Sustaining Ethical Aquaculture Trade

Environmental Life Cycle Assessment of South-East Asian Aquaculture Systems for Tilapia, Pangasius Catfish, Peneid Shrimp and Macrobrachium Prawns

- Goal & Scope Definition Report -

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Preface

Aquaculture has, over the last decades, grown faster than any other animal production sector and today supplies half of the world's finfish. Simultaneously the growth of the import of Asian aquatic products into the EU has increased steadily. Current EU policy supporting international trade between Asia and Europe concentrates on issues of food safety as measures of quality, whilst market-forces drive development of standards and labels that identify social and environmental parameters. The SEAT (*Sustaining Ethical Aquatic Trade*) project proposes to establish an evidence-based framework to support current and future stakeholder dialogues organised by third party certifiers. This will contribute to harmonising standards, helping consumers to make fully informed choices with regards to the sustainability and safety of their seafood. The 'Ethical Aquatic Food Index' (EAFI), a qualitative holistic measure of overall sustainability intended to support consumers' purchasing decisions, will be based on detailed research centred on a Life Cycle Assessment (LCA) of current processes. Systems thinking will be applied to analyse livelihood impacts along the global value chains of four farmed aquatic products, tilapia, shrimp (*P. vannamei*), freshwater prawns (*Machrobrachium spp.*) and Asian catfish (*Pangasius spp.*) in China, Thailand, Vietnam and Bangladesh, all major producing countries. Initial assessments of environmental impacts by and on aquatic production and processing systems, and impacts on product safety and social equity will lead towards prioritisation of critical issues and supportive action research. Micro, small and medium enterprises (MSMEs) based in the EU and Asia will participate in this process, enhancing their relative competitiveness. By strengthening the knowledge base surrounding EU-Asia seafood trade the project will provide the evidence required to support further expansion whilst ensuring a fair deal for producers who are meeting appropriate social and environmental goals and offering a safe and sustainable product for consumers.

This document is deliverable D2.4 of work package 2 (WP2) of the SEAT project. D2.4 concerns a so-called Goal and Scope Definition report. This is a report that is drafted at the beginning of an LCA study on the Goal and Scope Definition (GSD) phase of an LCA. The GSD is the first phase of an LCA, establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim. It merely covers qualitative descriptions of the issues raised by aquatic product life cycles, identifying the intended goals of the study and stakeholder needs and relating these to clear system definitions, (methodological) choices and assumptions, and data quality and availability with respect to the LCAs that will afterwards be performed. A very important issue concerns the role of the LCAs fulfilled for the EAFI aimed for.

Executive summary

Aquaculture production has increased over tenfold during the last 30 years. It is expected that production will continue to grow to about 80 million tons per year, almost equalling the magnitude of fisheries. Europe's share in global aquaculture production is about 4.5 %, whereas Asia's share is about 88.9 % mainly aimed for local consumption. Important European aquaculture products include salmon (Norway, Iceland and Scotland), sea bass and sea bream in the Mediterranean sea (Turkey, Greece, Italy, Spain) and mussels and oysters (Spain, France, Netherlands, Ireland). China is the biggest runner-up in the fast expansion of Asian aquaculture production. Important Asian aquaculture products include green mussels, shrimps, prawns, tilapia and catfish.

Sustaining Ethical Aquaculture Trade (SEAT) is a large collaborative project within the "Food, Agriculture and Fisheries, and Biotechnology" theme of the EU 7th Framework Programme (FP). The overall aim of the SEAT project is to enhance the sustainability (environmental impact, social justice, economic efficiency, nutritional quality and safety) of four major aquatic food commodities farmed in Asia and exported to Europe by developing an improved framework for sustainability assessment of the trade in farmed aquatic products between Asia and Europe.

Until now a range of different sustainability tools has been used to assess aquaculture production systems. Increasingly LCA (Life Cycle Assessment) is used for industrial and agricultural production, and since 2004 LCA has also been increasingly applied to aquaculture systems. Previous Life Cycle Assessment (LCA) studies within the aquaculture sector have mainly focused on production in developed countries, while the sector is dominated by developing countries. The application of LCA to some major aquaculture systems in Asia, which is one of the goals of the SEAT project, will therefore be an important step in the understanding of sustainability concerns involved with EU seafood imports.

