2**, can be 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. peelings which can be valorised. For this situation it is important that outputs of the valorisation need to replace another marketable product. Some of the environmental burden from the upstream supply chain will be attributed to the outputs going into this situation.

The advantage of co-product valorisation over valorisation as part of waste management is that it utilizes, in general, outputs for which the source and origin are known, which are uncontaminated, high quality material flow, which therefore may allow usage within the food supply chain.

Table 2: REFRESH situation: Co-product valorisation

Co-product valorisation: The flow is valorised into a product that replaces another marketable product. The generator of the flow sees a value with the flow.	
Technology routes	**Examples**
- Animal feed production - Biobased material and biochemical processing - Bio-energy production - Fermentation	- Use of bagasse for energy production - Use of by-product plant material for bioplastics, such as PLA - Use of fish industry residues as input for feed production - On-site treatment of manufacturing food waste in AD (it is of value for the generator) - On-site recycling (for a different use than its original) e.g. used coffee grounds as fertiliser for office plants assuming it replaces fertilizer - On-site composting - Home composting (if compost replaces shop bought compost or substances used for soil improvement).

5.2.3 Valorisation as part of waste management

Valorisation as part of waste management (**Table 3**) can be at any point in the life cycle. The material flow may be mixed with other materials for further treatment with the aim to utilize the material before final disposal. This stage can include a change of owner of the material flow and may be accompanied by a loss of traceability or an increase in contaminations. It starts, e.g. by being collected within a municipal waste management system. The output from this valorisation still replaces a marketable product.

Table 3: REFRESH situation: Valorisation as part of waste management

Valorisation as part of waste management: the flow is mixed with other materials and treated in waste treatment process that gives a product that replaces another marketable product. The generator of the flow wants to discard the flow (sees no value).	
Technology routes	**Examples**
- Composting by waste management companies - plough in if for the purpose of soil enhancement - Not harvested if for the purpose of soil enhancement - Anaerobic digestion - Co-generation/Incineration if with energy recovery	- Bio gas production in an anaerobic digestion - Incineration linked to district heating system

5.2.4 End of life treatment

The purpose of this situation is to handle material, reduce its quantity and stability for final disposal. The technologies are not designed to maximize any valuable outputs. For instance, a landfill is not designed to optimize methane production, quite the contrary. Examples are given in **Table 4**.

Table 4: REFRESH situation: End of life treatment

End of life treatment: the treatment does NOT result in any product that replaces another marketable product	
Technology routes	**Examples**
- Plough in - Not harvested with no change in fertilizer use - Incineration without energy recovery - Wastewater treatment - Landfill with and without gas recovery - Discards to land or sea	- Incineration without energy recovery - Composting as treatment to stabilise material - A consumer pouring spoilt milk down the drain and no biogas production from waste water treatment plant - Left over product in a production line washed out during line change over

6 LCC and food waste: state of art and methodological aspects

6.1 Application of LCC to food systems and food waste

As mentioned, LCC has traditionally been applied to analyse products or investments with high initial acquisition costs, usually durable and expensive goods. Therefore, the use of LCC for food products and food waste streams has been only recent and minimal. A general overview is provided in **Table 5** while more details can be found in the Annex B10 (**Table 11** and **Table 12**).

The review showed that food or food waste are only rarely addressed in Standard and policy guidelines, Grey literature, and Business Sustainability Reporting. Indeed, most of Standards are referring to C-LCC and focus on decisions over products or investments requiring a high initial capital, such as buildings or energy sectors. The only explicit mention to a potential LCC of food was found in the EU policy guideline on Public Procurement, with reference to catering services. However, it mainly refers to the life cycle cost of refrigerators and freezers (a relevant hotspot for both environmental and costing impacts of food) but not directly to food or (avoided) food waste. No LCC application of food systems or food waste has been identified in business sustainability reporting of food industries. Most of the time, an environmental life cycle perspective is provided in these reports.

Some discussion and guidance of food-related LCC could be retrieved in books. Specifically, it was argued that LCC has in general a rather microeconomic perspective. Further, the different costing approaches lead to diverse applications. The following examples were found in the literature:

C-LCC can be seen as a discounted cash flow analysis and used to evaluate large investments, such as new food processing plants or machineries. Life cycle costs related to these durable goods can then be attributed to single products basing on yield or other allocation criteria. Potentially, it can be combined to selected life cycle inventory results, such as energy use or emissions.

E-LCC is carried out in combination with LCA. In this case, costs are directly matched or attributed to input flows identified in LCA, thus following the same functional unit and the same system boundaries (see following sections).

An S-LCC example analysed costs related to both the agricultural and industrial phases (cradle to gate) of conventional and organic olive oil: lower costs occurred in organic olive oil because of the reduced external impact deriving from fertilizers and pesticides (Notarnicola et al. 2004).

Table 5: Amount of reviewed documents by approach and topic

Topic	Approach			
	C-LCC	E-LCC	S-LCC and	Others

		LCSA		
LCC general	6	6	3	1
LCC food	2	4	1	-
LCC (food) waste	1	8	3	7

Note: documents may fall under several categories at the same time

As far as waste management is regarded, LCC is considered as a useful tool for both the analysis of current systems and the evaluation of economic consequence of scenarios. However, different approaches can assess different goals. For example, C-LCC has not an environmental focus, thus focuses on the economic viability or impacts of a certain treatment or the identification of best performing solutions. E-LCC is usually simultaneous with LCA and, in addition to C-LCC, it can also show the distribution of net costs or savings within the waste supply chain. Finally, S-LCC is reputed to be useful in estimate broader welfare impacts (Martinez-Sanchez et al. 2015). Two papers applying LCC to waste management were included in the review for their methodological relevance (Rigamonti et al. 2016, Martinez-Sanchez et al. 2015).

Examples of food waste LCCs were found in academic publications. Most of them applied life cycle costing to previous or contextual LCA and are thus classifiable as E-LCC of food waste. In one case a comparison between different LCC approaches was carried out, including an S-LCC (Martinez-Sanchez et al. 2016). This is also the only known source for LCC of food waste prevention, though only at a consumer level. Only one paper used LCSA to assess used cooking oil disposal options (Vinyes et al. 2013). Almost all of these studies focused on the analysis of urban food waste management, mainly but not exclusively from the consumption segment. In one case the focus was on restaurants and catering waste (Escobar et al. 2015). Other papers did not use LCC in a strict sense or explicitly, but they were nevertheless considered in the review. A series of 3 papers dealt with costs related to food waste in South Africa, respectively at the household level, along the supply chain, and incorporating inedible food waste (Nahman et al. 2012, Nahman and de Lange 2013, de Lange and Nahman 2015). Only one paper focused on food waste recovery by charities and NGOs through an Input-Output framework, evaluating recovery costs, saved food value, calories, embodied water, energy, and greenhouse gases (Reynolds et al. 2015). As mentioned, details about methodological aspects are discussed in the next sections.

Finally, other relevant information was found in reports from previous European Projects (FUSIONS 2015) and International Organizations (FAO 2014). Despite LCC not being mentioned or applied, these studies are specifically related to food waste and are explicitly evaluating also socio-economic impacts of food waste. In the specific, the report from Fusions project was particularly interesting from the point of view of potential economic trade-offs of food waste reduction measures on the interaction between demand and supply of food and prices (FUSIONS 2015). The FAO (2014) study proposed a Full-Cost Accounting framework with a societal perspective for the monetary evaluation of socio-economic and environmental impacts of global FLW. The approach included direct financial costs, an evaluation of ecosystems good and services lost, and of social costs deriving from natural resources degradation.

Box 1: Take out: LCC in food and food waste studies

The use of LCC in food waste studies is rather limited and mainly related to (food) waste management. Most of this literature can be retrieved in academic publications or reports. E-LCC is usually used as economic assessment in combination with an LCA study. Only one LCC study encompassed food waste prevention at the consumer level as a possible scenario. Finally, other methodological approaches could represent a reference for certain specific aspects (e.g. externalities; trade-offs; etc.).

6.2 Functional units and system boundaries

Functional units and system boundaries are essential methodological aspects in the analysis of LCC methodologies. Considering that results from this report should pave the way for developing measures and methodologies for the LCA and LCC of food waste and that these approaches should be consistent, it was deemed necessary to identify whether and how different LCC approaches deal with system functions, units, and boundaries.

6.2.1 Functional units

As described in the previous chapter, C-LCC is not characterized by the same perspective as LCA. Therefore, functional units are not always explicitly mentioned, despite the applicability to several products, processes, services, and assets. Indeed, some standards indicate that the C-LCC should include costs related to a specified function or item of equipment. For instance, some standards focus on life cycle cost related to the function "owning or operating" a building (ASTM 2015). Other standards state that in a detailed life-cycle costing, costs of a quantum of individual elements or components of the constructed asset should be summed up to produce a LCC estimate (ISO 2008).

The definition of system function and its reference unit is instead more relevant for E-LCC, being integrated with LCA. Both books deriving from the SETAC working group stressed that also in E-LCC the functional unit should be consistent with provisions of ISO 14040/44 (2006) especially when LCA and LCC are conducted together on the same system. So, while the E-LCC perspective could include or exclude one or more actor or stakeholder, and have a different goal and scope, it should maintain the same functional unit as in LCA. Some examples of goal and scope are also listed: identify total costs for an actor; assess competitiveness (of cost of ownership); company management; marketing; trade-offs or win-win with environmental measures or between different costs; optimization of maintenance. The scope should present information not only on function and its unit, but also on the product/service under study, system boundaries, allocation, methods of interpretation, data sources and quality, value choices, etc. (Hunkeler et al. 2008, Swarr et al. 2011).

Some examples of functional units found in the various literature are: 1 kWh of generated electricity, 1 refrigerator, washing of laundry of a certain typology of household, a standard public transport heavy duty bus, a washing machine, electronic waste management, a constructed asset, etc. (see **Table 12**). In the case of LCC of food systems, functional units depend on the focus of the study. If the main segment under investigation is the agricultural phase, area-based (hectares) functional units are used, especially to assess the financial viability of long term cultivations (e.g. orchards) (Pergola et al. 2013, Mohamad et al. 2014). However, also kilograms of production were used as alternative FU to take into account yield differences. Obviously, FUs are different when further segments such as processing and consumption are considered (Notarnicola et al. 2004) or if the product studied has more ingredients (Schmidt Rivera and Azapagic 2016).

As far as waste systems and food waste are concerned, functional units used in reviewed literature are generally mass based and coherent with LCA when the two methods are combined.

The two studies on municipal solid waste (MSW) analysed environmental and economic impacts related to 1 ton of collected and treated waste (Rigamonti et al. 2016, Martinez-Sanchez et al. 2015). In the case of food waste specific studies, regardless of the approach (LCC or not), cost and value loss from wasting food or from its various disposals is usually referred to a mass based unit or a specific quantity. Some examples are:

1 ton of (household) food waste managed in different scenarios (Kim et al. 2011);

Yearly amount of edible/inedible food waste from a country/globally;

Average organic waste from restaurants and catering per person per year (Escobar et al. 2015);

Yearly amount of used cooking oil generated in a neighbourhood (Vinyes et al. 2013).

Besides the general typology of unit used, it has been underlined during the review that further specifications should be provided to clarify the definition on FUs. Certain characteristics of FU should be disclosed in the goal and scope description. For example, one paper specifically mentioned that the FU was expressed in wet weight (Takata et al. 2012). Another aspect is the inclusion of a specific reference to generated, collected, or treated food waste. In fact, different food waste collection systems (e.g. UCO collection) can have different efficiencies, thus resulting in higher or lower amounts of waste treated, but with the same function (Vinyes et al. 2013).

Finally, in two cases, FU was related to the end product of the valorisation process (Schievano et al. 2015, Daylan and Ciliz 2016). Given that these studies aimed at assessing costs related to energy products (electricity from biogas and ethanol from lignocellulosic by-products), functional units were expressed in kWh generated and km travelled, respectively. Obviously, while mass based FU allows confronting all treatments, in the case of FUs related to very different final products/functions, a comparison may be more difficult.

Box 2: Take out: Functional units

In C-LCC functional units are not always mentioned and only some standards indicate that LCC should include costs related to a specified function (e.g. "owning or operating" a building). In E-LCC the functional unit should be consistent with provisions of ISO 14040/44 especially when LCA and LCC are conducted together on the same system. Most of FUs related to waste management or food waste were mass based. It must be stated if FU is referred to (food) waste collected, managed, treated, or to end products.

6.2.2 System boundaries

As for functional units, also for system boundaries a clear definition and guidance is more relevant in E-LCC approaches than in C-LCC. Nevertheless, some indications are provided by international standards dealing with C-LCC. In particular, they recommend including all known material costs associated with the functional unit of an item or group of items. For instance, system boundaries of ownership of Personal Property C-LCC should include not only the acquisition value, but also activities related to the studied item, such as costs from acquisition through utilization and disposition (ASTM 2013). C-LCC usually takes into account costs or cash flows, i.e. relevant costs arising from acquisition through operation to disposal (ISO 2008). Consequently, other costs such as incomes, non-construction costs, externalities and environmental costs are not taken into account in C-LCC.

In the case of E-LCC, it is quite established that also for system boundaries, coherence with LCA and compliance with ISO 14040/44 (2006) should be pursued (Hunkeler et al. 2008, Swarr et al. 2011). However, two basic exceptions are underlined by most of the references. The first exception allows a potential E-LCC practitioner to use different criteria for the inclusion or exclusion of certain processes from the analysis. In the specific, in E-LCC cut-off can be based on financial significance (Swarr et al. 2011). In fact, given that the goal is to analyse costs, all process related to the system under study that are causing a relevant share of costs can be included, regardless of their relevance for the environmental analysis. This is the case of activities such as: research and development, training, marketing, product design, etc. It must be highlighted that in certain studies, the use of an environmental or economic cut-off could radically change final results. For example in a reviewed study on differences between home-made and ready-made meals, only input flows from a previous LCA were considered for the cost analysis, without considering for example personnel costs for manufacturers or time used for cooking at home (Schmidt Rivera and Azapagic 2016). Thus, the choice of a specific cut-off criterion should be disclosed, justified and checked for sensitivity.

The second exception is that in E-LCC the analysis perspective can be of one or more given market actors. This would allow also focusing only on the supply chain segment where costs are higher or more relevant from the study perspective. Depending on the point of view, costs associated with upstream or downstream process could be treated with different methods. An example can be the use of producer price or average market price for material inputs or feedstock instead of modelling background process (Hunkeler et al. 2008, Swarr et al. 2011).

In general, economic, social and environmental system boundaries could be different in terms of process cut-off and geographical scope. However, if a LCA and an E-LCC are carried out simultaneously, they should be identified in the same way and consistently with the goal and scope. For example, in the case of analysis of food system, according to Settanni et al. (2010), it can be possible to have different perspectives:

If the economic analysis is focused on durable goods (e.g. investment in a new food processing plant), then also the environmental analysis should have the same perspective (life cycle of the asset used in food production).

If the physical life cycle of the food product is the main focus, then LCC should have the same perspective, linking costs to specific flows, processes and life cycle phases.

In all the reviewed papers on LCC of food systems, the second perspective was used, with the food product or cultivation being the functional unit. As for LCAs, also in LCC of food, physical system boundaries can be either cradle to grave or cradle to gate (of farm or processor). Depending on the LCC approach, costs deriving from upstream processes may be included, especially when LCC is carried out together with an LCA. Furthermore, time boundaries should be described. Food products in fact are not durable, but their production system may have a long life span. Thus, this means that future costs of durable goods (e.g. maintenance or final disposal) used in the production system could be allocated to the product studied. Similarly, in case of perennial cultivation systems, the whole life span of plants can be considered (Notarnicola et al. 2004, Mohamad et al. 2014, and Pergola et al. 2013).

These findings can be relevant also in the case of LCC applied to waste and food waste. In both MSW management studies, a grave to grave/gate perspective is used. All segments from collection to treatment and final disposal or use are included (Rigamonti et al. 2016, Martinez-Sanchez et al. 2015). In the reviewed studies on food waste, system boundaries could be categorized in two not mutually exclusive typologies:

Studies with a focus on value loss, costs and impacts from disposal;

Studies with a focus on disposal options evaluation.

In the first typology, food waste generated in each step of the supply chain can be included and its overall cost and economic impact is calculated, including average treatment and eventual externalities. Most of these studies were not properly LCC, thus they not described explicitly system boundaries (Nahman et al. 2012, Nahman and de Lange 2013, de Lange and Nahman 2015). In the second typology, most of the studies adopt a “grave to gate” perspective. The boundaries can thus include one or several segments from: discharge, collection, transportation, treatment. Use of recovered materials or energy, as well as by-products are not always mentioned or included. However, sales of recovered products or avoided production of displaced products can be included as revenues (see following section) (Kim et al. 2011, Escobar et al. 2015, Takata et al. 2012, and Martinez-Sanchez et al. 2016).

Box 3: Take out: System boundaries

While in C-LCC system boundaries may include acquisition (or investment), utilization, and, eventually, disposition, in E-LCC coherence with LCA should be pursued. Two basic exceptions are: financial relevance cut-off; multi-actor perspective with inclusion or exclusion of upstream/downstream segments. In LCCs of food, physical system boundaries can be either defined as cradle to grave, cradle to gate (of farm or processor or consumer). Time boundaries should be described. In (food) waste management studies, a grave to grave/gate perspective was used, unless the focus was on food value loss (not CC studies).

6.3 Cost modelling

During the literature review, it appeared that several crucial methodological aspects in LCC are related to cost modelling. When analysing costs related to the life cycle of a product, several choices must be made in terms of categories of costs included, their aggregation, the allocation of costs, and the discounting of future costs. This section reports literature review results regarding these aspects.

6.3.1 Cost categories

As described in the previous chapter, C-LCC focus on material costs of a function or an item, from its conception to its disposition. **Table 6** shows the main categories considered in C-LCC.

Table 6: Cost categories in C-LCC

C-LCC Cost categories	
Categories	**Examples**
Initial investment costs	Planning Design Engineering Site acquisition and preparation Construction

	Purchase Installation
Financing costs	Related to investment decision
Recurring operating and maintenance costs and capital replacement costs	Scheduled and unscheduled maintenance Repairs Energy Water Property taxes Insurance
Resale value or salvage/disposal costs	Disposal inspections Disposal and demolition Reinstatement to meet contractual requirements Taxes, etc.