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1.1 Introduction

Aquaculture is an industry that is engaged in cultivating aquatic animals and plants. Aquaculture distinguishes itself from fisheries. Whereas fisheries is a sort of hunting, aquaculture is a form of agriculture cultivating animals and plant from cradle (egg, seed) to grave (consumable product). More than 300 different species are cultivated. On a global scale 68.3 million tons of fish, molluscs, crustaceans and aquatic plants are produced, of which 55.3% is produced in salt and brackish water and the remainder in fresh water. In 2008:

- 33.8 million tons of finfish;
- 15.8 million tons of aquatic plants;
- 13.1 million tons of molluscs; and
- 5.0 million tons of crustaceans

were produced, excluding various invertebrates. (FAO Fishstat 2010).

Aquaculture is not so much an alternative for fisheries but rather a necessary supplement. Due to population growth and increasing standards of living, the demand for seafood is on the increase. Fisheries have reached their limits, often even exceeded these, and only aquaculture can accommodate this increasing demand (FAO 2009).

Aquaculture production has increased over tenfold during the last 30 years (FAO 2007). It is expected that production will continue to grow to about 80 million tons per year (FAO, 2006), almost equalling the magnitude of fisheries (about 95 million tons per year in 2004 (FAO, 2007). Seafood is a global industry with more than one third of total production entering international trade (FAO 2009); thus trade in farmed species is growing rapidly and becoming a significant component of global levels of seafood supplies.

Europe's share in global aquaculture production is about 4.5 %, whereas Asia's share is about 88.9 % mainly aimed for local consumption (FAO Fishstat, 2010). Important European aquaculture products include salmon (Norway, Iceland and Scotland), sea bass and sea bream in the Mediterranean sea (Turkey, Greece, Italy, Spain) and mussels and oysters (Spain, France, Netherlands, Ireland). China is the biggest runner-up in the fast expansion of Asian aquaculture production. Important Asian aquaculture products include green mussels, shrimps, prawns, tilapia and catfish.

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Until now a range of different sustainability tools has been used to assess aquaculture production systems. Increasingly LCA (Life Cycle Assessment) is used for industrial and agricultural production, and since 2004 LCA has also been increasingly applied to aquaculture systems although the number of cases is still limited (Table 1).

Table 1: Overview of LCA studies performed on aquaculture systems.

Author	Title	Journal
Papatryphon et al. 2004	Environmental impact assessment of salmonid feeds using Life Cycle Assessment (LCA)	Ambio
Mungkung 2005	Shrimp aquaculture in Thailand: application of life cycle assessment to support sustainable development	PhD thesis
Aubin et al. 2006	Characterisation of the environmental impact of a turbot (Scophtalmus maximus) re-circulating production systems using Life Cycle Assessment	Aquaculture
Ellingsen & Aanondsen 2006	Environmental Impacts of Wild Caught Cod and Farmed Salmon – A Comparison with Chicken	Int. Journal of LCA
Grönroos et al. 2006	Life cycle assessment of Finnish cultivated rainbow trout	Boreal Environ. Research
Pelletier & Tyedmers 2007	Feeding farmed salmon: Is organic better?	Aquaculture
Aubin et al. 2009	Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment	J. of cleaner production
Ayer & Tyedmers 2009	Assessing alternative aquaculture technologies: life cycle assessment of salmonid culture systems in Canada	J. of cleaner production
d'Orbcastel et al. 2009	Towards environmentally sustainable aquaculture: Comparison between two trout farming systems using Life Cycle Assessment	Aquacultural Engineering
Pelletier et al. 2009	Not all salmon are create equal: Life cycle assessment (LCA) of global salmon farming systems	Environ. Sci. and Technol.
Iribarren et al. 2010	Revisiting the Life Cycle Assessment of mussels from a sectorial perspective	J. of cleaner production
Pelletier & Tyedmers 2010	A life cycle assessment of frozen Indonesian tilapia fillets from lake and pond-based production systems	J. of Industrial Ecology
Phong 2010	Dynamics of sustainability in Integrated Agriculture-Aquaculture systems in the Mekong Delta	PhD thesis

Previous Life Cycle Assessment (LCA) studies within the aquaculture sector (see Table 1) have mainly focused on production in developed countries (non-shaded rows in Table 1), while the sector is dominated by developing countries. The application of LCA to some major aquaculture systems in Asia, which is one of the goals of the SEAT project, will therefore be an important step in the understanding of sustainability concerns involved with EU seafood imports.

Although LCA is a quite well-developed and ISO-standardized tool (ISO, 2006a; ISO, 2006b), LCA is not a "silver bullet". It focuses on an environmental analyses of an as broad as possible range of impact over the whole life-cycle of the aquaculture systems considered. It however does not address all sustainability dimensions and it even cannot address all environmental impacts properly. It is therefore explicitly placed among a portfolio of other tools, like risk assessment, life cycle costing, global value chain, social, and ethical analyses. Recently, Klöpffer & Renner (2008), Klöpffer (2008), Zamagni et al. (2009), Heijungs et al. (2010) and Guinée et al. (*accepted*) have advocated broadening and deepening current environmental LCA to Life Cycle Sustainability Analysis (LCSA) including social and economic aspects and, for example, economic mechanisms into a life-cycle based analysis (see section 1.2). LCSA is expected to be a trans-disciplinary integration framework of models rather than a model in itself. LCSA works with a plethora of disciplinary models and guides

selecting the proper ones, given a specific sustainability question. Structuring, selecting and making the plethora of disciplinary models practically available in relation to different types of life cycle sustainability questions is a major challenge and still requires a lot of research. Therefore, this study will work on the basis of LCA as described in Chapters 2-3 and from there on try to add other elements to it (e.g., life cycle costing (LCC)) as far as possible and feasible in practice.
But even if broadened and deepened, LCSA is still not a “silver bullet”. LCSA is a framework for looking from one viewpoint, i.e. the life cycle viewpoint, to sustainability questions and only providing life cycle answers and no other; risk assessment (RA) is, for example, not part of this framework and is still needed as a complementary tool, as well as other tools and approaches.

The SEAT project focuses on four major cultured aquatic commodities and four producer countries in Asia (Table 2) and so will the LCA studies.

Table 2: Scope of the SEAT project in terms of cultured species.

Country/Species	**Tilapia**	***Pangasius* Catfish**	***Penaeid* Shrimp**	***Macrobrachium* Prawns**
China	√√	√	√	?
Vietnam	√	√√	√√	(√)
Thailand	√	√	√√	√
Bangladesh	(√)	√	√√	√√
Europe	(√)	(o)	(o)	(o)

Tilapia

***Pangasius* Catfish**

***Penaeid* Shrimp**

***Macrobrachium* Prawns**

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1.2 Environmental Life Cycle Assessment (LCA)

LCA is defined by ISO as a "compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 2006a; ISO, 2006b). It comprises of four phases (see Figure 1):

- Goal and scope definition;
- Inventory analysis;
- Impact assessment;
- Interpretation.

It is a method meant to evaluate systematically, via a 'from-cradle-to grave'-approach, the environmental impacts of products and or activities. This approach is based on the identification and quantification of the flows of substances and materials to and from the economy and the environment during the whole life cycle of the product or activity.