Source: Authors elaboration on standards (See sections 2.1, 2.2, 2.3, 2.4, and 2.5 of **Table 12***)*

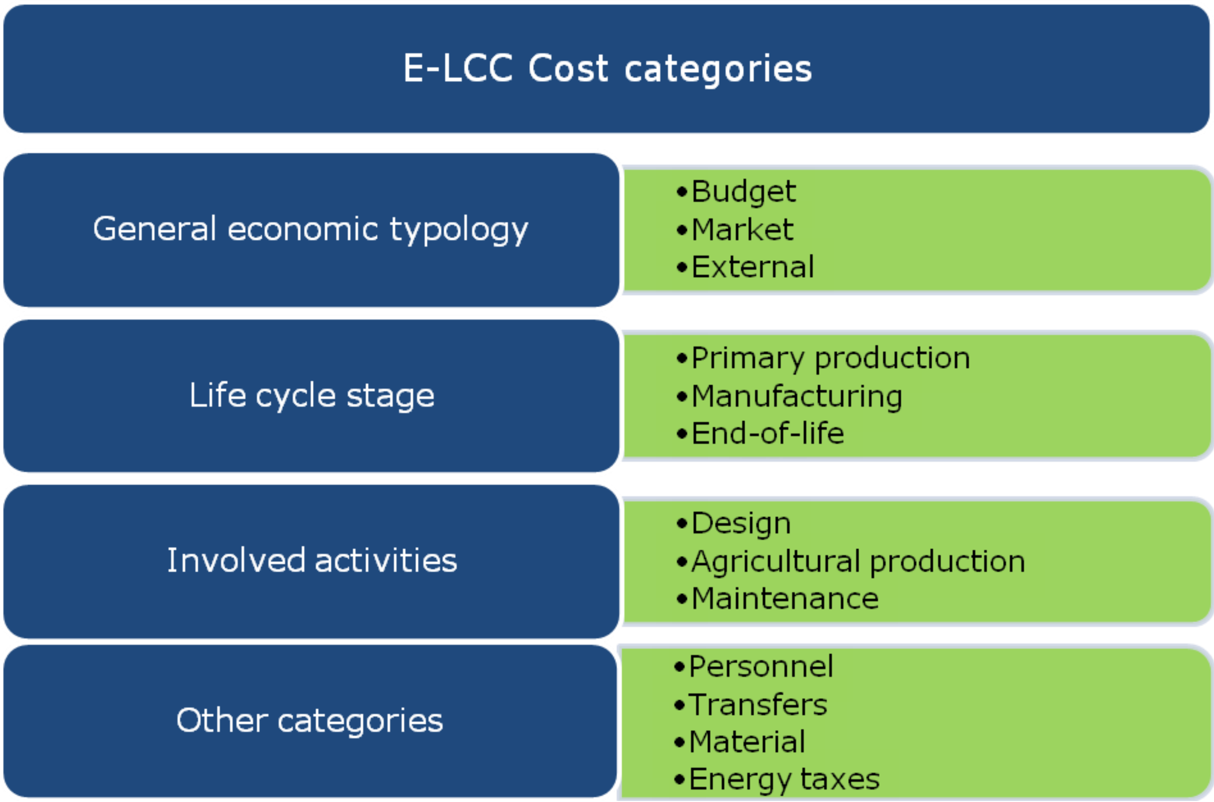
The above listed categories are taken into account in the investigated standards and some studies, sometimes joint or split in sub categories. In fact, according to the goal of the study, costs can be divided in other kind of typologies, such as: procurement and ownership; recurring and nonrecurring; material, labour, repair and maintenance; others.

In E-LCC cost categorization can be quite different due to the needed coherence with LCA and the potential inclusion of several actors (and perspectives). According to books from the LCC SETAC working group, an E-LCC cost modelling should follow the related goal and scope. A product tree or life cycle must be defined; relevant costs should then be identified and classified in a cost breakdown. Complete sources of data (including time, geography, currency, uncertainty) should be disclosed (Hunkeler et al. 2008, Swarr et al. 2011). **Figure 2Error! Reference source not found.** shows the possible level of details that can be used to categorize costs.

Reviewed literature on LCC of food systems provided some examples of relevant cost categories that may be included in this sector. In general, flows usually considered in LCA, such as raw materials and various inputs, energy uses, packaging and waste, are also relevant for LCC. Other cost categories related to labour, certifications (organic food, HACCP, etc.), interests, depreciation, quotas, and insurances, are sometimes included. In the case of food processing plants, several capital and operating costs can be considered. These items can be relevant in the case of an investigation of food waste prevention measures in food processing (e.g. investment for new machineries/techniques reducing losses). Several other categories to be included are food-related taxes, transport (e.g.

refrigerated or animal transport), and disposal. As far as revenues from sales and subsidies are regarded, they were included in the comparisons between cultivation systems (conventional and organic products - Notarnicola et al. 2004) or to determine value added along the supply chain (meals - Schmidt Rivera and Azapagic 2016)). Also in this case, the review results suggest that investigation on food waste prevention measures could benefit from the inclusion of these categories: an example may be the modelling of potential increase of sales, although uncertain impacts on prices must be taken into account (See Par. 6.4). The categorization of these costs was different according to reviewed studies. In some studies, grouping was following the parallel LCA (with a division by life cycle phase), in others costs were grouped according to economic typology (present and future investment, operational, etc.), related agricultural activity (e.g. pruning, disease control, irrigation, etc.), or by cultivation phase (e.g. orchard life phase).

Figure 2: Examples of cost categorizations in E-LCC



Source: Authors elaboration on Hunkeler et al. 2008

As far as LCCs of waste management are regarded, in one study (Rigamonti et al. 2016) costs were divided according to the specific stage, meaning collection (including transport and a first processing), treatment, and final disposal. All costs were net of profits from the sale of recovered energy or materials, and net of transfers. Capital use costs were included in terms of depreciation, accruals, and return on investments. The model provided by the other study (Martinez-Sanchez et al. 2015) classified costs in budget costs (in all 3 LCC approaches), transfers (only in C-LCC and E-LCC) and externality costs (only in SLCC).

According to the authors, budget costs needs to be considered in different ways according to the LCC approach: factor prices (market price minus transfer) for C-LCC and E-LCC; shadow prices (factor price per "net tax factor") in S-LCC. Transfers were divided in flows that redistribute income between stakeholders (e.g. taxes or subsidies) and pecuniary externalities that occur to offset facilities (substitution of heat, electricity, etc.). Furthermore, externalities that are priced and covered within the system (e.g. tax) become transfers. C-LCC included all budget costs (factor price) and transfers. E-LCC included also anticipated transfers (externalities expected to be internalized). S-LCC accounted for budget costs and externalities in terms of shadow prices. All activities/technologies were defined per ton of food waste, with a bottom-up approach. The first step was to divide waste system into activities or waste stages (separation, collection, transportation etc.); per each activity cost items like machinery, salaries, fuel and maintenance costs were disaggregated; to each of these items, a physical (quantity) and economic (cost) parameter were assigned. Finally, each item was classified as budget, transfer or externality cost.

Food waste related studies that are not applying LCC usually focus on the direct loss of food value, usually through average market price of wasted food. The cost of disposal can be also included in the evaluation, by using average costs of landfilling with some externalities. If the inedible fraction is included another cost that can be considered is the opportunity cost of conventional treatment against, for example, biogas production or composting, using prices of substitute products as proxies (Nahman et al. 2012, Nahman and de Lange 2013, de Lange and Nahman 2015). One study evaluated the economic impact of food waste recovery for food donations in terms of both monetary value of rescued food waste and "costs" for the economic system, through an Input Output methodology (Reynolds et al. 2015). The report from FUSIONS reported potential costs of prevention measures suggested by OECD (FUSIONS 2015). Cost items were classified by supply chain stage and by typology of measure (infrastructure and hardware, technology, and information). Several of these examples may be relevant for an LCC study on food waste prevention. In the FAO (2014) study on full cost accounting of FLW, direct internal and external costs were included, plus scarcity cost estimates from the increased pressure on land. Impacts on other stakeholders were discussed in terms of potential costs and benefits, but not included. Also when an LCC approach is applied, different cost items and categorizations can be found in the literature, with varying degree of detail and depending on system boundaries. Probably the largest and most detailed cost models can be found in Kim et al. (2011) and Martinez-Sanchez et al. (2016). In most of the other case, a rather limited amount of items and categories is used by authors to describe their cost modelling. However, it is possible to say that labour costs, energy and material inputs, machineries and their maintenance are always considered. The categorization is sometimes carried out in terms of stages, other times in terms of cost typology.

Box 4: Take out: Cost categories

Standards recommend including in C-LCC: investment costs; financing costs; recurring operating and maintenance costs; capital replacement costs; resale value or salvage/disposal costs. An E-LCC cost modelling should define a product tree, identify and classify costs in a breakdown with appropriate level of detail. In food LCC, raw materials and various inputs, energy uses, packaging and waste, are included, as well as other cost categories related to labour, certifications (organic food, HACCP, etc.), interests, depreciation, quotas, and insurances, food-related taxes, transport (e.g. refrigerated or animal transport), disposal, revenues from sales, and subsidies. In LCCs of (food) waste management, labour costs, energy and material inputs, machineries and their maintenance are considered. The categorization is sometimes carried out in terms of stages, other times in terms of cost typology. Food waste related studies that are not applying LCC usually focus on the direct loss of food value.

6.3.2 Cost bearers

In general, categorizations are not mutually exclusive and can be used together depending on the cost bearers included. In fact, while several stakeholders can be part of the same life cycle of a product, not every actor is bearing the same categories of costs. Thus, depending on the system boundaries (cradle to gate vs. cradle to grave) an E-LCC may include costs for producers (e.g. design, production, and marketing), costs for distributors (e.g. transport, storage, and sale), costs for consumers (e.g. purchase, use, and maintenance), and costs for waste companies. In the case of Societal LCCs, also governments, country and global societies may be included as cost bearers (Hunkeler et al. 2008, Swarr et al. 2011). The identification of cost bearers leads to the inclusion of different upstream and downstream cost and should be disclosed in the description of the cost model. Since several perspectives and actors may be included in the same cost model, it is suggested to aggregate costs with caution, depending on the goal of the study (Hunkeler et al. 2008, Swarr et al. 2011). For example, a diverse aggregation is required if the focus is on specific costs along the supply chain or on net distribution of costs between different stakeholders. An appropriate level of detail is required basing on the purpose of the LCC. Similarly to an LCA, costing impacts can be grouped according to the life cycle stage and/or appropriately summed to express total costs from a certain perspective.

In almost all the reviewed case studies, costs are assessed from just one perspective or there is no diversification of costs according to potential bearers. Only in two studies, models for reporting costs for different stakeholders are provided. The first paper (Schmidt Rivera and Azapagic 2016) related to food included the following perspectives: life cycle cradle to grave; value added up to distribution (retail price minus retail life cycle cost); life cycle up to consumer (no disposal); consumer (retail price plus cost of consumption). The second paper (Martinez-Sanchez et al. 2015) related to waste management, in the C-LCC application, divided costs by the following foci: 1) costs for the entire system; 2) costs for households (waste fee); 3) costs incurred by incinerator operator; 4) costs incurred by collection operator.

Box 5: Take out: Cost bearers

Not every actor is bearing the same categories of costs, thus an E-LCC may include different perspectives (e.g. costs for producers, distributors, consumers, waste companies. Various costs can be grouped by life cycle stage and appropriately summed to express total costs from a certain perspective. For (food) waste management costs could be thus divided among the waste management company, the households, the collectors, and other involved actors.

6.3.3 Cost allocation

Another important aspect regarding cost categorization is related to data collection and the geographical diversity of accounting systems. Companies from different countries may report costs or allocate costs to goods in various ways depending on legal requirements. This is particularly relevant when addressing indirect expenses (such as overheads) that need to be attributed to products through some allocation. While cost allocation is not mentioned in standards related to C-LCC, it is rather relevant aspect in E-LCC as it is carried out together with LCA. The SETAC Working Group (Swarr et al. 2011) highlighted that the ISO (2006) suggests avoiding allocation by partitioning processes or by expanding system boundaries in LCA. On the contrary, in E-LCC costs are often to be allocated if needed. Thus in order to ensure consistency, the hierarchy provided by ISO (2006) should be followed. In case of LCA system partitioning, allocation amongst various outputs can be carried out for costs of personnel, capital, goods and services, basing on physical measures (weight, volume, etc.) or market value methods (estimate value at production or future income from sale) (Swarr et al. 2011). If possible, cost breakdown should be made at unit process level, by linking flows of cost inputs to the related output (e.g. number of working hours of personnel or machinery per ton of product, etc.). Particular methodological challenges are the allocation of indirect costs (as overheads or components costs). A simple system is to assign an established overhead rate to all products. Another possible allocation criterion is the number of working hours. As mentioned for cut-off rules, also in the case of allocation it must be paid attention to the representativeness of the allocation base for both costs and environmental impacts. It is thus suggested to perform a sensitivity analysis. In case of LCA system expansion, the basic rule provided by the SETAC (Swarr et al. 2011) is to ensure consistency of system boundaries also for LCC. In order to expand LCC boundaries, costs representing the avoided products displaced must be subtracted. One way of dealing with this is to consider coproducts as avoided costs and include revenues from their sale as negative costs.

In the reviewed food LCCs, the allocation of overhead and similar costs is usually not specified. The same applies to the allocation of costs to coproducts. In one case (Schmidt Rivera and Azapagic 2016) all considered costs were attributed to the functional unit although some revenues from the sale of chicken waste to rendering industry were included. Similarly, in Notarnicola et al. (2004), oil husk was mentioned as co-product of oil milling and economic allocation was used for the LCA inventory, but no specific indication is provided for the costing part.

In waste management LCCs, no coproduction was considered and all costs were allocated to the functional unit. In Martinez-Sanchez et al. (2015) so called one-off costs (such as capital, etc.) were allocated by converting lump sums (in present or future values) into annuities and dividing annuities by annual usage rates (€/y divided per t/y). Annual usage rates can differ from annual capacity (e.g. incinerator operating at lower level because of avoided wastage) and can change depending on the technology. The same principle was used to allocate annual fixed costs to tons of waste treated, while variable costs and transfers were allocated by multiplying physical amounts of inputs needed per their price/transfer amount.

As far as food waste studies are regarded, costs or impacts are allocated on the mass of food wasted and/or treated. Only one study mentioned overheads specifying that a standard ratio was assumed (Escobar et al. 2015). In another study dealing with collection centres (Vinyes et al. 2013), all costs and economic outputs needed to be allocated since centres treat different type of waste. The share related to the specific flow under study (UCO) was used as criterion. In case of multi-output systems (Kim et al. 2011, Escobar et al. 2015), a consequential approach was used also in the LCCs by translating co-products with market value into avoided costs (revenues) for the producer, as if they were (e.g. electricity from cogeneration, digester sludge, glycerol, and compost).

Box 6: Take out: Cost allocation

In E-LCC costs are often to be allocated if needed according to the hierarchy provided by ISO. Cost breakdown should be made at unit process level. Indirect costs can be allocated either by number of working hours or by an established overhead rate. In multi-output systems, a consequential approach can be used by translating co-products with market value into avoided costs (revenues).

6.3.4 Discounting

The other relevant aspect related to cost modelling is discounting of future costs, e.g. the conversion of cash flows occurring at different times, to an equivalent cost in a fixed point in time. The selection and use of appropriate rates of discount is extensively covered in the LCC literature, and the influence of different choices of discount rate on the outcome of calculations is also widely covered. For instance, the ISO 15686:5 (ISO 2008) argues that present value should be calculated by discounting future cash flows to the base date, and should be used for comparing alternatives over the same period of analysis. Present value calculations should be used to calculate the present monetary sum that should be allocated for future expenditure on an asset. Likewise, the ASTM E917 (ASTM 2015) specifies that the discount rate selected should reflect the investor's time value of money, which means that the discount rate should reflect the rate of interest that makes the investor indifferent between paying and receiving a dollar now or at some future point in time. The discount rate is used to convert costs occurring at different times to equivalent costs at a common point in time. As reported by Langdon (2007), in practice clients and other users of LCC in the construction sector appear to adopt more generalized approaches. Public sector procurers tend to favour much lower levels of discount than their private sector counterparts – in some countries the appropriate public financing authorities (Government Departments of Finance or Treasury) recommend rates that are typically between 2% and 5% net of inflation – i.e. real discount rates). In the private sector discount rates adopted tend to be more akin to investment hurdle rates (and vary between some 2-14% 'real') (Langdon 2007).

As far as E-LCC is regarded, the literature tends to make a distinction between the discounting of cash flows and the discounting of results. The first represents the allocation of costs deriving from capital (e.g. investment), future costs (e.g. maintenance and final disposal of machineries) and taxes, long term external costs (e.g. leaching from landfilling), and future revenues. According to SETAC working group a discounting of cash flows (with a time frame similar to depreciation period) can be carried out and should be appropriately justified and then examined for sensitivity (Hunkeler et al. 2008). They propose some guidance on the specific rate, suggesting avoiding discounting when life cycle is shorter than 2 years, to use lending rate for consumers, expected bond rate for government, internal rate of return for manufacturers. Discounting of results is instead not recommended, as E-LCC is based on the same steady-state assumption of LCA. Results may be discounted in case of Societal (with some assumptions) and Conventional LCC (although not applied) (Hunkeler et al. 2008, Swarr et al. 2011).

Despite the relevance of this issue, discounting was not specified or applied so frequently in the studies reviewed. In the case of food LCCs, just one study (Mohamad et al. 2014) applies a 1.25% discount rate, while Martinez-Sanchez et al. (2015) applied discounting to future operating and maintenance costs as well as revenues, despite this contrasts with the suggestion from SETAC working group.

Box 7: Take out: Discounting

In C-LCC a discount rate is usually selected and used. In E-LCC a discounting of cash flows (with a time frame similar to depreciation period) can be carried out, while discounting of results is not recommended. However, discounting was not specified or applied so frequently in the studies reviewed.

6.4 Externalities

Externalities are defined as being quantifiable cost or benefit that occurs when the actions of organizations and individuals have an effect on people other than them Hunkeler et al. (2008). Externalities are positive if their effects are benefits to other people and negative or external costs, if the external effects are costs on other people and therefore have a negative influence. Since these externalities are external to the constructed asset or function, they are only taken into account in E-LCC and S-LCC, and not in C-LCC. Externalities can include various external costs, such as environmental cost, social costs and benefits and other costs which can impact the business reputation or the functional efficiency. Some authors define externalities as transfer, whenever externalities are priced and covered within the system (e.g. tax). When externalities are non-compensated effects on individuals' welfare, they can be environmental or not, e.g. noise or time spent for waste sorting (Martinez-Sanchez et al. 2015).

To be introduced into an 'accounting' LCC process, environmental costs must be expressed in monetary terms. In other words, environmental costs should be quantified and monetized so they can be considered as an additional cost input in a LCC analysis. However, depending on which external costs are included, may impact the ranking of alternative options. Environmental costs may come from LCA analyses on environmental impacts, and measure for example the external costs of global warming contribution associated with emissions of different greenhouse gases. Environmental costs can be calculated also in respect of acidification (grams of SO_2, NO_X and NH_3), eutrophication (grams of NO_X and NH_3), land use (m^2*year) or other measurable impacts. Typically, C-LCC analyses do not include a wider range of externalities or non-construction costs, such as finance costs, business costs and income streams (ISO 2008). Nevertheless, there is an increasing need to include also social and environmental cost and benefits in public procurement accounting, so C-LCC should also include these externalities, although it is difficult to account for or forecast them (Perera et al. 2009)). For instance, the Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles initiated the implementation or externalities in green public procurement. Indeed, under this Directive, contracting authorities and entities are obliged to take energy consumption and emissions into account in their purchases of road transport vehicles. One of the ways of doing this is by assigning a cost to these factors in the evaluation of bids. The Annex to the Directive provides a set of common costs to be applied in this case. This allows emissions to be priced for inclusion in the evaluation and comparison of bids. Categories of costs are specified according to the energy content of different fuel types and the lifetime mileage of different vehicle categories (EC 2016).