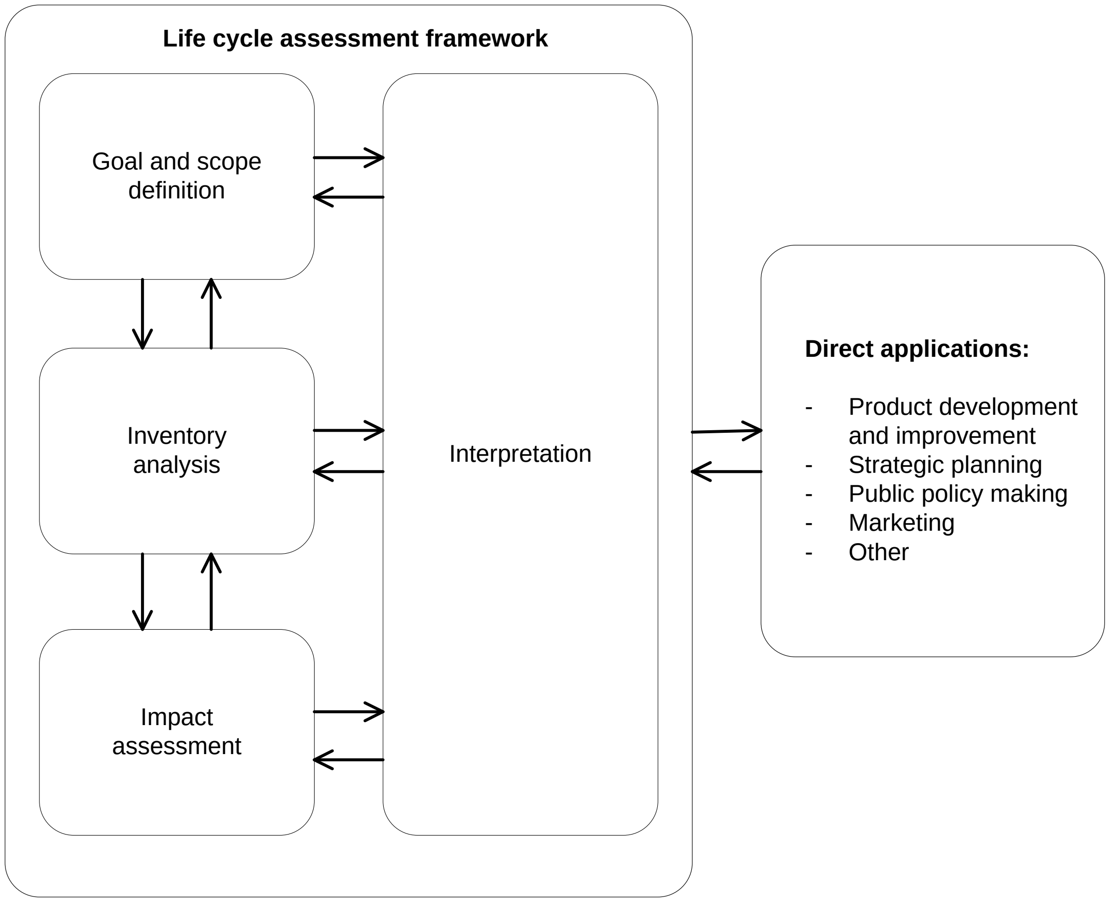

Figure 1: The general methodological framework for LCA (ISO, 2006a).

These ISO International Standards are important in providing an international reference with respect to principles, framework and terminology for conducting and reporting LCA studies. The ISO standards do not, however, provide a 'cookbook' of step-by-step operational guidelines for conducting an LCA study. Although the ISO Standards contain steps that shall or should be considered when conducting an LCA, these are not ordered in stepwise fashion.
Therefore, Guinée et al. (2002) drafted a Handbook on LCA, aiming to provide just such a stepwise 'cookbook' based on the ISO (International) Standards, by making the various elements and requirements of these standards operational into a 'best available practice' for each step.
As this study will be largely based on the Handbook by Guinée et al. (2002), while replenishing with specific aquaculture topics and updating where necessary, the key characteristics of this handbook are briefly summarised in Annex 1. In addition to this Handbook, we will also adopt the recently published International Reference Life Cycle Data System (ILCD) Handbook. In 2005, the EU identified a growing need of have quality-assured life cycle data, methods and studies for reliable decision support in public policy and in business and established the European Platform on LCA (EPLCA) for this. One of the EPLCA's tasks was to develop The International Reference Life Cycle Data System (ILCD) Handbook. The ILCD Handbook is a series of technical guidance documents in line with the ISO 1404 and 14044 standards for a number of archetype goal and scope situations (http://lct.jrc.ec.europa.eu/index_jrc).

On top of this, we have made a review of existing LCA studies on aquaculture (Henriksson et al., *in prep.*) in order to learn from experiences, identify key issues, methodological gaps and data sources and to get insight into differences within aquaculture LCA approaches. The lessons from this review have been included in this report.

2 Goal definition

The Goal definition of an LCA "shall unambiguously state the intended application, including the reasons for carrying out the study and the intended audience" (ISO, 2006a).

2.1 Determining the goal, application, initiator, performer and target group

This first step of the Goal definition includes the following topics: the definition of the goal of the LCA, the use of the results, the initiator, and the performer of the study and for whom the results are meant. For the SEAT project, these are relevant questions and determine further selection of systems, representative farms etc.

2.1.1 Goal of the study

The SEAT project proposes to establish an evidence-based framework to support current and future stakeholder dialogues organised by third party certifiers. For this, the ‘Ethical Aquatic Food Index’ (EAFI), a qualitative holistic measure of overall sustainability intended to support consumers’ purchasing decisions, will be developed. The EAFI should be based on detailed research centred on a Life Cycle Assessment (LCA) of current processes. Initial LCAs of aquatic production and processing systems should support prioritisation of critical issues and supportive action research (WP9). LCAs should thus support identifying critical issues within these systems and starting point for improvement options.