Similarly, externality costs in businesses nowadays should not only include staffing, productivity and user costs but also environmental cost (e.g. impact cost from food waste): these can be taken into account in a LCC analysis but should be explicitly identified. Data for LCA and sustainability assessment is widely available and quite extensive. Companies however are mainly concerned with climate change impacts – for which CO_2 emissions and energy use are the two main environmental indicators. Different methodologies have been also developed in order to evaluate environmental external cost related to a service or a product. For instance, the EP&L – Environmental Profit and Loss account developed by Trucost, places a financial value on environmental impacts along the entire value chain of a business to help companies combine sustainability metrics with traditional business management. Though companies pay fees for services such as water abstraction, energy use, waste disposal and land use, the true costs of these environmental impacts are usually externalized and unaccounted for. An EP&L assesses how much a company would need to pay for the environmental impacts it causes, providing a shadow price for risk and opportunity analysis (Trucost 2016).

Within E-LCCs, a distinction has to be made in the definition of externalities between standards and papers, books and reports. On one hand, standards related to E-LCC define that externalities can have an impact on society in general, but should not be included in the LCC analysis, unless it is explicitly requested to do so. On the other hand, some authors in books, papers and reports state that externalities could be included (Hunkeler et al. 2008, Notarnicola et al. 2004, Martinez-Sanchez et al. 2015, Vinyes et al. 2013, Valdivia et al. 2011, and Langdon 2007). According to the definition from SETAC Working Group, an E-LCC will always include externalities as they are included in LCA (Hunkeler et al. 2008). Thus in the costing part no externalities already included in the environmental assessment should be take into account in order to avoid double counting. However, some external costs could be included. They should be market based or resemble other money flows (e.g. taxes and tariffs) and distinguished from the cost deriving from external effects. All externalities that may become real money flows in the decision relevant-future could be included in a systematic way. An example for this is a scenario of future internalization of taxes or subsidies from certain environmental impacts. **Table 7** shows the criteria for the inclusion of external costs.

In S-LCC, all impacts from LCA and LCC are monetized, so it should theoretically avoid double counting (if transfers and taxes are subtracted) and provide a net welfare impact on the whole society. However, it cannot always be generalized and in the literature some authors include externalities in different ways in the LCC approaches (C-LCC, E-LCC, and S-LCC).

Table 7: Criteria for the inclusion of external costs

External cost categories inclusion criteria
Covering all significant types of effects without overlapping (e.g. LCA and SLCA)
Characterized in indicators
Possible to model a quantitative relation with the human activity
Monetized

Source: Authors elaboration on Hunkeler et al. 2008

In food related LCCs, externalities can have a certain influence in the ranking of alternative options (Settanni et al. 2010), but only one study included externalities from energy and chemicals (Notarnicola et al. 2004): the scores of economic impacts of the production of organic and conventional olive oil are radically different if external costs are included. In another paper (Schmidt Rivera and Azapagic 2016) LCA and LCC were combined, thus no externalities were included in the costing part. Only in one of the two waste management studies (Martinez-Sanchez et al. 2015), external costs were included in the S-LCC multiplying unit emissions per FU by accounting prices of emission, which can represent society's willingness to pay for avoiding emissions/impacts or abatement costs. 3 potential externalities where be included: direct, upstream (from commodities and goods production), downstream (from displaced productions, as in recycling). Positive net externality costs were registered for source separation and collection of waste, ash landfilling and neutralization of air control residues. Negative net externalities were reported for energy and material recovery. Authors also listed some critical issues regarding the externalities:

Certain externalities (e.g. resource scarcity) may be already reflected, although partially, by market prices (especially short term availability) and by transfers (e.g. taxes), thus some double counting may occur.

Time is an important issue: current emissions can have future damages that may be discounted, and current waste management can have future emissions to be accounted and discounted; in both case, future annual damage costs should be considered in present value through transparent discount rates.

Assumptions made on the inclusion/exclusion and valuation techniques of externalities may affect the outcomes of S-LCC: for example, time spent by household in sorting could be valued (or not) as a cost/burden for families (thus a positive external cost) or as a benefit (thus a negative external cost).

As far as food waste is regarded, the monetisation of social and environmental impacts is proposed in order to engage decision-makers on sustainable resource use (FAO 2014). It is suggested that not only economic costs, but also environmental costs, and social (well-being) costs should be included. In the latter category primary (individual and direct) and secondary (society as a whole) costs could be considered. Nevertheless, not all food waste costing examples are considering externalities. In Nahman et al. (2012), external costs of landfilling (leaching and gas as well as transports and disamenities) were included in the disposal of food waste, but without a LCC approach.

When LCC was used, externalities were included in Kim et al (20011) and in Vinyes et al. (2013). The first conducted an environmental LCC and compared the management of 1 ton of food waste in 8 different scenarios. They included the benefits deriving from by-products and CO_2 reduction. Thereby they considered the unit market price for substituted products and the carbon price trading in the carbon market. In the second study, the comparison of 3 UCO (used cooking oil) collection systems included monetized CO_2 emissions in the LCC as an external cost, but in order to avoid double counting they were not considered in the final scoring process. Similarly, 3.13 conducted a simultaneous LCA and LCC study comparing looped and non-looped food waste recycling facilities, without including and quantifying CO_2 emissions in monetary value in the analysis.

Box 8: Take out: Externalities

> 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. An E-LCC includes externalities in the LCA part, but externalities that may become real money flows in the decision relevant-future could be included in the costing part. In food waste LCC externalities were included in two cases (monetization of CO2 emissions) but they were not scored in case of joint LCA-LCC evaluation.

6.5 Evaluation of impacts and sensitivity analysis

The impact assessment in LCC presents some differences when compared to LCA. In fact, being expressed in terms of costs, the inventory already provides an evaluation of impact. Nevertheless, several financial and non-financial analyses may be used to evaluate consequences on revenues, cost hotspots, correlations, breakeven points, etc. In fact, especially when several cost bearers may be identified, a low overall cost for a certain scenario could actually be redistributed unevenly. Thus, cost impacts needs to be evaluated. Likewise, sensitivity analysis can and should be carried out in this phase of an LCC study to further discuss results and highlight potential criticism in methods, value choices, data, and variables.

Evaluation techniques can be diverse according to the approach applied. In general, C-LCC is more characterized by financial evaluation techniques. Net present value (NPV), internal rate of return (IRR), and payback time (simple or discounted) are usually calculated after inventory of costs and revenues. Different methods can be found in the literature, but they will not be presented here in detail (for some examples: Dhillon 2010). It must be noted that these financial evaluation tools are usually well-known by businesses and managers, while their use by other stakeholders (e.g. public procurers) and the communication of results to a larger audience (e.g. consumers) may be less obvious. Among the reviewed studies, only one paper (Mohamad et al. 2014) showed results for NPV and IRR calculations: in the specific, investment (initial and future) costs were compared, as well as annual operating costs divided by stage. Then total costs and revenues and net cash flow were compared across the whole life span. Finally, basing on different product price levels (olives), NPV and IRR were derived for both the scenarios analysed. In another paper (Pergola et al. 2013), only cumulative costs over the life cycle were calculated.

However, both in public procurement and in business sustainability reporting, these tools are increasingly coupled or integrated with more holistic assessments. For example, the EU Clean Vehicles Directive on the promotion of clean and energy-efficient road transport vehicles states that operational energy and environmental impacts should be taken into account. Regarding business sustainability reporting, some methodologies such as the Total Impact Measurement & Management developed by PwC (2015), aim at improving the granularity of the reporting, by splitting the breakdown of impacts into the three categories of direct, indirect and induced impacts.

When E-LCC is applied - with or after an LCA - the evaluation of costs is usually less focused on financial management aspects and more interested in supply chain effects and in the identifications of trade-offs or win-win situations between the environmental and the economic impacts. Both books by the SETAC working group on LCC (Hunkeler et al. 2008, Swarr et al. 2011) state that interpretation of results is a key phase also in LCC and the provision contained in ISO 14040/44 (2006) should be applied especially for uncertainty, consistency, and completeness checks. Results analysis may include hot spot identification, NPV analysis, payback period, annuities, and IRR. However, LCC results should be reported and analysed together with LCA results. Some options are:

Portfolio presentations of impacts through the use of common tables and eventually graphs with different impact categories for LCA and different costs for LC stages/scenarios;

Plotted results of selected LCA and LCC results (e.g. GWP per LCC in different alternatives);

Potential use of normalization to derive aggregated indicators (such as the return on environment or the economic-environmental return).

Among the studies reviewed (regardless of the topic), only two used a portfolio presentation. The first (Kim and Ahn 2011) compared 4 variants of a refrigerator. Results were presented on separate matrices for LCA and LCC. Then, for each variant, a matrix showed LCA and LCC scores and percentage change in relation to the basic version. Percentage changes for all the variants for both LCA and LCC were then ranked through a graph, so to identify the least impacting variant. In the second (Schmidt Rivera and Azapagic 2016) LCC and several environmental results of different meal scenarios were summarized and ranked with a qualitative approach in a "heat map". A colour ranking was assigned to each scenario in each criterion, rankings were then summed per each scenario (assuming equal importance), and final scores were compared again for an overall ranking (the lower the sum the higher the ranking). In three cases, selected LCA and LCC results were plotted to identify win-win solutions. In the first case (Kim and Ahn 2011) GHG emissions and LCC of various energy sources were plotted to evaluate a potential correlation, using mean data from previous studies or literature (including standard deviation). In the second (Escobar et al. 2015), various LCA results and LCC were plotted with slopes measuring the trade-off between profits and selected environmental impacts. In the third (Rigamonti et al. 2016), a composite environmental indicators (energy and material recovered per ton of waste) was plotted against the economic indicator (costs per ton of waste), in order to identify the best possible win-win scenario. In the same study, it is also suggested the possibility to further combine the indicators in an aggregated index, which represent the third option among the abovementioned ones. More precisely, multiplying specific market values of materials and energy recovered from food waste per the amount recovered, it is possible to derive a monetary environmental indicator (€ recovered per ton of waste). Then, it can be confronted with the cost indicator. However, authors also signalled that economic multipliers can change over time and space. Another example of this aggregation could be found in a study on UCO management (Vinyes et al. 2013). Since a LCSA was used, in order to have total scores per scenario, authors first distinguished indicators in negative and positive, basing to their contribution to sustainability (e.g. costs are negative). Values for each indicator were then converted in comparative percentages (100% is the worst or best scenario). Different scales (1-5) for negative (100%=1) and positive indicators (100%=5) were used to assign scores. Total scores per scenario and assessment were calculated as sum and then recalculated in relative terms (0-1): the closer to 1 the higher the contribution to sustainability.

Besides combining or plotting LCA and LCC results, other evaluations may be carried out apart from life cycle cost assessment. One evaluation tool used in two studies was profits/value added calculation. In the first paper (Escobar et al. 2015) the authors stressed how since the study assessed costs and revenues, the economic value added (EVA) and the profit could have been measured. The first, being calculated as revenues minus the costs of intermediate inputs, should give an estimation of the economic impact of the system on the gross domestic product (GDP). However, a breakdown of costs is needed to calculate the EVA so profits were chosen as indicator. They were derived as the revenues minus the costs of material inputs, labour, capital and purchased services, thus offering an estimation of earnings of an enterprise. In the second paper (Schmidt Rivera and Azapagic 2016), before combining LCA and LCC results, it was determined the value added along the supply chain from cradle to distribution, by subtracting the life cycle cost up to distribution to the retail price. Then, differences in both LCC and VA were compared across the various scenarios (meals). As mentioned in Par. 6.3.2, also different cost bearer perspectives can be used to categorize and then evaluate costs (see Martinez-Sanchez et al. 2015). Finally, if studies include revenues or benefits (such as incomes from by-products or external positive costs) they may be used to estimate a benefit/cost ratio (as in Kim et al. 2011).

Box 9: Take out: Evaluation of impacts

C-LCC is more characterized by financial evaluation techniques (NPV, IRR, payback time). In E-LCC evaluation of costs is usually more interested in supply chain effects and in the identifications of trade-offs or win-win situations. Thus LCC results should be reported and analysed together with LCA results. Some options are: portfolio presentations; plotting of results; potential normalization for aggregated indicators.

Since data quality and value choices are very relevant, sensitivity analysis must be applied. In any case, sensitivity analysis is required to confirm the validity of the study and to measure the connections between parameters and calculated outputs. Sensitivity analyses can be undertaken to examine how variations across a (plausible) range of uncertainties can affect the relative merits of the options being considered and compared. These ranges should be probable, within the limits of what is anticipated and fit within the study goal. These analyses can help to identify which input data have the most impact on the LCC result and how robust the final decision is.

Table 8 shows potential key assumptions that can have the biggest effects on C-LCC and E-LCC outcomes.

Table 8: Key costing assumptions to analyse for sensitivity

Key costing assumptions to analyse for sensitivity
Discount rates
Period of analysis
Incomplete or unreliable service life or maintenance, repair and replacement cycles
Cost data based on assumptions
Expected variations in prices, also due to normative changes
Value choices

Sensitivity analysis can be an important guide to assessing what additional information it is worthwhile collecting and what the most significant assumptions to be made are. It can also be used to consider how flexible or variable requirements can be during the period of analysis or the life cycle. The change in outputs should be presented as a function of variation in parameters, as well as eventual changes in ranking of alternatives. Both Monte Carlo and analytical hierarchy process can be applied.

Despite its importance, sensitivity analysis was used in only two LCC study. In the first (Escobar et al. 2015), authors stressed particularly the aspects of data quality and uncertainty. In the specific, it is stated that, despite being rarely used, uncertainty analysis are important to assess several issues such as "taxation, wages, discount rates, changes in market prices driven by surpluses and market trends". Therefore, technical and economic parameters were defined as probability distributions, rather than assigning specific values, and for most input and output prices, equipment lifespan and various technical parameters a distribution was defined (either uniform, PERT, or real). Then, Monte Carlo simulations were conducted to analyse stochastic uncertainty and correlations of differentials between scenarios and varying parameters were showed on tornado diagrams.

In the second, focused on food (Schmidt Rivera and Azapagic 2016), authors carry out a comparative analysis on the same scenarios contained in the LCA study. They first identified cost hotspots and differences in LCC and then they carried out a sensitivity analysis on the influence of ingredient sourcing and cooking appliances on the meal cost, as they were the more relevant factors. When sensitivity is not applied, it is however possible to apply other potential methods, as a break even analysis on major cost factors. An example is provided by Martinez-Sanchez et al. (2015), where a break-even analysis was carried out and presented on certain crucial difference between the two scenarios (conventional waste management and organic waste source separation). In the specific, they assess:

what price level for the digestate is needed to raise enough revenues in Sc.2;

what is the minimum number of households sharing a container to reach a 75% reduction in difference between scenarios;

what positive external cost value should be attributed to time spent in sorting waste, to balance the extra costs of separately treat organic waste.

Box 10: Take out: Sensitivity analysis

Sensitivity analysis should be used to test the validity of the study and to measure the connections between parameters or value choices and outputs (such as discount rates, period of analysis, cost data, price variations, etc.). Despite its importance, sensitivity analysis was used in only two LCC study, and another study only applied a break even analysis.

6.6 Other aspects

Other issues were raised in the examined literature. One of the main methodological aspects to be considered is the currency issues. According to the SETAC Working Group, costs incurred in different regions should be homogenized. Costs incurred in different time may be stated as such. Nevertheless, the ASTM E917 (2015) proposes different methodology depending on the type of currency and situations (see **Table 9**).

Table 9: Future cash flows: current vs. constant currency for

Expressed in	Type of cash flows		
	Fixed amounts e.g. loan payments	**Different rate than inflation** e.g. energy costs	**Other costs**
Current currency General inflation included in projecting future costs	No adjustments	Estimate on the basis of the specific rate of price change	Use rate of general price inflation
Constant currency General inflation excluded in projecting future costs	No adjustment	Multiply base-time value by differential rate of price change	No adjustment

Source: Authors elaboration on ASTM 2015

Among the studies reviewed, only in one case currency value was clearly stated (Daylan and Ciliz 2016), with a time reference.

Another relevant aspect is data availability and quality, which is underlined as one possible focus for future research. Data regarding costs are not always available. Literature suggests that also databases and published prices may be used for background processes. Also cost data and functions may be used but it must be paid particular attentions as this may lead to inaccuracies. For example, transfers or revenues may be included or excluded. Besides, several sources underlined the importance of geography. For example accounting systems vary from country to country and from firm to firm and also different transfers may be applied in different geographical contexts (even within a country). When using prices, volatility should be assessed, for example through normalization of data for cross-country comparisons and through scenarios as cost items may be volatile, stable or subject to scale. Scenario development, forecasting, or cost estimation methods may be employed in case of missing information. Thus, a critical review is strongly suggested in case of disclosed LCC. Literature also suggests that research may focus on benchmarking with common cost figures.

Finally, other relevant aspects related to food and food waste were identified in reviewed literature. Food products and systems are mentioned frequently as a potential focus of further LCC research (Settanni et al. 2010). Food waste prevention was not present in the reviewed studies on food, but food by-products and waste were sometimes considered. For example, in the paper on meals (Schmidt Rivera and Azapagic 2016) FLW are included as a source of cost (disposal losses and waste) and/or revenues (chicken waste). Differences across the scenarios (frozen vs. chilled, ready- vs. home-made organic vs. conventional) led to different the values of initial inputs (chicken and vegetables), amount of chicken waste, levels of products losses and wastes, and final food waste. This has also effects on final costs, as when manufacture and distribution are frozen, food waste tends to be lower, and food waste is minimized when the meal is home-made.

From a methodological point of view, it is particularly important to provide a complete definition of the food waste assessed. In fact, as underlined in Takata et al. (2012), food waste valorisation scenarios and their costs can be largely influenced by the food waste quality at the source and by the destination. In most of reviewed papers, food waste is implicitly defined as household food waste but no further specification is provided on its composition (edible, non-edible, etc.). Usually, authors used a zero-burden approach, thus excluding upstream activities generating waste flows, but it was explicitly mentioned only once.

Another interesting aspect is that for the valorisation of several agro-industrial residues and organic waste (thus also food losses and waste) a price could be paid either by tax payers, or by valorisation plant owners (e.g. biogas) (Schievano et al. 2015). This aspect needs to be properly assessed in the case of a comparative LCC (e.g. prevention vs. treatment) in order to avoid double counting or inconsistencies in considering transfers, taxes, and price paid for feedstock.

Finally, another set of critical aspects to be assessed is related to external impacts of food waste prevention or valorisation. As highlighted in the FUSIONS project (FUSIONS 2015) trade-offs can arise from investments/actions of FLW reduction or prevention. FLW prevention can have uncertain impacts on the demand and supply of food that a LCC approach should probably take into consideration. Lower food prices resulting from food waste reduction could actually lead to a higher consumption and to some extent also in more food waste. Likewise, if consumers are reducing food waste, producers would produce less, requiring less manpower. Finally, an investment in losses reduction could have uncertain outcomes in the long term from price reduction. Similarly, the use of agro-industrial residues and organic waste (thus also food losses and waste) for example in biogas plants, could result in lower biomass supply costs for plant owners, thus reducing reliance on energy crops, the related impacts and markets. It is not clear whether these avoided impacts should be included and how (Schievano et al. 2015). In a similar way, the upgrading of FLW into animal feed could have not only effects in terms of cost improvement for animal feed facilities but also cascade effects on substitute products (Takata et al. 2012).

Box 11: Take out: Other aspects

Other LCC methodological aspects are currency issues, data availability and quality, scenario development, and cost estimation methods. As far as food waste is regarded, prevention was not present in the reviewed studies, and then specific challenges should be identified and addressed, such as the definition of the food waste assessed, its qualities at source, the specific destination. Transfers and prices paid to valorise certain residues and food wastes must be taken into account in order to avoid double counting. Finally, trade-offs can arise from investments/actions of FLW reduction or prevention.

7 Conclusions

Work Package 5 aims at providing the environmental and cost dimension of food waste prevention and valorisation routes and options by using life cycle assessment (LCA) and life cycle cost (LCC) methodologies. Task 5.1.2 thus aimed at collecting and analysing the literature on life cycle costing with a focus on practical implementation on food waste.

As far as the LCC general approach is regarded, the main finding of the report is that an E-LCC approach would allow integrating costing techniques and LCA into a comprehensive assessment of food waste prevention and valorisation impacts. Regardless of the approach, in reviewed literature, LCC use in food waste studies was rather limited and mainly related to management. E-LCC was usually used as economic assessment within a LCA study. No LCC study encompassed prevention measures, thus specific challenges should be identified and addressed.

A functional unit coherent with LCA is usually suggested and used, especially in E-LCC. Most of FUs related to waste management or food waste were mass based.

It must be clearly defined if FU is referred to (food) waste collected, managed, treated, or to end products. Similarly, in E-LCC system boundaries should be coherent with LCA but two exceptions can be made: financial relevance can be used as cut-off criteria; several actor perspectives (with different upstream/downstream segments) can be used. In (food) waste management studies, a grave to grave/gate perspective was used, unless the focus was on food value loss (not LCC studies).

In C-LCC usually the following costs are included: initial investment costs; financing costs; recurring operating and maintenance costs; capital replacement costs; resale value or salvage/disposal costs. All these costs can be considered also in an E-LCC, but the cost modelling should define a product tree or life cycle, classify all relevant costs in a breakdown with appropriate level of detail and relate them to the functional unit (e.g. at a unit process level). In food LCC, raw materials and various inputs, energy uses, packaging and waste, are included, as well as other cost categories related to labour, certifications (organic food, HACCP, etc.), interests, depreciation, quotas, and insurances, food-related taxes, transport (e.g. refrigerated or animal transport), disposal, revenues from sales, and subsidies. In LCCs of (food) waste management are regarded, labour costs, energy and material inputs, machineries and their maintenance are always considered. The categorization is sometimes carried out in terms of stages, other times in terms of cost typology. Food waste related studies that are not applying LCC usually focus on the direct loss of food value.

Another relevant aspect is allocation. In E-LCC costs are often to be allocated if needed according to the hierarchy provided by ISO (2006). Besides, indirect costs can be allocated either by number of working hours or by an established overhead rate. In multi-output systems, a consequential approach can be used by translating co-products with market value into avoided costs (revenues). Discounting can be applied to cash flows (with a time frame similar to depreciation period) regardless of the LCC approach. In E-LCC, however, discounting of results is not recommended.

Externalities can be included as quantifiable costs or benefits, expressed in monetary terms, depending on the approach. In E-LCC it is suggested to include as costs only those externalities that are expected to become real money flows in the decision relevant-future. In food waste LCCs, for example, CO_2 emissions could be monetized in the LCC, but in case LCA and LCC results are combined or showed together then double counting of the same impact should be avoided. However, two basic problems may arise: on one side not every externality is associated to an LCA impact; not every environmental impact or externality can be fully or partially monetized. C-LCC is more characterized by a financial management perspective. Several evaluation techniques (NPV, IRR, payback time) exist. They can be applied to E-LCC as well, but usually in this approach the evaluation of costs is more interested in supply chain effects and in the identifications of trade-offs or win-win situations. Thus LCC results are reported and analysed together with LCA results through portfolio presentations, plotting, and normalization. According to most standards and books, a sensitivity analysis should be used to test the validity of the study and to measure the connections between parameters or value choices and outputs (such as discount rates, period of analysis, cost data, price variations, etc.). Despite its importance, sensitivity analysis was used in only two LCC study, and another study only applied a break even analysis.

Finally, other aspects should be addressed. For example, the relevance of currency, issues of data availability and quality, and cost estimation methods. Furthermore, as far as food waste is regarded, it must be mentioned the importance of the characterization of food waste assessed, the identification of potential transfers and prices paid by operators, the eventual inclusion and analysis of trade-offs and indirect effects triggered by FLW prevention or valorisation.

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9 Annex A: Alignment of REFRESH situations with other frameworks

Table 10 shows how FUSIONS and FLW standard destinations align to the REFRESH situations. Most notably prevention was not within the scope of either of these documents.

Table 10: Destinations of FUSIONS (2015) and Food Waste and Loss Standard (2015) aligned to the four REFRESH situations.

Situations	Prevention at source	Co-product valorisation	Valorisation as part of waste management	End of life treatment
Destinations in FUSIONS		Animal feed (B1), biobased material and biochemical processing (B2), Bioenergy (B6)	Composting (B3), plough in/not harvested (B4) (if for the purpose of soil enhancement), anaerobic digestion (B5), Co-generation (B7)	Plough in / not harvested (B4) *(if not for the purpose of soil enhancement)*, Incineration (B8), Sewer (B9), Landfill (B10), Discards (B11)
Destinations in FLW standard		Animal feed, bio-based materials and biochemical processing, fermentation	Codigestion / anaerobic digestion, composting / aerobic digestion, incineration *(if with energy recovery)*, land application, Plough in / not harvested *(if for the purpose of soil enhancement)*	Incineration *(if without energy recovery)*, landfill, Plough in / not harvested *(if not for the purpose of soil enhancement)*, open burn, refuse / discarded or dumped to land or sea, sewer

10 Annex B: Summary of reviewed document

Table 11: Overview of literature sources covered

(* indicates that the document is not fully/properly LCC; further specification is provided in corresponding tables)

1. Books	LCC general	LCC food	LCC (food) waste
1.1 Dhillon 2010	√		
1.2 Hunkeler et al. 2008	√	√	
1.3 Swarr et al. 2011	√		
1.4 Finkbeiner 2011	√		
1.5 Sonesson et al. 2010		√	
2. Standard and policy guidelines			
2.1 ISO 2000, 2001a, 2001b	√		
2.2 ISO 2008	√		
2.3 ASTM 2015	√		
2.4 ASTM 2013	√		
2.5 EC 2016	√		

3. Papers from journals		
3.1 Kim et al. 2011		√
3.2 Nahman et al. 2012		√*
3.3 Nahman and de Lange 2013		√*
3.4 de Lange and Nahman 2015		√*
3.5 Escobar et al. 2015		√
3.6 Rigamonti et al. 2016		√*
3.7 Schmidt Rivera and Azapagic 2016	√	
3.8 Notarnicola et al. 2004	√	
3.9 Mohamad et al. 2014	√	
3.10 Pergola et al. 2013	√	
3.11 Schievano et al. 2015		√*
3.12 Daylan and Ciliz 2016		√
3.13 Takata et al. 2012		√
3.14 Martinez-Sanchez et al. 2015		√*
3.15 Vinyes et al. 2013		√
3.16 Reynolds et al. 2015		√*
3.17 Martinez-Sanchez et al. 2016		√

4. Reports			
4.1 Ciroth et al. 2011	√		
4.2 Perera et al. 2009	√		
4.3 FUSIONS 2015			√*
4.4 FAO 2014			√*
5. Grey literature			
5.1 Ciroth and Franze 2009	√		
5.2 Langdon 2007	√		
6. Business Sustainability Reporting			
6.1 PwC 2015 and Trucost 2015	√		

Table 12: Detailed literature review

Books	
1.1	
TITLE	Life cycle costing for engineers
AUTHOR(S) and/or ORGANIZATION	Dhillon, B. S.
GENERAL THEME(S)	LCC It reviews past literature (1988-2008) and covers several aspects related to LCC economics, such as interest rates, depreciation methods, formulas, data sources, models and estimation methods, especially for specific costs (quality, reliability, maintenance, etc.). Costing models are provided for some product categories (computer systems, transports, civil engineering structures and energy systems).
LCC APPROACH(ES)	Conventional Life cycle costing models and methods presented are from the conventional approach, mostly related to producer's perspective. Life cycle cost is defined as "the sum of all costs incurred during the life span of an item or system (i.e., the total of procurement and ownership costs)."
FUNCTIONAL UNIT(S)	No specific guideline
SYSTEM BOUNDARIES	No specific guideline
COST ALLOCATION	No specific guideline
COST CATEGORIES	Procurement and Ownership; Recurring and Nonrecurring; Material; Labour; Repair; Maintenance;

	Others.
EXTERNALITIES	No specific guideline
IMPACT ASSESSMENT	Present value, calculated with different methods.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	Useful as source for some basic models and formulas (e.g. simple vs. compound interest, present value calculation, others). No specific guideline on food waste assessment.
1.2	
TITLE	Environmental Life Cycle Costing
AUTHOR(S) and/or ORGANIZATION	Hunkeler, D.; Rebitzer, G.; Lichtenvort, K., (eds.);
GENERAL THEME(S)	LCC This book presents the results of the SETAC-Europe Working Group on Life Cycle Costing, which aimed at developing Environmental LCC (EnvLCC) as second pillar of sustainability assessment (together with LCA and societal assessments).
LCC APPROACH(ES)	Environmental mainly, but also conventional and societal. *Conventional LCC* assesses all costs related to the life cycle of a product and directly covered by the main producer or user. Only real and internal costs are considered, sometime end of life or use costs are excluded. The perspective is mostly that of 1 actor, either the manufacturer or the user or consumer. A conventional LCC usually is not accompanied by LCA results. *Environmental LCC* assesses all costs deriving from the life cycle of a product and directly covered by

	1 or more actors in the product life cycle (supplier, manufacturer, user or consumer, and/or end of life actor), including those externalities that are anticipated to be internalized in the decision relevant future (definition as suggested by Rebitzer and Hunkeler 2003). It thus requires the inclusion of all life cycle stages and anticipated costs, as well as a separate LCA, with the same product system according to ISO 14040/44. The perspective can be that of 1 or more actors. If relevant, subsidies and taxes are included. *Societal LCC* includes all costs covered by anyone in the society, whether today or in the long-term future. It thus assesses also additional external costs by transforming impacts in monetary terms. The perspective is from society overall. Subsidies and taxes are excluded as they have no net effect.
FUNCTIONAL UNIT(S)	Various, according to goal and scope of EnvLCC, but consistent with ISO 14040/44: "The functional unit should be a given utility resulting in different reference flows". For EnvLCC should be the same as in LCA.
SYSTEM BOUNDARIES	The same product system as for LCA (according to ISO 14040/44) with the perspective of 1 or more given market actors. Possible to include R&D or marketing activities, especially if they fall above the common cut-off threshold. Cradle-to-gate costs (e.g. material prices) can be used in LCC for upstream processes: this means different processes included in LCA and LCC.
COST ALLOCATION	In case of multioutput systems, costs of personnel, capital, goods and services should be allocated, based on market prices. Other allocation method is the gross sales value method, basing on a "split-off point". Particular methodological challenges are the allocation of indirect costs (as overheads or components costs).
COST CATEGORIES	Both costs and revenues can be included (especially when dealing with coproducts), and it should be specified how revenues are dealt with. Four way of categorizing costs: "economic cost categories, life cycle stages, activity types, and other

	cost categories” with examples. It is suggested to use the latter category of costs. Important to define the cost bearer(s) as different upstream and downstream costs could be included. Cost aggregation and discounting: discounting of results is inconsistent and not recommended with the steady-state environmental LCC, while discounted cash flows for money flows occurring at different times within 1 product life cycle is commonly applied. Sensitivity analysis is suggested for different discounting rates. Results may be discounted in case of Societal (with some assumptions) and conventional LCC (although not applied).
EXTERNALITIES	External costs are market based or resemble other money flows (e.g., taxes and tariffs). They are distinguished from the cost deriving from external effects. In E-LCC all externalities that may become real money flows in the decision relevant-future would be included in a systematic way. Criteria for inclusion of external cost categories are: - they should cover all significant types of effects without overlapping (e.g. LCA and SLCA) - should be characterized in indicators - it should be possible to model a quantitative relation with the human activity - it should be monetized
IMPACT ASSESSMENT	Several methods can be used such as net present value, annuities, internal rate of return, and payback period. Influence of uncertain parameters used in LCC should be assessed through a sensitivity analysis. Uncertainty and sensitivity analysis should focus on assumed data, expected variations, value choices (as discounting rate). Monte Carlo or analytical hierarchy process can be applied. LCA and LCC results should be analysed together to identify win-win solutions or trade-offs, using portfolios of LCA-impacts and LCC results (no single scores). Potential use of normalization (e.g. Return on environment or econo-environmental return)

OTHER RELEVANT ASPECTS	Scenario development, forecasting, or cost estimation methods (see Dhillon) may have to be employed in case of missing information. Thresholds can be applied, as in LCA. Steady state vs. quasi-dynamic: EnvLCC usually uses steady state models for time value of money. Collection method: accounting systems vary from country to country and from firm to firm. Currencies: costs incurred in different regions should be transformed, while costs incurred in different times can be stated as such. Confidentiality and use of price as cost estimation.
RECOMMENDATIONS AND COMMENTARY	-
1.3	
TITLE	Environmental Life Cycle Costing: A code of practice
AUTHOR(S) and/or ORGANIZATION	Swarr, T.E.; Hunkeler, D.; Klopffer, W.; Pesonen, HL.; Ciroth, A.; Brent, A.C.; Pagan, R.
GENERAL THEME(S)	LCC This book provides a guide to EnvLCC, following the previous book from SETAC. It builds a basic framework and provides specific methods for assessing economic costs through a LCC consistent with LCA and ISO 14040. Only "new" aspects will be highlighted here.
LCC APPROACH(ES)	Environmental LCC
FUNCTIONAL UNIT(S)	Should be consistent with ISO 14040/44, especially when LCA and LCC are conducted together. It may

	differ depending on perspective (e.g. manufacturer vs. consumer vs. society) and the goal and scope. Goal must state: application; reasons for the study; intended audience; publicity. LCC may be used to: identify total costs for an actor; assess competitiveness (of cost of ownership); company management; marketing; trade-offs or win-win with env. measures or between different costs; optimization for ex. of maintenance. Scope must describe: product/service under study; function and related unit; boundaries; allocation; methods of interpretation; data sources and quality; assumptions; value choices; limitations; critical review.
SYSTEM BOUNDARIES	Same product systems as LCA but cut off based on financial significance rather than environmental.
COST ALLOCATION	While ISO suggests avoiding allocation by decomposing processes or by system expansion, in LCC, costs are to be allocated if needed. If allocation must be used also in LCA then the hierarchy provided by ISO must be followed. If pre-existing LCA is not using allocation, then ensure same system boundaries for LCC. First step: overhead costs are associated to different departments/locations (traditional costing) or different activities (ABC). Second step: department/activity costs are allocated to products through allocation bases. Two most frequently used cost allocation bases are: physical measures (weight, volume, etc.) or market value methods (estimate value at production or future sale). The first is not always possible (different measures for coproducts). A simple system is to assign an established overhead rate to all products. It must be paid attention to representativeness of allocation base for both costs and environmental impacts. Sensitivity to allocation base should be assessed.

COST CATEGORIES	Cost modelling requires: goal and scope; definition of product with a product tree of its life cycle; cost classification/breakdown; sources (including time, geo, currency, uncertainty). Databases and published prices may be used for background processes. Cost items may be volatile, stable or subject to scale, etc. Pedigree matrix for definitions, time, space, and confidentiality of costs may be used for quality assessment and communication. Example framework of potential categorization provide in table 5-1. Cost model may present different levels (e.g. representing the different levels of the system or of the cost typology, from social to item costs). Given the inclusion of different actors/perspectives with different way of modelling costs, aggregation must be carried out with caution, especially when it is needed to analyse the resolution per category (e.g. training costs along the supply chain). Decisions needed: type of category system; which categories are included; definitions of costs.
EXTERNALITIES	Those that are possibly internalized via taxes or subsidies could be double counted in LCC and LCA, especially in the case of environmental impacts that may be internalized in the decision-relevant future.
IMPACT ASSESSMENT	Interpretation is a key phase. All the provision contained in ISO should be applied also to LCC results interpretation especially for uncertainty, consistency, and completeness. Hot spot identification, net present value analysis and payback period are particularly useful in the interpretation of results. As for results presentation, LCA and LCC results may be reported in a table with different impact categories for LCA and different costs for LC stage for LCC. In case of comparative studies, LCA and LCC results can be plotted in portfolio presentations (e.g. CED over LCC in different alternatives). In any case, sensitivity analysis is required to confirm the validity of the study and to measure the

OTHER RELEVANT ASPECTS	connections between parameters and calculated outputs. The change in outputs should be presented as a function of variation in parameters, as well as eventual changes in ranking of alternatives. Monte Carlo and other statistical analysis can be used. Discounting: must be appropriately justified and then examined for sensitivity. Some guiding principle are: avoid if LC <2 yy; for consumers, lending rate +2%, depending on region; for government, expected bond rate (closest length to system studied); for manufacturers, internal rate of return for investment (confidential); for long term, 0.01%. Critical review strongly suggested in case of external LCC, either accompanying or a posteriori.
RECOMMENDATIONS AND COMMENTARY	-
1.4	
TITLE	Towards Life Cycle Sustainability Management
AUTHOR(S) and/or ORGANIZATION	Finkbeiner, M. (ed.)
GENERAL THEME(S)	Life Cycle Sustainability Management The book is a selection of the most relevant contributions to the LCM 2011 conference in Berlin, covering several aspect of Life Cycle thinking and its various approaches.
LCC APPROACH(ES)	LCC is used or discussed in two chapters: Ch. 45. *Kim H and Ahn TK, Analysis on Correlation Relationship Between Life Cycle Greenhouse Gas Emission and Life Cycle Cost of Electricity Generation System for Energy Resources*. Ch. 50. *Kurczewski P and Koper K, The Concept of Monitoring of LCM Results Based on Refrigerators Case Study*.