Therefore, the main goal of this LCA study is formulated as getting insight in:

- the environmental impact and its causes of aquaculture systems for Tilapia, Catfish, Shrimp and Prawns in Bangladesh, China, Thailand and Vietnam.
- starting points (“hot spot identification”) for improving the environmental performance of aquaculture systems for Tilapia, Catfish, Shrimp and Prawns in Bangladesh, China, Thailand and Vietnam, which includes insight into the effects of choices in methods and data on the outcomes.

On top of these main goals, learning (of the environmental ins and outs of aquaculture systems) is another important goal of this study (cf. Baumann &Tillman, 2002).

It is thus not the intention to draw general conclusions for any of these aquaculture systems for each country, not to compare systems between countries. For that we would need to make a statistical representative sample of LCAs for each fish species and each country, which would be practically unfeasible. The intention of this study is to get a first understanding of critical environmental issues for each fish species and each country on a life cycle basis, to highlight areas of concern and contribute to development towards best practice.

Not all fish species may be relevant for all countries. In WP2 a selection will be made for this which will then be adopted as basis for the further LCAs. This may reduce the number of fish species – country combinations and thus the number of LCAs performed, the latter which of course has a practical limit.

The focus of the LCAs is on finished products covering the whole life cycle and thus not on products from cradle to farm gate. In WP2 the specific finished products and systems to be studied will be identified; as this work package is yet to be finished at the time of writing of this report, we cannot make a detailed and final selection of these particular products and related systems. Currently, however, the expected outcome in terms of species and countries is as follows:

Country	Major Species	Minor Species
Bangladesh	Prawn	Shrimp
Thailand	Shrimp	Tilapia
Vietnam	Pangasius	Shrimp
China	Tilapia	Shrimp

2.1.2 Intended application of the study results

The intended application mainly determines the nature of the study. A LCA to be used for the award of an 'Ecolabel' will have to meet other criteria and requirements as to representativeness etc. than an LCA meant to be used by the commissioner for internal purposes only, such as product innovation.

Together with the results of other WPs within the SEAT project, the LCA studies should support a more holistic sustainability assessment of South-East Asian aquaculture systems brought together in the ethical aquatic food index (EAFI) mentioned before.

The results of this study will only be used as input of (predominantly qualitative) information into discussion between stakeholders and for improving existing aquaculture practices. In future, the LCAs may also start supporting criteria setting for a next generation of the EAFI label but that is outside the scope of the current project and has its own specific problems (cf. Mungkung et al., 2006).
Within SEAT, the LCAs will not be used to directly compare different aquaculture systems amongst each other. Nevertheless, as the EAFI may in future be used for public assertions, the ISO requirements with respect to "comparative assertions" will be adopted in this study as far as reasonable.

2.1.3 Initiator

The initiator and commissioner of this LCA study is the European Commission through the Seventh Framework Programme - Sustainable Development Global Change and Ecosystem, project no. 222889.

2.1.4 Performer

The performer of this LCA study is the Institute of Environmental Sciences (CML), department of Industrial Ecology, Universiteit Leiden, the Netherlands.

2.1.5 Target group

The target groups for this study are the EU, Asian farmers, producers, processors and traders – both small and medium sized enterprises (SMSEs) and bigger enterprises - , NGOs, policy-makers and other parties interested in the environmental performance of aquaculture products.

2.2 Type of analysis: attributional and consequential

In literature, two modes of LCA can be found:

- attributional LCA (ALCA);
- consequential LCA (CLCA).

Attributional LCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Consequential LCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions.
Attributional LCA, also referred to as status-quo or descriptive LCA, addresses questions such as:

- Which environmental impacts can be attributed to a certain product?
- What is the share of a certain product in global environmental impacts?
- What are the “hot spots” (processes or interventions with relatively high impacts) of a certain product system?

Consequential LCA, also referred to as prospective or change-oriented LCA, addresses questions such as:

- What changes in environmental impacts occur if product A is replaced by product B?
- What are the environmental impacts of choosing product A rather than product B for fulfilling a certain function?
- What changes in environmental impacts occur when demand of an existing product changes?