	This study evaluates the correlation between life cycle greenhouse gas (GHG) emissions and life cycle cost of various energy resources, including coal, natural gas, nuclear power, hydropower, geothermal energy, wind power, solar thermal energy, and solar photovoltaic energy.	This paper analyses the life cycle economic and environmental impacts of refrigerators production and use, and compares them to three potential variants.
	LCC approach not specified. Both LCA GHG emissions data and LCC data are sourced from other studies and then plotted to test for correlation.	LCC approach not specified, but presumably Environmental LCC, as it is run in parallel with LCA.
FUNCTIONAL UNIT(S)	1 kWh of generated electricity.	1 refrigerator.
SYSTEM BOUNDARIES	Not specified, probably from resource extraction to electricity production.	From manufacture to final disposal.
COST ALLOCATION	Not specified.	Not specified.
COST CATEGORIES	Overall cost, no specific categories mentioned, measured in US cents.	Overall cost divided per segment of life cycle.
EXTERNALITIES	None.	None.
IMPACT ASSESSMENT	Results from data collection in terms of means and standard deviations are plotted to verify the correlation. Win-win solutions (low GHG – low to average costs) can be then identified. Confidence errors are included.	Research was conducted on the basic version and the three variants. Then results were first presented on separate matrices for LCA and LCC, with scores in Points for LCA and Poland currency for LCC. Then for each variant a matrix with LCA and LCC scores and percentage change in relation to the basic version. Percentage changes for all

		the variants for both LCA and LCC were then ranked through a graph, so to identify the least impacting variant.
OTHER RELEVANT ASPECTS	Electricity from biomass/biogas is excluded, although some references for LCC can be found.	None.
RECOMMENDATIONS AND COMMENTARY	The analysis presented in the study can be easily applied to food and food waste, in case where several cost and environmental data are available. In general, it can be a rapid and simple way of combining results to show win-win solutions (regardless of correlation analysis).	The matrix-based presentation of results is relevant whenever LCA and LCC are run in parallel and it is coherent with the code of practice provided by Swarr et al. (2011). Relative changes with respect to basic scenarios and the use of a synthetic graph for ranking is easily replicable in case of LCA-LCC analysis related to food waste. However, it assumes the presentation of a single score also for the LCA part or the need to choose only one indicator.

1.5	
TITLE	Environmental assessment and management in the food industry
AUTHOR(S) and/or ORGANIZATION	Sonesson, U.; Berlin, J.; Ziegler, F. (eds).
GENERAL THEME(S)	Life Cycle Sustainability Management in the food industry. This book provides an overview of the environmental impacts of food industry and of methodologies for their assessment. It largely deals with LCA, but also the inclusion of economic and social aspects are considered.
LCC APPROACH(ES)	LCC is discussed in Ch. 11. *Settanni et al., Combining Life Cycle Assessment of food products with economic tools.* This chapter discusses various economic tools that have been or might be combined

	with LCA in order to analyse food products economic impacts. LCC is considered as a tool with a microeconomic perspective, while Input-Output tables and economic extended Material Flow Analysis are reputed as tools with a macroeconomic perspective. As for LCC, few applications to food products have been found, and with various approaches: - Traditional LCC, being a discounted cash flow analysis, can be used especially to evaluate investments in new food plants (durable) and then link costs to product yield; it can be combined to selected life cycle inventory results such as energy use or emissions. - Environmental LCC can be used in combination with LCA by matching costs with input flows, etc.
FUNCTIONAL UNIT(S)	Not specifically mentioned.
SYSTEM BOUNDARIES	System boundaries should be consistent: - If the economic analysis is focused on durable goods, then also the environmental analysis should have the same perspective (life cycle of the asset used in food production) - If the physical life cycle of the food product is analysed, then LCC should have the same perspective, linking costs to specific flows, processes and life cycle phases
COST ALLOCATION	Not mentioned.
COST CATEGORIES	Several capital and operating cost examples in case of food plants. Some cost items that might be applied to food products are mentioned: subsidies, taxes, transport, and disposal.
EXTERNALITIES	Some external costs may impact the ranking of alternative options.
IMPACT ASSESSMENT	Not mentioned.
OTHER RELEVANT ASPECTS	None.
RECOMMENDATIONS	It is remarked how further research should investigate the application of LCC to food industry.

AND COMMENTARY	Some useful references are provided.
Policies and standards	
2.1	
TITLE	Petroleum and natural gas industries — Life-cycle costing : — Part 1: Methodology — Part 2: Guidance on application of methodology and calculation methods — Part 3: Implementation guidelines
AUTHOR(S) and/or ORGANIZATION	International Organization for Standardization – ISO Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum and natural gas industries*.
SOURCE CATEGORY	International standard.
GENERAL THEME(S)	LCC petroleum and natural gas industries.
LCC APPROACH(ES)	Conventional LCC.
FUNCTIONAL UNIT(S)	A specified function or item of equipment.
SYSTEM BOUNDARIES	Part 1: The scope of this part of ISO 15663 is limited to life-cycle costing (the development and operation of facilities for drilling, production and pipeline transportation within the petroleum and natural gas industries). It is not concerned with determining the life-cycle cost of an item of equipment, since then it would be necessary to determine all costs associated with that equipment during the life of the asset.
COST ALLOCATION	Not mentioned.

COST CATEGORIES	Part 2: **Capital expenditure** should cover the relevant initial investment outlay, from discovery through appraisal, engineering, construction and commissioning including modifications until normal operations are achieved. *e.g.: project management, engineering personnel, contractor project support, asset purchase cost, fabrication follow-up cost, initial spares, TTE, documentation, installation, commissioning manpower, commissioning consumables, transport cost, materials, initial training, insurance, reinvestment cost, for equipment of expected lifetime shorter than installation/function lifetime*. **Operating expenditure** should cover the relevant costs over the lifetime of operating and maintaining the asset. Revenue impact should cover the relevant impact on the revenue stream from failures leading to production shutdowns, planned shutdowns and penalties. Only effects from the specific asset or system alone should be considered. *e.g.: operation man-hours, maintenance man-hours, maintenance spares and materials, tools and equipment, scheduled overhaul, sub-contractor's manpower, transport of personnel; transport of consumables, fuel/oil, energy consumption cost, chemicals, onshore support, rental/lease payments, insurance.* **Revenue impact** should cover the relevant impact on the revenue stream from failures leading to production shutdowns, planned shutdowns and penalties. Only effects from the specific asset or system alone should be considered. *e.g.: cost of lost/deferred production, planned shutdown, cost of lost/deferred production, unscheduled, penalties, and tax credit/debit.* **Decommissioning cost** should cover relevant costs of abandonment of the asset, if there will be a cost difference between alternatives evaluated. *e.g.: project management, survey costs, scheme development, scheme implementation, transportation, plant and equipment, care and maintenance, storage costs, asset sale*. Sunk costs, which are not relevant for the decisions to be made, should not be included in the

	calculations.
EXTERNALITIES	Not mentioned.
IMPACT ASSESSMENT	Not mentioned.
OTHER RELEVANT ASPECTS	Part 2: Practical guidance towards the individual steps of the life-cycle costing process are provided and aim to: - show how the potentials for added value can be achieved without life-cycle costing turning into a costly and time-consuming process; - indicate how to structure the work within the process and define focus areas; - transfer the experience of industry in applying the methodology, so that a common and consistent approach can be achieved. Advice and methodologies are provided for the following steps: - Step 1 — Diagnosis and scope definition; - Step 2 — Data collection and structures breakdown of costs - Step 3 — Analysis and modelling; - Step 4 — Reporting and decision making; Life-cycle costing related techniques are also provided for: - Economic evaluation methods (Net present value, life-cycle costs, internal rate of return, the payback method); - Reliability, availability and maintainability techniques. Part 3: The greatest benefit is realized when life-cycle costing is integrated across the entire life-cycle. While the life-cycle costing principles are identical across all phases, the organization in each phase differs in terms of - the actions that need to be taken; - the contribution each participant can make.

Figure 2 shows the "standard" field or project life-cycle together with some of the technical decisions taken at each stage, which may be the subject of life-cycle cost studies. The technical processes which are developed are concept selection, outline, design and FEED, detailed design, construction hook-up & commissioning, operation, production & maintenance and disposal. It is important to notice that the step "production and maintenance" includes a disposal strategy and review.

Focus on the step "disposal":

The work carried out at earlier stages will have considered the options in this phase. A basic disposal plan should have been agreed during outline design, but timing, schedule and final strategy will need to be decided in the light of actual production experience. The generic options are as follows:

- decommission the facility and dispose;
- re-use the facility in whole or part;
- sell on the asset (facility and field) as a going concern prior to the end of field life.

In comparing these options, there are timing differences between the first two and sale of the asset. Where asset sale is considered, life-cycle costing can be used to investigate the cost, revenue and time trade-offs. Where decommission and disposal is preferred, the appraisal techniques for evaluating disposal options are based on selection of the best practical environmental option taking into account cost, safety and the environment. These techniques are evolving and costing includes the use of shadow pricing and valuation on the basis of energy value. Developments in this area may in the future influence the appraisal criteria applied at early phases.

Part 3:

RECOMMENDATIONS AND COMMENTARY

- Common implementation issues are developed in order to provide technical solutions for the operator of the LCC;
- Roles and responsibilities of the operator are defined in order to optimize the realization of the LCC.
- Practical steps are also provided in order to minimize the impact of uncertainty in data during

the LCC's steps.

2.2	
TITLE	ISO 15686-5:2008, Buildings and constructed assets -- Service-life planning -- Part 5: Life-cycle costing
AUTHOR(S) and/or ORGANIZATION	ISO
SOURCE CATEGORY	International standard
GENERAL THEME(S)	LCC of buildings, constructed assets and their parts.
LCC APPROACH(ES)	Conventional LCC and WLC (Whole life costing i.e. Environmental LCC).
FUNCTIONAL UNIT(S)	Not mentioned explicitly. However it is specified that "a detailed life-cycle costing analysis should be based on the proposed design detailing and a quantum of individual elements or components of the constructed asset, which should be summed up to produce a LCC estimate."
SYSTEM BOUNDARIES	Life-cycle costing takes into account cost or cash flows, i.e. relevant costs (and income and externalities if included in the agreed scope) arising from acquisition through operation to disposal. Life-cycle costing typically includes a comparison between options or an estimate of future costs at portfolio, project or component level. Life-cycle costing is performed over an agreed period of analysis. It is advisable to make clear whether the analysis is for only part or for the entire life cycle of the constructed asset.
COST ALLOCATION	Not mentioned.
COST CATEGORIES	LCC cost categories **Construction** (professional fees, temporary works, construction of asset, initial adaptation or

	refurbishment of asset, taxes, other); **Operation** (rent, insurance, cyclical regulatory costs, utilities, taxes, other); **Maintenance** (maintenance management, adaptation or refurbishment of asset in use, repairs and replacement of minor components/small areas, replacement of major systems and components, cleaning, grounds maintenance, redecoration, taxes, other); **End-of-life** (disposal inspections, disposal and demolition, reinstatement to meet contractual requirements, taxes, other) WLC costs categories **LCC cost categories, with in addition:** **Externalities** **Non construction cost** (land and enabling works, finance, user support costs such as strategic property management, use charges and administration, taxes, other); **Income** (income form sales, third-party income during operation, taxes on income, disruption, other) **Environment cost** Environmental legislation can introduce costs (or savings via rebates) to life-cycle costing depending on the impacts that the asset's location, design, construction, use and disposal place on the environment. Where these costs are external to the constructed asset, they may form part of a WLC analysis. Included in the WLC not in the LCC.
EXTERNALITIES	Typically, the difference between WLC and LCC analysis is that the variables for WLC can include a wider range of externalities or non-construction costs, such as finance costs, business costs and income streams.

IMPACT ASSESSMENT	LCC impact assessment Detailed life-cycle costing analysis should be based on the proposed design detailing and a quantum of individual elements or components of the constructed asset. These should then be summed up to produce a LCC estimate based on first principles. As the design evolves, the impact of specific options should be tested to assess the impact on the overall cost (and other project performance requirements, such as time to complete the work). The level of analysis may include the specific consideration of service-life planning of the proposed design of composite items. More detailed service lives for particular assets should be considered to evaluate and inform specification choices. WLC impact assessment may also include impacts assessments related to: - environmental costs (Consideration of the environmental impact of potential investments can allow for the delivery of decisions based on sustainability issues. Further guidance on LCA is found in ISO 14040 and ISO 14044 and the link between service planning and LCA is dealt with in ISO 15686-6); - social costs and benefits; - intangibles (which can impact business reputation or the functional efficiency).
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	-

2.3	
TITLE	Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, ASTM E917 – 15
AUTHOR(S) and/or ORGANIZATION	ASTM
SOURCE CATEGORY	Standard

GENERAL THEME(S)	LCC buildings or building systems
LCC APPROACH(ES)	Conventional LCC
FUNCTIONAL UNIT(S)	Owing or operating a building or a building system and building systems over a period of time.
SYSTEM BOUNDARIES	Applied to buildings or building systems, the LCC encompasses all relevant costs over a designated study period, including the costs of designing, purchasing/leasing, constructing/installing, operating, maintaining, repairing, replacing, and disposing of a particular building design or system.
COST ALLOCATION	The LCC method is not suitable for allocating a limited budget among a number of non-mutually exclusive projects (where the acceptance of one does not preclude the acceptance of others), unless all of the projects can be meaningfully combined into the single overall LCC measure.
COST CATEGORIES	The measurement of the LCC of a building design or building system requires data on initial investment costs, including the costs of planning, design, engineering, site acquisition and preparation, construction, purchase, and installation; financing costs (if specific to the investment decision); annually and non-annually recurring operating and maintenance costs (including, for example, scheduled and unscheduled maintenance, repairs, energy, water, property taxes, and insurance); capital replacement costs; and resale value (or salvage/disposal costs). Data will also be needed for functional use costs if these costs are significantly affected by the design or system alternatives considered. These are costs related to the performance of the intended functions within the building, such as salaries, overhead, services, and supplies.
EXTERNALITIES	Not mentioned.
IMPACT ASSESSMENT	Important to have a realistic assessment of the project's resale (or residual) value at the end of the study period be included in the LCC analysis.
OTHER RELEVANT ASPECTS	Include the timing of each cost as it is expected to occur during the study period. The shorter the study period selected for the LCC analysis relative to the expected useful lifetime of the project being considered, the more important the assessment of resale value becomes, even if the

	building or system will not be sold at the end of the study period. Where relevant, deduct tax liabilities due to anticipated gains in asset value.
RECOMMENDATIONS AND COMMENTARY	-
2.4	
TITLE	Standard Practice for Determining the Life-Cycle Cost of Ownership of Personal Property, ASTM E2453 − 13
AUTHOR(S) and/or ORGANIZATION	ASTM
SOURCE CATEGORY	Standard
GENERAL THEME(S)	LCC of personal property assets owned or used by an entity. For businesses, these personal property assets are required to achieve financial returns from producing and selling goods or services, or both. For institutions and agencies, these personal property assets are required to accomplish their primary mission. Real and personal property assets may include capital (fixed) assets and movable, durable assets including: customer supplied assets, rental/leased assets, contract/project direct purchased assets, or expense items.
LCC APPROACH(ES)	Conventional LCC
FUNCTIONAL UNIT(S)	Owned or used item or group of items.

SYSTEM BOUNDARIES	Sum of all known material costs associated with an item or group of items and these costs include not only the acquisition value, but also activities related to an item from acquisition through utilization and disposition. Sometimes referred to as (total cost of ownership).
COST ALLOCATION	Not mentioned.
COST CATEGORIES	- Acquisition: Budgetary/planning–concept, feasibility, studies, funding, lease/buy, make/buy, and so forth and site acquisition, construction, design, purchase, receipt, and so forth; - Utilization: Skills, training required and knowledge of the user, utilities; recurring and preventive maintenance; - Disposition: Identification of idle or excess items or both, disposition determinations, actual disposal costs, and so forth.
EXTERNALITIES	Not mentioned.
IMPACT ASSESSMENT	Not mentioned.
OTHER RELEVANT ASPECTS	Two types of equations are provided to calculate the LCC of an item or of a group of items.
RECOMMENDATIONS AND COMMENTARY	-
2.5	
TITLE	Life cycle costing and Green Public Procurement
AUTHOR(S) and/or ORGANIZATION	European Commission
SOURCE CATEGORY	Green public procurement and LCC recommendations
GENERAL THEME(S)	Green public

LCC APPROACH(ES)	Conventional and Environmental LCC
FUNCTIONAL UNIT(S)	Supplies, services or works.
SYSTEM BOUNDARIES	Whole life-cycle of the supplies, services or works, and not solely on the purchase price. This allows costs associated with the use, maintenance and end-of-life of the supplies, services or works to be taken into account – sometimes also referred to as total cost of ownership.
COST ALLOCATION	Not mentioned.
COST CATEGORIES	Four main cost categories are assessed in order to estimate internal environmental costs: investment, operation, maintenance and end-of-life disposal expenses. An environmental LCC methodology takes into account the above four main cost categories plus external environmental costs, the externalities.
EXTERNALITIES	To be introduced into an 'accounting' LCC process, environmental costs must be expressed in monetary terms. In other words, environmental costs should be quantified and monetised so they can be considered as an additional cost input in a LCC analysis. Environmental costs may come from LCA analyses on environmental impacts, which measure for example the external costs of global warming contribution associated with emissions of different greenhouse gases. Environmental costs can be calculated also in respect of acidification (grams of SO2, NOX and NH3), eutrophication (grams of NOX and NH3), land use (m2*year) or other measurable impacts. **Example: Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles** [2] Under this Directive, contracting authorities and entities are obliged to take energy consumption and emissions into account in their purchases of road transport vehicles. One of the ways of doing this is

[2] DIRECTIVE 2009/33/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0033&from=EN

IMPACT ASSESSMENT	by assigning a cost to these factors in the evaluation of bids. The Annex to the Directive provides a set of common costs to be applied in this case. This allows emissions to be priced for inclusion in the evaluation and comparison of bids. Values are also provided in the Directive for the energy content of different fuel types and the lifetime mileage of different vehicle categories. **The Clean Vehicles Directive** on the promotion of clean and energy-efficient road transport vehicles, it is specified that the operational energy and environmental impacts to be taken into account shall include at least the following: - energy consumption; - emissions of CO 2 ; and - emissions of NOx , NMHC and particulate matter.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	-
Papers **3.1**	
TITLE	Evaluation of food waste disposal options by LCC analysis from the perspective of global warming: Jungnang case, South Korea
AUTHOR(S) and/or ORGANIZATION	Mi-Hyung Kim, Yul-Eum Song, Han-Byul Song, Jung-Wk Kim, Sun-Jin Hwang
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste

LCC APPROACH(ES)	Environmental LCC
FUNCTIONAL UNIT(S)	1 ton of food waste managed in 8 different scenarios: dry feeding, wet feeding, composting, anaerobic digestion, co-digestion with sewage sludge, food waste disposer, dryer incineration, landfilling.
SYSTEM BOUNDARIES	Included discharge, separate collection, transportation, treatment, and final disposal stages. By-products and final residues from the above scenarios were all within the system boundary.
COST ALLOCATION	Consequential approach. Allocation is avoided through substitution in LCA, henceforth also in LCC.
COST CATEGORIES	Different costs included, according to the scenarios. Discharge: equipment, electricity, water use; Collection: diesel, truck, labour cost (including wage, incentives, allowance, retirement pay), insurance (industrial disaster, health, unemployment, annuity), depreciation, repair fees, license tax, inspection fee, usage wear, and other costs; Transfer station: excavator, labour, energy and material use; Transportation to treatment: distance based cost; Treatment and disposal: material costs, labour costs (salary, incentives, allowance, retirement pay), net costs (electric charge, water usage, fuel cost, depreciation, repairing, inspection fee, insurance, welfare, chemicals, wastewater disposal costs, screenings and sludge disposal costs, taxes and fees), and general management expenses, margin, and incidental expenses.
EXTERNALITIES	Benefits deriving from by-products and CO_2 reduction were included by considering respectively the unit market price for substituted products and the carbon price trading in the carbon market.
IMPACT ASSESSMENT	Calculation of the 8 different total cost, total benefits, and benefits/costs ratios.
OTHER RELEVANT ASPECTS	-

RECOMMENDATIONS AND COMMENTARY	Food waste is implicitly defined as household food waste but no further specification is provided on its composition (edible, non-edible, etc.). Prevention is not included in the scenarios. Interesting the integrated application of LCA (GWP calculation with avoided impact from substitute products) and LCC with calculation of economic benefits from by-products and emission saving. Scores are not summed, so no risk of double counting.
3.2	
TITLE	The costs of household food waste in South Africa
AUTHOR(S) and/or ORGANIZATION	Nahman A., de Lange W., Oelofse S, Godfrey L.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	(LCC) food waste
LCC APPROACH(ES)	Not specified. The paper does not explicitly adopt a life cycle costing perspective, but it could be argued that it falls in the conventional costing perspective.
FUNCTIONAL UNIT(S)	Yearly household food waste in South Africa
SYSTEM BOUNDARIES	From household to disposal in landfill
COST ALLOCATION	Not specified
COST CATEGORIES	Direct loss of potentially valuable resource to feed the hungry using a weighted average market price of the wasted food, only applied to the edible share (using UK figures). The weighted average price per unit weight of food consumed was diversified by income group and then allocated to edible wasted fraction.

	Direct loss of value for wastage of inedible but compostable fraction ignored (no local market for composting, feeding or digestion). Cost of disposing in landfill including some externalities.
EXTERNALITIES	Emissions of landfill gas and leachate as well as transport externalities and disamenities were included in the cost of disposal.
IMPACT ASSESSMENT	No specific assessment or interpretation carried out.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	Useful as reference for external social costs that may be included for traditional disposal.
3.3	
TITLE	Costs of food waste along the value chain: Evidence from South Africa
AUTHOR(S) and/or ORGANIZATION	Nahman A., de Lange W.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	(LCC) food waste
LCC APPROACH(ES)	Not specified. The paper does not explicitly adopt a life cycle costing perspective, but it could be argued that it falls in the environmental life cycle costing perspective, as it encompasses all food value chain up to consumption.
FUNCTIONAL UNIT(S)	Yearly food waste in the whole value chain

SYSTEM BOUNDARIES	From agricultural production through to consumption
COST ALLOCATION	Not specified
COST CATEGORIES	As in the previous study, prices were used to estimate the direct cost deriving from the loss of value. No costs were associated to inedible fraction (see following paper). No disposal costs were included.
EXTERNALITIES	Not included.
IMPACT ASSESSMENT	No specific assessment or evaluation.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	-

3.4	
TITLE	Costs of food waste in South Africa: Incorporating inedible food waste
AUTHOR(S) and/or ORGANIZATION	de Lange W., Nahman A.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	(LCC) food waste
LCC APPROACH(ES)	Not specified. The paper does not explicitly adopt a life cycle costing perspective, but it could be argued that it falls in the environmental life cycle costing perspective, as it encompasses all food value chain up to consumption.

FUNCTIONAL UNIT(S)	Yearly inedible food waste
SYSTEM BOUNDARIES	From agricultural production through to consumption
COST ALLOCATION	Not specified
COST CATEGORIES	Opportunity cost of disposing food waste through landfill rather than using it as input to biogas production or composting. Estimates were based on: - LPG price as a proxy of biogas value - bulk compost price used as a proxy of compost from food waste (25% of value due to yield)
EXTERNALITIES	Not included.
IMPACT ASSESSMENT	No specific assessment or evaluation.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	-
3.5	
TITLE	Uncertainty analysis in the financial assessment of an integrated management system for restaurant and catering waste in Spain
AUTHOR(S) and/or ORGANIZATION	Escobar N., Ribal J., Clemente G., Rodrigo A., Pascual A., Sanjuán N.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste

LCC APPROACH(ES)	Environmental LCC. Although not explicitly the paper adopts LCC in adherence with a previous LCA, so it can be defined as an Environmental LCC
FUNCTIONAL UNIT(S)	It is defined as the "management of the amount of organic waste from restaurants and catering (excluding packaging residues) produced per person during a year in Spain" and it is equal to 1.70 kg of Used Cooking Oil (UCO)/inhabitant and year and 35.50 kg of Solid Organic Waste (SOW)/inhabitant and year.
SYSTEM BOUNDARIES	Two scenarios were analysed, both with a "grave to gate" perspective: - Scenario A included UCO collection, biodiesel production, SOW collection and sorting, anaerobic digestion of the SOW and energy cogeneration in a CHP engine. - Scenario B represents the average treatment in Spain and thus included the same phases with the exception of SOW disposal, which is landfilling of most of the SOW, composting of part and incineration of the remaining.
COST ALLOCATION	In general the paper argues that when dealing with co-product, both partitioning and system expansion could be adopted in LCC. While the first is done by allocation, the system expansion approach can be used by translating co-products with market value into revenues for the producer, as if they were avoided costs. In the paper: - in scenario A there are the electricity from the CHP engine and the digester sludge from the AD; - in scenario B there are electricity, glycerol and compost.
COST CATEGORIES	A detailed breakdown of costs (labour, electricity, depreciation, etc.) was carried out for biodiesel production, AD and cogeneration, while for the rest of the processes the unit cost of large facilities was deemed as more reliable. Straight-line depreciation was carried out for machineries, considering as capital stock the value of new replacements. Working hours were used to calculate labour cost, considering fixed wages and social security expenses. A standard overhead ratio was assumed.

EXTERNALITIES	Not included as it is a financial LCC applied in parallel to a LCA study.
IMPACT ASSESSMENT	Since the study assessed both costs and revenues, the authors stressed how the economic value added (EVA) and the profit could be measured. The first, being calculated as revenues minus the costs of intermediate inputs, gives an estimation of the economic impact of the system on the gross domestic product (GDP). The second is derived as the revenues minus the costs of material inputs, labour, capital and purchased services, thus offering an estimation of earning of an enterprise. However, a breakdown of costs is needed to calculate the EVA, profits were chosen as the variable to assess.
OTHER RELEVANT ASPECTS	Data quality and uncertainty is particularly stressed by the authors. In the specific, it is stated that, despite being rarely used, uncertainty analysis are important to assess several issues such as "taxation, wages, discount rates, changes in market prices driven by surpluses and market trends". Therefore, the authors defined technical and economic parameters as probability distributions rather than assigning specific values. So for most input and output price, equipment lifespan and various technical parameters a distribution was defined, either uniform, PERT, or real. Then the Monte Carlo simulation was chosen to analyse stochastic uncertainty. Tornado diagrams are then produced to show correlation of differentials between scenarios and varying parameters. LCC and LCA results are plotted with slopes measuring the trade-off between profits and environmental impacts.
RECOMMENDATIONS AND COMMENTARY	Scenario analysis beside uncertainty one is strongly recommended for all those normative changes that may result in change in regulated prices (e.g. electricity sale).
3.6	
TITLE	Integrated municipal waste management systems: An indicator to assess their environmental and economic sustainability
AUTHOR(S) and/or ORGANIZATION	Rigamonti L., Sterpi I., Grosso M.

SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC (food) waste The paper proposes a new composite indicator to assess the material and energy recovery of integrated waste management, together with costs. Food waste is considered in the organic waste stream (green and kitchen waste). Final indicator is not referred to single streams so it is not possible to identify costs attributable just to food waste.
LCC APPROACH(ES)	E-LCC Despite not being explicitly mentioned, authors analysed cost together with environmental indicators, and final results were also plotted. Thus the paper can be defined as a case of application of environmental LCC.
FUNCTIONAL UNIT(S)	All indicator are referred to 1 ton of collected MSW
SYSTEM BOUNDARIES	Grave to gate/grave. All segments from collection to treatment and final disposal are included in cost calculation.
COST ALLOCATION	Not mentioned. All costs are allocated to waste collected.
COST CATEGORIES	Collection costs: separate and residual waste collection (including transport and first processing); Treatment costs: operational costs from different treatment; Final disposal costs: from landfilling. All costs are net of profits from sale of energy, material, and transfers. Depreciation costs, accruals, and return on investments are considered as capital use.
EXTERNALITIES	Not included.

IMPACT ASSESSMENT	All costs from integrated waste management are summed and divided by the amount of collected waste. The final indicator is measured in €/t. Results are plotted against the composite energy and material recovery indicator. In the discussion section, another potential method of aggregation is suggested: specific market values of different materials and energy recovered are used to express also environmental indicators in €/t (authors signal that economic multipliers can change over time and space).
OTHER RELEVANT ASPECTS	None.
RECOMMENDATIONS AND COMMENTARY	Despite not being focused on food waste, the paper presents some useful information on conventional treatment costs (with reference to Italy) and on potential plotting or aggregation of environmental and economic assessments.
3.7	
TITLE	Life cycle costs and environmental impacts of production and consumption of ready and home-made meals
AUTHOR(S) and/or ORGANIZATION	Schmidt Rivera X. C., Azapagic A.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food (waste) The paper compares ready and homemade meals LCC and environmental impacts, with several scenarios and sensitivity analysis.
LCC APPROACH(ES)	E-LCC The authors refer to Swarr et al. (2011) and Hunkeler et al. (2008). The paper explicitly builds on a

	previous LCA study, therefore same functional unit, scope, and system boundaries were used.
FUNCTIONAL UNIT(S)	It is defined as "preparation and consumption of a meal for 1 person" composed of "chicken meat, three vegetables and tomato sauce." (pp. 215).
SYSTEM BOUNDARIES	Given the cradle to grave perspective, system for ready meal includes all stages from production and pre-processing of ingredients, their transport to a distribution centre, the preparation of the meal at a factory, another transport, the retail stage, the home purchase and consumption. In the case of home-made meal, the preparation of the meal is carried out at home, so no manufacturing and chilled/frozen transport is included.
COST ALLOCATION	All costs are attributed to the functional unit; no allocation is mentioned as no coproduction is considered. Chicken waste is assumed to be sold at the rendering industry so these revenues are included. Indirect costs such as overhead or others are not considered in the analysis and therefore not allocated.
COST CATEGORIES	Only flows considered in the LCA are included in the cost analysis. Therefore the following costs were collected for each segment: raw materials and ingredients, energy (electricity, natural gas, steam, and fuel oil), water and its disposal, refrigerant, different packaging materials and the disposal, transport. Food losses, wastes, and by-products were also considered for their disposal.
EXTERNALITIES	No externalities were considered in terms of costs.
IMPACT ASSESSMENT	The following indicators were calculated: - total life cycle cost from cradle to grave (including cost of materials, pre-processing, meal manufacturing, packaging, distribution, consumption and waste disposal); - value added from cradle to distribution (retail price minus life cycle cost up to distribution); - total life cycle cost from cradle to consumer (no disposal); - total consumer costs (retail price plus cost of consumption).
	Authors carry out a comparative analysis on the same scenarios contained in the LCA study. They first

	identify cost hotspots and differences in LCC and VA across the 8 ready meal scenarios and across the 7 home-made scenarios respectively. In each case, they carry out a sensitivity analysis on the influence of ingredient sourcing and cooking appliances, which are the more relevant factors. Then LCC, VA and consumers costs are compared between ready-made and home-made scenarios. Finally, LCC and several environmental results are summarized with qualitative approach to rank different meals in a "heat map". A colour ranking is assigned to each scenario in each criterion, rankings are then summed per each scenario (assuming equal importance), and final scores are then compared again for ranking: the lower the sum the higher the ranking.
OTHER RELEVANT ASPECTS	As food losses and wastes are regarded, authors did not carry out a specific analysis, but they included them as source of cost (disposal losses and waste) and/or revenues (chicken waste). However, due to the differences across the scenarios (frozen vs. chilled, ready- vs. home-made organic vs. conventional) the values of initial inputs (chicken and vegetables), chicken waste, products losses and wastes, and final food waste are different. This has also effects on final costs, as authors underline: "production costs of chilled and frozen meals are the same – the slightly higher energy costs from freezing are countered by lower wastage along the supply chain". In fact as shown in table 3 and 4, when manufacture and distribution are frozen, food waste tends to be lower, and food waste is minimized when the meal is home-made.
RECOMMENDATIONS AND COMMENTARY	Environmental cut off as been used also for cost inclusion. An economical cut off may change figures (e.g. labour cost, capital costs, machineries, etc.)
3.8	
TITLE	Environmental and economic analysis of the organic and conventional extra-virgin olive oil
AUTHOR(S) and/or ORGANIZATION	Notarnicola B., Tassieli G., Nicoletti G. M.
SOURCE CATEGORY	Journal paper

GENERAL THEME(S)	LCC food E-LCC
LCC APPROACH(ES)	The LCC in this paper is carried out in parallel with an LCA. Nevertheless, some external costs are included, so it may also be classified as a S-LCC.
FUNCTIONAL UNIT(S)	1 kg of extra virgin olive oil
SYSTEM BOUNDARIES	Cradle to gate approach, from agriculture to oil extraction, including packaging, indirect processes (production and transport of inputs and energy), transport of workers involved.
COST ALLOCATION	While oil husk is mentioned as co-product and economic allocation is used for LCA inventory, no specific indication is provided for LCC. Mill wastewater is assumed to be spread on the field.
COST CATEGORIES	Costs of inputs (pesticides and fertilizers, oils, electricity, water, fuel), cost of labour, cost of certifications (organic and HACCP), cost of transport, cost of packaging, waste disposal fee.
EXTERNALITIES	External costs relative to energy and chemicals use were included and overall LCC with or without external costs were compared.
IMPACT ASSESSMENT	Not specific aspects.
OTHER RELEVANT ASPECTS	None.
RECOMMENDATIONS AND COMMENTARY	-
3.9	
TITLE	Optimization of organic and conventional olive agricultural practices from a Life Cycle Assessment and

	Life Cycle Costing perspectives
AUTHOR(S) and/or ORGANIZATION	Mohamad R. S., Verrastro V., Cardone G., Bteich M. R., Favia M., Moretti M., Romac R.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food
LCC APPROACH(ES)	C-LCC, but with a cradle to gate perspective.
FUNCTIONAL UNIT(S)	1-ha olive-growing area. The impacts of two systems were compared (conventional and organic).
SYSTEM BOUNDARIES	Cradle to gate: boundaries all costs occurred during the entire olive life cycle.
COST ALLOCATION	Not mentioned.
COST CATEGORIES	Investment costs (soil preparation and planting); future investments (irrigation system); operational costs (inputs, labour, interests). Taxes excluded. Revenues: olives and subsidies for organic.
EXTERNALITIES	Not included.
IMPACT ASSESSMENT	Net present value and Internal rate of return were calculated. Discount rate estimated to 1,25%. Investment (initial and future) costs are compared, as well as annual operating costs divided by stage (juvenile, growth, productive). Then total costs and revenues and net cash flow are compared across

	the whole life span. Finally, basing on olive prices, NPV and IRR are calculated for both the scenarios and for different organic prices.
OTHER RELEVANT ASPECTS	None.
RECOMMENDATIONS AND COMMENTARY	None.

3.10	
TITLE	Sustainability evaluation of Sicily's lemon and orange production: An energy, economic and environmental analysis
AUTHOR(S) and/or ORGANIZATION	Pergola M., D'Amico M., Celano G., Palese A.M., Scuderi A., Di Vita G., Pappalardo G., Inglese P.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food
LCC APPROACH(ES)	E-LCC Being carried out in parallel with an LCA, this study can be classified as an E-LCC.
FUNCTIONAL UNIT(S)	The main functional units under study are 1 ha of cultivation of oranges and lemons, but also a mass-based FU of 1 kg of output (fruit crop average yield) is considered. The reference period is 50 yy (estimated life of orchards).
SYSTEM BOUNDARIES	Cradle to gate. The whole orchard life cycle was included in the system studied, from the plantation (including soil preparation) to final removal.
COST ALLOCATION	All costs were allocated to the functional unit and fruit was the only output of the orchard.

COST CATEGORIES	Cumulative costs related to materials (chemicals, energy, water and others), labour and services, quotas and other duties (cost of workers, equipment, depreciation, and interests) were assessed for the whole life cycle. Costs were then grouped by specific operation (pruning, disease control, irrigation, etc.) and by orchard phase (plantation, growing tree, full production, plants removal).
EXTERNALITIES	No externality was considered.
IMPACT ASSESSMENT	Whole LCC was calculated as sum of cumulative costs of each cultivation phase.
OTHER RELEVANT ASPECTS	None
RECOMMENDATIONS AND COMMENTARY	As far as pruning by-products are regarded, they were considered to be manually removed from the lemon orchards and then burned, while they were left on the ground in orange orchards. As far as not harvested fruit or product loss are regarded, there is no specific mention in the paper.

3.11	
TITLE	Biogas from dedicated energy crops in Northern Italy: electric energy generation costs
AUTHOR(S) and/or ORGANIZATION	Schievano A., D'Imporzano G., Orzi V., Colombo G., Maggiore T., Adani F.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	(LCC) food waste The study estimates electric generation costs from dedicated energy crops and evaluates the potential impacts of their substitution with agroindustrial residues and organic waste (data from a previous study).

LCC APPROACH(ES)	The approach can be considered a quasi-LCC as it includes several cost, from field operations and inputs up to management/maintenance of biogas plant and depreciation.
FUNCTIONAL UNIT(S)	Total costs are assessed at different level per different functional units, as follows: - Production cost: €/ha of land cultivated - Biomass cost: €/t (both fresh and dry matter) - Biogas cost: €/Nm^3 - Electricity generated: €/kWh_e
SYSTEM BOUNDARIES	From crop production to electricity generation.
COST ALLOCATION	All costs are allocated on the product studied (biomass, biogas, electricity).

COST CATEGORIES	The following costs were collected by the authors:
	- Biomass supply (in case of dedicated crops)
	  o Soil preparation
	  o Fertilization and fertilizers
	  o Seeding and seeds
	  o Various operations
	  o Harvest, including chopping, transport and ensiling
	  o Management costs
	  o Negative costs from CAP incentives
	- Plant management and maintenance (literature)
	- Depreciation charge (literature)
	
	In the case of agro-industrial by-products, different costs were derived from previous studies, while in the case of organic waste, cost was considered null (already covered by the waste tariff).
	
	Notably, management/maintenance and depreciation costs of plants able to treat organic waste are different.