ALCA assumes *ceteris paribus* ("all other things being equal or held constant"). This assumption may be valid for decision situations causing only marginal changes in product systems and related markets. ALCA does thus not take into account indirect effects of product systems changes and decisions, e.g., if aquaculture industry uses more soy, the production of soy will need to increase and this may lead to the destruction of rainforests in Brazil ......etc. The mapping of such indirect effects is the aim and strong point of CLCA.

However, there is a subtle difference between consequential LCA (CLCA) and consequential modelling. Consequential LCA is basically about setting up life-cycle based scenarios for the future. How such scenarios are modelled, is basically an open issue: consequential modelling is just one way. Other possibilities are: modelling future scenarios or consequences bottom-up from product to world (mainstream of CLCA today) or modelling a (top-down) future scenario for a product starting from global future scenarios on resources, land, materials and technology developments (Guinée et al, *accepted*).

On top of that, current main stream consequential modelling is also not one methodology. According to Weidema (2003, 2009), consequential modelling differs in two ways from attributional modelling:

1. co-product allocation is avoided by system expansion instead of applying allocation factors (semi-consequential modelling);
2. consequential LCA includes the suppliers actually affected by a change in demand instead of averages as in attributional LCA (“full” consequential modelling).

Many studies that characterize themselves as CLCAs, however, only apply the first difference. Schmidt refers to these approaches as semi-consequential (Schmidt, 2010).

Other issues related to CLCAs are:

- CLCAs are more time-consuming;
- they are more complex and less transparent;
- huge uncertainties are introduced by the relatively arbitrary choice of marginal processes (e.g., Mathiesen et al., 2009).

Since the primary goals of the SEAT LCA studies are getting insight into:

- the environmental impact and its causes; and
- the identification of hot spots and starting points for improving the environmental performance

of aquaculture systems for Tilapia, Catfish, Shrimp and Prawns in Bangladesh, China, Thailand and Vietnam, we will start by performing attributional LCAs. In a later stage, when improvement options could be modelled, we may adopt a consequential LCA approach, but considering the various drawbacks mentioned above, we will not adopt consequential modelling, but rather a top-down approach. However, top-down approaches are still to be developed as alternative for the bottom-up consequential approach and as this is not a subject of this research, it is unclear what we can do within SEAT in a later stage of the project.

3 Scope definition

In the Scope definition the subject and the depth and breadth of the study are established in relation to the stated reasons for performing the study in the Goal definition. "The following items shall be considered and clearly described: the function of the system(s), the functional unit, the system to be studied, the system boundaries, allocation procedures, types of impacts considered and the methodology of impact assessment and interpretation, and impact, data requirements, assumptions, limitations, initial data quality requirements, the type of critical review, the type and format of the report" (ISO, 2006a).

3.1 Level of sophistication

According to Guinée et al. (2002), an LCA can be performed at different levels of sophistication:

The first is a *detailed* LCA, which is believed to be representative for studies typically requiring between 20 and 200 days of work. The detailed LCA is the *baseline* LCA elaborated in Guinée et al. (2002) and summarized in Annex 1.

The second is a *simplified* version of LCA, typically requiring between 1 and 20 days of work, and not completely following the ISO-guidelines. One may, for example, deviate from the economy-environment system boundary specified for detailed LCA, or choose a different time horizon for leaching of landfill. The choice of deviations is entirely the responsibility of the LCA practitioner. Note that a simplified LCA is not simple in the sense of being easy.

Finally, on some topics an indication is provided of possible *extensions* for improving the quality of detailed LCA in those respects where shortcomings are most obvious. A key example is the absence of economic mechanisms in the LCA model, an unfortunate feature in cases where there are extreme in-elasticities of supply or demand. In the case of rechargeable batteries, for example, a shift to non-cadmium types of battery will not result in a smaller influx of cadmium to the economy and hence will not lead in the long run to lower cadmium emissions. This is because the supply of primary cadmium is extremely inelastic. In such a situation, LCA may yield a misleading outcome.

For this LCA on aquaculture systems detailed LCAs will be performed for a selected number of systems and simplified LCAs may be done for other systems. Detailed LCA is necessary in order to meet the goals and application of this study, but detailed LCAs are time-consuming and cannot be performed for all farm-systems identified within WP2 of the SEAT project. Therefore we focus on four detailed LCAs, in which we may even go deeper and add some extensions to detailed LCA for specific topics. This means that we adopt the baseline choices for these detailed LCAs from Guinée et al. (2002) and that we will elaborate some non-defaults in additional sensitivity analysis.