EXTERNALITIES	None considered.
IMPACT ASSESSMENT	Total cost of electricity generation was assessed across several scenarios with different feedstock used (dedicated energy crops or by-products and waste). Then costs are compared with electricity generation costs related to other energy sources, and with the final consumer price.
OTHER RELEVANT ASPECTS	None.
RECOMMENDATIONS AND COMMENTARY	For several agroindustrial residues a price is paid by biogas plant owners. These prices can be sometimes retrieved through literature or business organizations. In the case of organic waste, costs were considered null as a waste treatment tariff was already paid by waste producers. This aspect needs to be properly assessed in the case of a comparative LCC (e.g. prevention vs. treatment) in order to avoid double counting or inconsistencies in considering transfers, taxes, price paid for feedstock. One of the main aspect of the paper is that agro-industrial residues and organic waste (thus also food losses and waste) could result in lower biomass supply costs for biogas plant owners, thus reducing reliance on energy crops, the related impacts and markets (these avoided impacts should be included? how?).
3.12	
TITLE	Life cycle assessment and environmental life cycle costing analysis of lignocellulosic bioethanol as an alternative transportation fuel
AUTHOR(S) and/or ORGANIZATION	Daylan B. and Ciliz N.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste

LCC APPROACH(ES)	E-LCC The paper compares through combined LCA and ELCC analyses the environmental and economic impacts of running a flexi-fuel vehicle with bioethanol from lignocellulosic feedstocks or conventional gasoline.
FUNCTIONAL UNIT(S)	Since the focus of the analysis is on vehicle fuel, the functional unit is a 1 km travel distance run with a FFV.
SYSTEM BOUNDARIES	System included feedstock acquisition in the field (baling of straw/stover, transport, storage), bioethanol production, distribution of blend, and combustion of fuel. No cultivation stage was included as corn stover and wheat straw are reputed as by-products.
COST ALLOCATION	No cost allocation used. All cost is attributed to fuel consumed. Bioenergy produced with by-products was entirely consumed by the facility.
COST CATEGORIES	The following costs were included in the analysis: feedstock, variable costs related to inputs (chemicals, enzymes, and nutrients, etc.) and fixed costs (employee salaries and maintenance) Costs related to chemicals and salaries were indexed to 2010 dollar values, while the gasoline production cost was based on the year 2009.
EXTERNALITIES	Not included.
IMPACT ASSESSMENT	Total life cycle costs were referred to the functional unit of 1 km, and then reported also in terms of €/kg through fuel economy balance (km/kg).
OTHER RELEVANT ASPECTS	None
RECOMMENDATIONS AND COMMENTARY	Lignocellulosic wastes from food systems can be converted into bioethanol, thus this study can be useful for costing of this potential valorisation route.

3.13	
TITLE	The effects of recycling loops in food waste management in Japan: Based on the environmental and economic evaluation of food recycling
AUTHOR(S) and/or ORGANIZATION	Takata M., Fukushima K., Kino-Kimata N., Nagao N., Niwa C., Toda T.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste
LCC APPROACH(ES)	E-LCC This paper evaluated the environmental impacts and economic efficiency of current food waste recycling in so called looped facilities in Japan. LCA and LCC analysis were simultaneously applied and a comparison of looped and non-looped facilities was conducted.
FUNCTIONAL UNIT(S)	Since function of looped facilities is the recycling of food waste, the functional unit of the study was defined as the management of 1 ton (wet weight) of food waste.
SYSTEM BOUNDARIES	Depending on the 5 scenarios (different facilities), different processes were included: Scenario 1 (S1) machine integrated composting: FW crushing and mixing with moisture conditioner in containers on shelves; electricity is used for temperature and moisture control; Scenario 2 (S2) windrow composting: FW is crushed, mixed with a moisture conditioner, then stacked in windrow until compost is mature; electricity and diesel are used; Scenario 3 (S3) liquid feed manufacturing: edible FW (defective and unsold products) are collected, then crushed and mixed basing on specific target in terms of nutrients and taste; strict controls are in place in order to guarantee animal safety; Scenario 4 (S4) dry feed manufacturing: separation from plastic, crushing, mixing, drying (with propane); electricity is also needed; Scenario 5 (S5) bio-gasification: wet thermophilic anaerobic digestion plant with wastewater

	treatment; electricity is used within the system
COST ALLOCATION	Not specified.
COST CATEGORIES	For all scenarios the following costs were collected: maintenance, labour, utility, purchased waste, flocculants. Collection fees and sales of recycled products were considered as negative costs and subtracted to running costs.
EXTERNALITIES	Not included.
IMPACT ASSESSMENT	A comparison across the scenarios was carried out. Results showed in the case of composting facilities very low costs deriving from collection fee received. Animal feed production showed higher costs because of the need for safe and nutritional food waste. High costs were also registered for biogasification due to the purchase of flocculants for water treatment, labour costs, and maintenance. As far the comparison with non-looped facilities is regarded, four factors were assessed: FW collection, sales of products, collection fees, operating rates. Both the amount and the revenues from FW collection in looped facilities were significantly higher. Differences in operating rates were not statistically significant
OTHER RELEVANT ASPECTS	It is mentioned that both GHG emissions and costs in most food recycling facilities were lower than in incineration facilities (although not specified how much and if significant). Composting facilities have low impact but also low economic efficiency. Comparison of collection fees was carried out on the basis of food waste quality: high for by-products from food manufacturers, middle for unsold products from food retailers and low for kitchen waste from food service. High quality food waste was charged with a higher collection fee which is expected to reduce the amount of food waste emission from food industry.
RECOMMENDATIONS AND COMMENTARY	Recycling loop determined a cost improvement for animal feed facilities

3.14	
TITLE	Life cycle costing of waste management systems: Overview, calculation principles and case studies
AUTHOR(S) and/or ORGANIZATION	Martinez-Sanchez V., Kromann M. A., Astrup T. F.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC (food) waste
LCC APPROACH(ES)	Comparison between C-LCC, E-LCC and S-LCC in assessing waste management systems. The authors provide an overview of differences between approaches, cost structures, etc. with a thorough review of the literature and then provide an example of application to a case study. Definitions from Hunkeler et al. are followed.
FUNCTIONAL UNIT(S)	GENERAL Planning LCCs aim at evaluate economic consequences of changes in the system, while analysis LCCs provide a photograph of current situation. Depending on the approach, they may have different goals: - C-LCC: no environmental focus, thus economic viability or impacts of a certain treatment or identification of best performing solutions; - E-LCC: simultaneous with LCA, inclusion of several stakeholders, thus distribution of net costs or savings; - S-LCC: estimation of welfare impacts. CASE STUDY Goal of the case study is to analyse costs from source separation and treatment of organic waste from 100000 Danish households under 2 scenarios (current treatment and source separation plus digestion

	of organic waste). Functional unit is 1 ton of food waste treated.
SYSTEM BOUNDARIES	GENERAL This is one of the critical issues raised by the authors with regard to literature: system boundaries do not always correspond between economic, social, and environmental assessment. This is true for both process cut-off and geographical scope. They depend on the specific study in question (especially for C-LCC) but in the case of E-LCC and S-LCC they should be identical to LCA. CASE STUDY Grave to grave approach: boundaries include source separation, collection, treatment, transport, final disposal or use. Differences among scenarios of the case study are: 1) Current treatment method (incineration applied to mixed waste including organic, separation of paper and glass); 2) As current scenario except for source segregation of organic waste, its co-digestion with animal manure, and final disposal of digestate.
COST ALLOCATION	GENERAL AND CASE STUDY All activities/technologies are defined per ton of food waste, with a bottom-up approach. The first step is to divide waste system into activities or waste stages (separation, collection, transportation etc.); per each activity cost items like machinery, salaries, fuel and maintenance costs were disaggregated; to each of these items, a physical (described quantity) and economic (described cost) parameter are assigned. Finally, each item is classified as budget, transfer or externality cost. One-off costs (capital, etc.) were allocated by converting lump sums (present or future values) into annuities and dividing annuities by annual usage rates (€/y divided per t/y). Annual usage rates can differ from annual capacity (e.g. incinerator operating at lower level because of avoided wastage). Annual usage rates are different depending on the technology. Same rates were used to allocate annual fixed costs to tons of waste treated. Variable costs were allocated directly by multiplying

COST CATEGORIES	physical amounts of inputs needed per their price. Discounting was used for future operating and maintenance costs as well as revenues. Similar allocation was used for transfers (amount of item per FU and transfer per item). GENERAL Internal: monetary costs inside and outside the waste management system; External: outside the economic system, they have no direct monetary value in the market. 3 types of cost in the cost model (UCM): budget costs (in all 3 LCCs), transfers (only in CLCC and ELCC) and externality costs (only in SLCC). Authors account for budget costs in different ways according to LCC approach: factor prices (market price minus transfer) for C-LCC and E-LCC; shadow prices (factor price per "net tax factor") in S-LCC. Two types of transfers are identified: flows that redistribute income between stakeholders (e.g. taxes or subsidies); pecuniary externalities that occur to offset facilities (substitution of heat, electricity, etc.). Externalities are non-compensated effects on individuals welfare, they can be environmental or not (e.g. noise or time spent for waste sorting). Whenever externalities are priced and covered within the system (e.g. tax), they become transfers. C-LCC included all budget costs (factor price) and transfers. E-LCC included also anticipated transfers (externalities expected to be internalized). S-LCC accounted for budget costs and externalities in terms of shadow prices. Authors identified how discounting future financial costs is quite crucial when results are to be showed together with LCA (this contrasts with Hunkeler et al.). CASE STUDY Per each scenario the following costing perspectives were used: 1) costs for the entire system 2) costs for an individual household (waste fee) 3) costs incurred by the incinerator operator 4) costs incurred

	by the collection operator.
EXTERNALITIES	GENERAL Besides what previously mentioned, further details regarding the inclusion of externalities is provided by authors. Unit emissions per FU are multiplied by accounting prices of emission, which can represent society's willingness to pay for avoiding emissions/impacts or abatement costs. 3 potential externalities can be included: direct, upstream (from commodities and goods production), downstream (from displaced productions, as in recycling). When accounting for externalities, time is an important issue: current emissions can have future damages that may be discounted; current waste management can have future emissions to be accounted and discounted. In both case, future annual damage costs should be considered in present value through transparent discount rates. Outcomes of S-LCC may be largely affected by valuation techniques and lack of appropriate measures. For example, time spent by household in sorting could be valued not only as a cost/burden for families (thus a positive external cost) but also as a benefit (thus a negative external cost). Assumptions made on the inclusion/exclusion and valuation principles of externalities may affect results. Authors also point out that certain externalities (e.g. resource scarcity) may be already reflected but only partially by market prices (especially short term availability). In this case, E-LCC combines both short term effects on the economic side and long term effects on the environmental side. CASE STUDY No externality was included (as anticipated transfer) in the E-LCC. In the S-LCC, positive net externality costs were registered for source separation and collection of waste, ash landfilling and neutralization of air control residues. Negative net externalities were reported for energy and material

IMPACT ASSESSMENT	recovery. GENERAL AND CASE STUDY Evaluation is carried out according to the following costing perspectives: 1) costs for the entire system 2) costs for an individual household (waste fee) 3) costs incurred by the incinerator operator 4) costs incurred by the collection operator. Results shows that scenario 2 is more costly than 1, leading to an extra financial cost of 16€/year/household. C-LCC allowed tracing differences between scenarios (costs associated with the source separation of organics with extra bins and bags and increased collection costs). For the E-LCC, the LCA results were taken into account (no externalities internalized). In the S-LCC, net externality costs added. Since a sensitivity analysis was beyond the scope of the paper, a break-even analysis was carried out to assess the following: - digestate price level to raise enough revenues in Sc.2; - minimum number of households sharing a container to reach a 75% reduction in difference between scenarios; - potential value of sorting time to balance extra costs of separately treat organic waste.
OTHER RELEVANT ASPECTS	Some studies reviewed reapplied cost data or functions as inputs: this may lead to inaccuracies. For example, transfers or revenues may be included or excluded. Besides, authors underlined that different transfers may be applied in different geographical contexts (even within a country). Authors used a zero-burden approach, thus excluding upstream activities generating waste flows.
RECOMMENDATIONS AND COMMENTARY	-
3.15	
TITLE	Application of LCSA to used cooking oil waste management

AUTHOR(S) and/or ORGANIZATION	Vinyes, E., Oliver-Solà, J., Ugaya, C., Rieradevall, J., Gasol, C.M.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste
LCC APPROACH(ES)	E-LCC Costing is carried out in combination with a parallel LCA and SLCA.
FUNCTIONAL UNIT(S)	Yearly amount of used cooking oil (UCO) generated in a neighbourhood of 10000 inhabitants in Barcelona.
SYSTEM BOUNDARIES	Cradle to collector gate. 3 domestic UCO collection systems are compared: schools (SCH), door-to-door (DTD) and urban collection centres (UCC). The objective is to determine which systems should be preferred for the collection of UCO in Mediterranean countries. Thus system boundaries include collection by workers with disabilities, transport to a special working centre, storage and cleaning of containers and transport to biodiesel plant for SCH and DTD. For UCC, consumers are taking containers to UCC (walk distance) and then cleaning them at home; UCC stores UCC and then transport it to biodiesel plant. Burden from upstream and downstream segments are excluded. Since the 3 systems have different efficiency, different volumes of UCO were collected.
COST ALLOCATION	In the case of UCC system, costs and economic outputs needed to be allocated since centres treats different type of waste. Allocation has been based on UCO share on the total waste collected (4%).
COST CATEGORIES	Internal costs are: collection and storage container production, salary of different employer categories and fuel cost related to transport stages. External costs are: the cost of mitigating CO2 emissions, according to the international CO_2 market. These costs are included in the LCC but are not summed up in the final aggregation (avoid double counting).
EXTERNALITIES	Since the approach is LCSA, environmental and social LCAs are assessing externalities. However, in the separate LCC result discussion, also potential costs from CO_2 emissions are included.

IMPACT ASSESSMENT	GENERAL Being a combination of social, economic, and environmental impacts, LCSA requires a multi-criteria approach. First, indicators were distinguished in negative and positive, basing to their contribution to sustainability (e.g. costs are negative). Values for each indicator were converted in percentages (comparatively). Different scales of scores for negative and positive indicators were used to assign scores. Total scores per scenario and assessment were calculated as sum and then recalculated in relative terms (0-1). The closer to 1 the higher the contribution to sustainability. CASE STUDY UCC: lowest management cost (fewer employees), higher cost of transport due to higher collection of UCO and need to transport to biodiesel plant. DTD: highest management cost (number of employees required plus complex logistics). SCH: suitable values for social performance but not for the environmental and economic components, higher cost during collection. Higher cost in CO_2 mitigation due to more intermediate transport stages.
OTHER RELEVANT ASPECTS	Sima Pro 7.2. used
RECOMMENDATIONS AND COMMENTARY	In order to avoid double counting, CO2 emissions costs have been included as external cost in the LCC, but these costs are not considered in the LCC scoring process, because CO2 emissions have already been scored in LCA.
3.16	
TITLE	Rescuing Food from the Organics Waste Stream to Feed the Food Insecure: An Economic and Environmental Assessment of Australian Food Rescue Operations Using Environmentally Extended Waste Input-Output Analysis
AUTHOR(S) and/or ORGANIZATION	Reynolds, C.J., Piantadosi, J., Boland, J.

SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	(LCC) food waste
LCC APPROACH(ES)	Not a proper LCC. Authors used a so called waste supply-use (WSU) analysis, which is derived from a Waste Input-Output (WIO) framework and a food waste environmental impact quantification methodology. Nevertheless it is relevant for the report as it assess the rescued food value and the economic impact (economic activity needed), confronting it with conventional disposal.
FUNCTIONAL UNIT(S)	Being a different approach, no explicit FU is used. Results are referred to 1 ton of food waste rescued, 1 dollar spent on food rescue.
SYSTEM BOUNDARIES	Not mentioned. An economic system perspective is considered. In the I-O model, charities are moved to waste treatment activities.
COST ALLOCATION	Monetary value of rescued food waste was derived by calculating the price per ton of food (gross production value from FAO divided by tonnage produced per each category) and multiplying values per food waste quantities. It was assumed that food waste has still market value (basic price).
COST CATEGORIES	Monetary value of rescued food waste; Economic impact (cost for the economic system) as per I-O methodology.
EXTERNALITIES	Not monetized.
IMPACT ASSESSMENT	Economic impact per ton processed by charities as proxy of activity cost: it has higher activity costs than landfill and composting, due to the higher inputs in terms of service, transport, manufacturing, industries, etc. These costs are however lower than purchase price of the same amount of food: 6$ of food value rescued per dollar spent in food rescue.
OTHER RELEVANT	None.

ASPECTS	
RECOMMENDATIONS AND COMMENTARY	None.
3.17	
TITLE	Life cycle costing of food waste management in Denmark: importance of indirect effects
AUTHOR(S) and/or ORGANIZATION	Martinez-Sanchez V., Tonini D., Moller F., Astrup T.F.
SOURCE CATEGORY	Journal paper
GENERAL THEME(S)	LCC food waste
LCC APPROACH(ES)	Comparison between E-LCC and S-LCC in assessing food waste scenarios, including direct and indirect effects. The authors build on previous paper (see Martinez-Sanchez et al. 2015) as per cost modelling
FUNCTIONAL UNIT(S)	"The management of annual food waste generated by Danish households: 1,500,000 single-family housing (SFH) and 1,000,000 multi-family housing (MFH) units". Further specifications are: - shares of vegetable food waste (VFW) and animal derived food waste (AFW); - shares of edible food waste for both previous categories. Four scenarios analysed: - Incineration of FW with mixed municipal solid waste; - Source separation and anaerobic digestion with manure plus incineration of non-segregated food waste; - Source separation of VFW and treatment to be used as animal fodder, plus incineration of AFW and

	non-segregated VFW; - Prevention of 100% of the edible food waste and incineration of the inedible FW. Function is the same regardless of the fact that in the fourth scenario the amount of FW treated is lower.
SYSTEM BOUNDARIES	For all scenarios the following direct effects are included: - Food production (With the exclusion of prevention scenario); - Food waste generation; - Collection (either mixed or source-separated); - Treatment of related mass; - Outputs (energy or resources recovered as avoided products). In food production, the use and transportation of food by households and its packaging were excluded due to lack of data. Consequential approach (system expansion) is used for outputs; marginal products are identified for substitution. The following indirect effects were included: - Indirect land use change from food production (With the exclusion of prevention scenario); - Income effects (from cost net savings on waste management).
COST ALLOCATION	All costs are allocated on the FU. Using a consequential approach, coproducts from waste management are treated as avoided products.

COST CATEGORIES	E-LCC includes budget costs and transfers, distinguished by six actors (waste managers, energy sector, food industry, agriculture, other industries, and the State), whose expenses are transferred to households as final cost bearers. In the specific, budget costs include: cost for waste management and food production plus savings from resource and energy recovered from FW. Transfers include: tax revenues from waste management and food production; lost tax revenues from avoided energy and resources; subsidies for biogas. For indirect effects, no financial consequence was considered for indirect land use change while income effect were considered as further expenses, including transfers received by the State (VAT).
EXTERNALITIES	Environmental impacts were calculated through a LCA and monetized only in S-LCC as externality costs (willingness to pay to avoid adverse impacts of emissions). Impacts from indirect effects (including expenses on other goods/services due to income savings) were included in LCA and S-LCC
IMPACT ASSESSMENT	Both E-LCC and S-LCC were applied as described in Martinez-Sanchez et al. 2015. E-LCC includes LCC plus LCA, while S-LCC merged both in social costs. Authors stressed that both approaches have limitations as "only environmental impacts of emissions are included in the environmental part of the E-LCC (i.e. in the LCA), and only externalities with available accounting prices are included in the S-LCC".
OTHER RELEVANT ASPECTS	Authors assumed: - no effect on price of food; - households are paying for the entire system; - level of saving is constant (income effect is only on consumption).
RECOMMENDATIONS AND COMMENTARY	Only source for E-LCC and S-LCC of FW prevention (besides other treatments). Some limitations are:

	- only household food waste; - prevention only at consumer level; - no price effects; - few valorisation options foreseen;
Reports **4.1**	
TITLE	Towards a life cycle sustainability assessment: making informed choices on products.
AUTHOR(S) and/or ORGANIZATION	Ciroth, A.; Finkbeiner, M.; Hildenbrand, J.
SOURCE CATEGORY	Report
GENERAL THEME(S)	Life Cycle Sustainability Management This report from UNEP/ SETAC Life Cycle Initiative presents the concept of Life Cycle Sustainability Assessment (LCSA) and proposes methods for the integrated evaluation of environmental, social, and economic life cycle impacts of products and services.
LCC APPROACH(ES)	Environmental LCC as defined by Hunkeler et al. (2008), proposed as "economic pillar" of LCSA.
FUNCTIONAL UNIT(S)	It represents the function which costs and benefits are related to. It should be defined together with goal and scope, following ISO 14040.
SYSTEM BOUNDARIES	Also system boundaries should follow ISO 14040. The viewpoint of the life cycle actor should also be defined.

COST ALLOCATION	After the cost breakdown structure is developed, costs should be inventoried at unit process level and then aggregated at a relevant level. Overhead and similar other costs should be distributed proportionally to various products, following a criterion, e.g. income or number of working hours.
COST CATEGORIES	They are used to aggregate costs. Different categorizations can be found in different regions and among different actors.
EXTERNALITIES	Benefits deriving from by-products and CO_2 reduction were included by considering respectively the unit market price for substituted products and the carbon price trading in the carbon market.
IMPACT ASSESSMENT	Results interpretation (and eventually a review) is the final step. Three dimensions are relevant: life cycle stage, cost category, product work/breakdown structure
OTHER RELEVANT ASPECTS	Research should focus on: definition of cost categories, data availability and data quality assessment and assurance. Case studies are provided on: - LCC of standard public transport heavy duty buses - LCC of a washing machine with water recirculation - LCC as part of a LCSA of electronic waste management
RECOMMENDATIONS AND COMMENTARY	-
4.2	
TITLE	Life Cycle Costing. A Question of Value.
AUTHOR(S) and/or	Perera O., Morton B., Perfrement T.

ORGANIZATION	
SOURCE CATEGORY	Report
GENERAL THEME(S)	Life Cycle Costing This report from IISD reviews public procurement policies and voluntary initiatives on sustainable publishing in order to discuss the role of LCC methodologies.
LCC APPROACH(ES)	Conventional LCC as defined in the International Organization for Standardization standard, Buildings and Constructed Assets, Service-life Planning, Part 5: Life-cycle Costing (ISO 15686-5)
FUNCTIONAL UNIT(S)	Not specific indications, but potential uses of LCC in public procurement (goal and scope): - design tender specifications; - develop indicators for evaluation; - provide justification for the purchase of goods/services with high initial cost; - choose between purchase or contracting assets/services. Also relevant the table on the suitability of LCC to several products and services: the level of applicability is considered high in the case of "waste handling" and "catering: beverages" and moderate in the case of "catering: food".
SYSTEM BOUNDARIES	Not mentioned
COST ALLOCATION	Not mentioned
COST CATEGORIES	Not mentioned
EXTERNALITIES	Increasing need to include also social and environmental cost and benefits in public procurement accounting, so LCC should also include these externalities, although difficult to account for or forecast.

IMPACT ASSESSMENT	Financial evaluation tools such as NPV or IRR are hardly known by procurers, and there's debate on the use of appropriate discounting rates, which can be lower in the case of public sector (2-7%) than the private one (2-18%). Tailored methodology and little to no application of risk assessments and/or sensitivity analysis.
OTHER RELEVANT ASPECTS	Database of enough quality are needed for benchmarking of proposals against common cost figures. Case studies are needed especially on frequent areas of public sector spending (e.g. food), and also in showing application of methodologies for externalities accounting. Price volatility and geographical variability should be assessed, for example through normalization of data for cross-country comparisons. Compatibility with LCA is also signalled as being requested by procurers. In all cases where alternatives are evaluated also with LCA, the most advantageous in terms of LCC was not the best solution for LCA.
RECOMMENDATIONS AND COMMENTARY	LCC should be part of public expenditure policy LCC should be made a necessary component in sustainable public procurement policies

4.3	
TITLE	Criteria for and baseline assessment of environmental and socio-economic impacts of food waste
AUTHOR(S) and/or ORGANIZATION	Scherhaufer S., Lebersorger S., Pertl A., Obersteiner G., Schneider F., Falasconi L., De Menna F., Vittuari M., Hartikainen H., Katajajuuri JM, Joensuu K., Timonen K., van der Sluis A., Bos-Brouwers H., Moates G., Waldron K., Mhlanga N., Bucatariu CA., Lee WTK., James K., Easteal S.
SOURCE CATEGORY	Report

	(LCC) food waste
GENERAL THEME(S)	This report concludes the research from the FUSIONS Work Package (WP) 1, aiming at a summary of the existing knowledge related to socioeconomic and environmental impacts of food waste. While no specific mention to LCC is done, information on economic impacts of food waste is summarized from previous literature, in chapter 6.
LCC APPROACH(ES)	None
FUNCTIONAL UNIT(S)	Not specified, but studies that calculated economic impacts of FLW by their economic value are cited (see also section 6.3). In these studies a mass unit (tonne) is used. However these approaches are usually not based on a life cycle perspective, but on a supply/value chain perspective.
SYSTEM BOUNDARIES	Not specified, but citing a study from OECD, several potential cost items or investments for reduction of FLW are provided (see table 6.4 in the document).
COST ALLOCATION	Not specified.
COST CATEGORIES	Some examples of cost items/categories are provided in table 6.4 of the document, in the case of reduction of FLW.
EXTERNALITIES	FLW prevention can have uncertain impacts on the demand and supply of food, with potential trade-offs, that a LCC approach should probably take in consideration. Citing a paper from Rutten, it is argued that lower food prices from food waste reduction could actually result in a higher consumption and to some extent also in more food waste. Likewise if consumers are reducing food waste, producers would produce less, requiring less manpower. Finally, an investment in losses reduction could have uncertain outcomes in the long term from price reduction. Other reviewed empirical studies show that reducing FLW in the EU does not benefit SSA, mainly because of price reduction and the following consequences for producers, depending on trade relations.

IMPACT ASSESSMENT	Not specified.
OTHER RELEVANT ASPECTS	Not specified.
RECOMMENDATIONS AND COMMENTARY	Useful document to include certain aspects such as trade-offs arising from investments/actions of FLW reduction or prevention.
4.4	
TITLE	Food Wastage Footprint. Full-cost accounting.
AUTHOR(S) and/or ORGANIZATION	FAO – Food and Agriculture Organization
SOURCE CATEGORY	Report
GENERAL THEME(S)	(LCC) food waste This report presents a methodology that enables the full-cost accounting (FCA) of the food wastage footprint, including: market-based valuation of the direct financial costs, non-market valuation of lost ecosystems goods and services, and well-being valuation to assess the social costs associated with natural resource degradation.
LCC APPROACH(ES)	Societal perspective Although the study has not a life cycle perspective, it presents relevant features for a Societal LCC, due to the monetization of social and environmental externalities. In the specific it adopts a "general equilibrium" approach, defining the full costs of food wastage "as the difference between the aggregate net welfare in society (i.e. total benefits minus total costs)

	derived from the current food system (i.e. with food wastage) and the aggregate net welfare from a hypothetical food system with less food wastage. The food wastage level that would be optimal is when the welfare difference is maximal between the current and hypothetical food systems. This accounts for the fact that a zero-food-wastage world is not socially optimal in economic terms, while a lower but positive level of food wastage is" (pag. 11). Given than not enough data are available for a CGE model, a linear approximation is then adopted.
FUNCTIONAL UNIT(S)	The yearly amount of food lost and wasted at the global level with reference to 2005-2009 figures.
SYSTEM BOUNDARIES	They include all parts of the food system where wastage may occur, the whole supply chain (including final disposal), all inputs to the supply chain, and outputs, as impacts on environment and society.
COST ALLOCATION	Costs are allocated on losses and wastes basing on mass.
COST CATEGORIES	Direct costs: "direct internal and external costs of food production for food that is eventually lost or wasted at each stage of the value chain" (pag. 16); Scarcity costs: linear approximation of increased pressure on land, water, phosphorus and oil, through their scarcity cost estimates; Impacts on stakeholders: not included but discussed the potential trade-offs between costs and benefits of different stakeholders.
EXTERNALITIES	While valuation of traded goods was carried out basing on prices, in the case of environmental goods and services preference valuation methods (values based on people's revealed or stated preferences) and well-being valuation approach (values based on observed changes in well-being due environmental changes) are discussed and applied. Both economic costs, environmental costs, and social (well-being) costs are included. In the latter category primary (individual and direct) and secondary (society as a whole) costs are considered.

	It is argued that the monetization of FW impacts "on environment and society is key to engaging decision-makers in risk mitigation and securing sustainability of resource use" (pag. 80).
IMPACT ASSESSMENT	In Table 2 at pag. 33, impact categories, valuation methods and unit value used are shown. This could be useful also in a LCC approach.
OTHER RELEVANT ASPECTS	Final estimation is equal to USD 2.6 trillion annually, with almost 0.7 trillion of environmental costs, almost 0.9 trillion of social costs and 1 trillion of economic costs. A differentiation by commodity groups and regions is also provided, in the case of cost categories where it was possible.
RECOMMENDATIONS AND COMMENTARY	Particular attention should be devoted to avoid double counting (e.g. price of land and other inputs as already internalized in the farm gate food prices or societal cost of GHG emissions and partial costs of specific impacts, such as N_2O. Also, some cost categories are characterized by a societal perspective while others are based on the individual point of view. More data collection and research should be carried out on specific costs (e.g.. pesticide health costs)

Grey Literature **5.1**	
TITLE	Life Cycle Costing in SimaPro
AUTHOR(S) and/or ORGANIZATION	Andreas Ciroth, Juliane Franze, GreenDeltaTC Berlin
SOURCE CATEGORY	Article
GENERAL THEME(S)	Methods on how to perform a LCC in SimaPro

LCC APPROACH(ES)	Environmental LCC.
FUNCTIONAL UNIT(S)	An Environmental LCC analysis is conducted in parallel of a Life Cycle Assessment, and shall have a similar structure and thus, shall have the same functional unit. This reference unit can be either mass, energy or time.
SYSTEM BOUNDARIES	Life Cycle Costing (LCC) is an assessment of all costs related to a product or service, over the entire life cycle, from production over use until disposal. An Environmental LCC analysis has a similar structure as a Life Cycle Assessment that is conducted in parallel, and shall have equivalent life cycle and system boundaries, but not necessarily the same as different processes may have different relevance for the environment and for the cost part. For example, research and development will rarely be considered in an LCA, while it is commonly taken into account in LCC. Further, Environmental LCC can be performed from the viewpoint of different "life cycle actors" (as: producers, product buyers, or End-of-Life actors).
COST ALLOCATION	Similar to LCA methodology.
COST CATEGORIES	For each cost category, it is possible to add on SimaPro subordinated cost items with prices. These cost items are the substances for the cost impact category. Revenues can be modelled as negative costs.
EXTERNALITIES	It is possible to define on SimaPro top level cost categories as "Damage category" costs.
IMPACT ASSESSMENT	Similar to LCA methodology. Economic issues are defined as costs or revenues per reference unit, the reference unit being either mass or energy or time.
OTHER RELEVANT ASPECTS	On SimaPro, it is possible to: - Edit specified costs - Add economic issues to all processes in the life cycle, where relevant. On the process level, the economic issues need to be given as per reference unit, i.e. the time, mass, or energy needed by the process. Some processes may have with only economic issues and no (relevant) environmental

RECOMMENDATIONS AND COMMENTARY	issues, as research, or infrastructure processes. - Calculate and display the Life Cycle Costs, just as any other method results. Note that in the result, not only the overall life cycle costs but also top level cost categories and other cost types as specified are available and can be displayed and analysed, for example in the Sankey diagram. LCC can be performed in SimaPro, stand-alone, but also, and especially, together with an (environmental) Life Cycle Assessment. The basic LCC approach is pretty straightforward to implement and use. On a more advanced level, some specific approaches of LCC are possible to apply but rather via workarounds: Discounting and dealing with cost fluctuations and cost uncertainties are probably the most striking ones. Changes in the SimaPro software are needed to provide more straightforward approaches here. For discounting and uncertainty analysis of costs, needed changes are probably rather little effort. At present, no cost data are available in Ecoinvent or other SimaPro databases, besides input/output tables. While this might change in near future, building detailed cost inventories means currently effort. It is therefore recommended to build the cost inventory in principle on a rather generic level, and detail where relevant.

5.2	
TITLE	Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology - Final Report
AUTHOR(S) and/or ORGANIZATION	European Commission
SOURCE CATEGORY	Green public procurement and LCC recommendations
GENERAL THEME(S)	Green public

LCC APPROACH(ES)	Environmental LCC
FUNCTIONAL UNIT(S)	A constructed asset.
SYSTEM BOUNDARIES	In practice LCC is used for a wide range of analysis periods, and the new Methodology needs to accommodate such variety which may include the life cycle (cradle to grave) from inception to disposal of a construction asset, and may also include the period of a long-term service contract (e.g. 25-30 years), or a pre-determined period relating to the client's/user's interest in the constructed asset under consideration. This could include periods covering design, construction and short-term operation, for example, or be restricted to periods that include only the maintenance and replacement (adaptation) of major components. It could also cover the period of Facilities Management (FM) or Public Private Partnership (PPP) contracts.
COST ALLOCATION	Not mentioned.
COST CATEGORIES	All costs associated with the design, construction, operation and disposal of the works.
EXTERNALITIES	Data for LCA and sustainability assessment is widely available and quite extensive. Clients however are mainly concerned with climate change impacts – for which CO2 emissions and energy use are the two main environmental indicators. Some clients are interested in the monetisation of environmental impacts (sometimes referred to as "environmental costs") though the underlying methodologies remain superficial and are hotly disputed by environmental experts and practitioners of LCA in particular. It was identified that a separate set of considerations governs LCA and therefore no attempts should be made to incorporate LCA into the new LCC Common Methodology.
IMPACT ASSESSMENT	The sustainability or environmental assessments are frequently closely associated with LCC. In many countries selecting between options of varied sustainability or environmental performance is a key driver for using LCC. Quite frequently LCC calculations are driven by the requirement to justify decisions supporting the sustainability or environmental performance of the complete assets as well as systems or components. The sustainability and environmental indicators and methods of assessment varied but LCA was identified as the most commonly encountered, though its use is by no

	means universal or common in construction.
OTHER RELEVANT ASPECTS	The Methodology also needs to be applicable not only to different periods of time over the life cycle of a constructed asset, but also at various points in the life of the asset. Users may adopt an approach to LCC at the inception stage, at the design stage, at the stage of bidding for a construction contract, at the commencement of construction, at the beginning of an O&M service contract, at the beginning of a warranty period, etc.
RECOMMENDATIONS AND COMMENTARY	Commentary: The methodology and the proposed supporting documentation are based on the definitions and terminology in Draft ISO/DIS 15686:2006 Part 5, and is fully consistent with that draft standard. Recommendation: A key area for further research is the integration of theoretical approaches to LCC and associated methodologies with the practical needs of clients and practitioners, taking account of such issues as the quality of data, the need for simplicity of calculation methods and interpretation of results. The Common Methodology produced under this project, focused clearly on clients and practitioners, is a starting point, and further work is needed particularly in the areas of: - Cost breakdown and reporting structures, to help the comparison of life cycle costs not only between different construction projects and sectors, but from country to country across the EU; - The collection, use and dissemination of data on the cost and performance of key construction systems and components in standardised 'use' settings; - The Member States should be encouraged to exchange experiences and information related to LCC to support the further development of the LCC methodology developed in this study; - Framework ought to be enabled for training activities and better monitoring/control of operational and maintenance expenses which also strengthens the dissemination of LCC practice in Public Procurement.

Business sustainability reporting

6.1	
TITLE	PwC – Total Impact Measurement & Management (TIMM) Trucost – Environmental Profit and Loss account (EP&L)
AUTHOR(S) and/or ORGANIZATION	PwC, TruCost
SOURCE CATEGORY	Businesses sustainability reporting
GENERAL THEME(S)	All sectors.
LCC APPROACH(ES)	N.A.
FUNCTIONAL UNIT(S)	Not explicitly specified. The analysis is related to a product or a service.
SYSTEM BOUNDARIES	TIMM: Framework to quantify and monetise the contribution of PwC's UK business to the UK economy and treasury, as well as the social benefits arising from our investment in talent, while transparently measuring the cost to the environment of our operations. For the TIMM of PUMA, the system boundaries were the entire value chain (material sourcing, manufacture and disposal). EP&L: entire value chain of a business (operation, products and supply chain)
COST ALLOCATION	-
COST CATEGORIES	-
EXTERNALITIES	TIMM: Public backlashes against businesses' increasing profits are becoming more high profile, as consumers, campaigning groups and governments question whether a business is paying its fair share of tax, driving water scarcity, depleting resources or destroying natural habitats. The impact not only rocks reputations, but can damage revenues, and leave the door open for competitors to step in. A holistic view allows risks to business to be identified and managed. 80% CEOs believe it's important to measure and try and reduce their environmental footprint. A total impact approach to making business decisions provides the holistic perspective business needs. By valuing social, environmental, tax and

	economic impacts, business is now able to compare the total impacts of their strategies and investment choices and manage the trade-offs. EP&L: An EP&L places a financial value on environmental impacts along the entire value chain of a business to help companies combine sustainability metrics with traditional business management. Though companies pay fees for services such as water abstraction, energy use, waste disposal and land use, the true costs of these environmental impacts are usually externalized and unaccounted for. An EP&L assesses how much a company would need to pay for the environmental impacts it causes, providing a shadow price for risk and opportunity analysis. TIMM is a relatively new framework, with :
IMPACT ASSESSMENT	- methodologies used to measure impacts, - an improved granularity of the reporting, by splitting the breakdown of impacts into the three categories of direct, indirect and induced.
OTHER RELEVANT ASPECTS	-
RECOMMENDATIONS AND COMMENTARY	-

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