3.2 Subject of the LCA

In this step the subject of the study is defined by establishing the functional unit, the reference system and the functionally equal alternative systems. But first we need to further define the subject of our LCAs in terms of the spatial and temporal context of our analyses.

Spatial context

The LCAs at stake here are significantly influenced by spatial differences in aquaculture practices. This is particularly true for aquaculture systems in South-East Asia. Not only may local technologies and industries be different from Western ones for which we have well-known databases, also our impact assessment models (e.g., the multi-media models used for toxicity assessment) may have to be adapted for this.

Based on the goal of this study, data and systems will be developed for each country specifically. This implies that feed producers, farming practices, processing procedures, energy production technologies will be distinguished for each of the four countries and each of the four species as far as practically possible and available.

Temporal context

The temporal context of an LCA refers to the reference year of the analysis. The most recent year for which process data from the farms and other processes are available is currently unknown, due to the still ongoing scoping activities. This reference year will therefore be determined later, but preferably is as recent as possible. It will also probably not be the same for all processes, and for this reason it might make sense to take the first decennium of the new millennium (2000-2010) as temporal context instead of a specific year.

3.2.1 Functional unit

The functional unit describes the main function(s) fulfilled by a product system and indicates how much of this function is considered. In comparative LCAs the functional unit forms the basis for the comparison but also without any comparison a functional unit is required in order to have something to scale calculations to.

For the definition of the functional unit one has to take into account the following elements:

- function,
- consumer's behaviour,
- unit, and
- quantity.

These elements are being discussed hereafter in relation to the LCA of the aquaculture systems for Tilapia, Catfish, Shrimp and Prawns in Bangladesh, China, Thailand and Vietnam.

Function

The function of aquaculture products has to be defined as clear and accurate as possible. One might say that aquaculture product fulfil just one function – providing food – but this function can be expressed in various terms: edible yield, gross energy content, protein content, nutritional value, moisture content, good taste, etc. The most commonly used functional unit in aquaculture LCA literature is a given mass of live fish at the farm gate (Aubin *et al.* 2009; Ayer & Tyedmers 2009; Pelletier *et al.*

2009) for cradle-to-gate analyses and a given mass of edible yield for cradle-to-grave analyses (Mungkung 2005; Ellingsen & Aanondsen 2006; Iribarren *et al.* 2010; Pelletier & Tyedmers 2010).

Since aquaculture products fulfil more than one function, it has to be established which functions aquaculture systems fulfil and whether only the main function is considered or also the alternative ones.

For this study we adopt the function "edible yield" since we are aiming for a full cradle-to-grave analysis and are not making comparisons between different fish species with possibly different calorific and protein values.
As defined in section 2.1.1, finished products will be the focus of the LCA studies covering the whole life cycle of the cultivated fish species.

<u>Consumer's behaviour</u>
Consumer's behaviour refers to the way the consumer prepares and consumes aquaculture products and how that influences its environmental life cycle performance. Consumer's behaviour may influence the functioning of a product system (food waste, frying, cooking, baking practices, etc.) but it is not included in this study.
Note that consumer's behaviour in the above sense is something different that the influence that consumers can have by buying or not buying specific products, by demanding labels, information etc.

<u>Unit</u>
The unit of edible yield is taken as kg.

<u>Quantity</u>
The amount considered can be arbitrary and is set to a 1000 kg.

The resulting *functional unit* then is: **1000 kg of edible yield of (frozen, packed or etc. is to be determined later) species X produced on farm type Y in country Z for consumption[1] in the EU**.

3.2.2 Functionally equivalent alternative systems

As the goal of this study rather is to map and get insight into the impacts of the various aquaculture systems and not a comparison of different aquaculture systems producing comparable food produce, it not necessary to select one or more product systems that can produce the functional unit defined before in different ways.

Taking into account the major and minor species-countries matrix presented in section 2.1.1, detailed LCAs will be performed for:

- 1000 kg of edible yield of Macrobrachium Prawns produced on model farm[2] "Y" on farm "Y" in Bangladesh for consumption in the EU;

[1] It reads here "for consumption" and not "consumed". In the latter case we would have to model human beings as "economic processes", which would make up a real cradle-to grave analysis. However, any useful data sets for modelling human beings in this way are currently lacking and it would be a project in itself to collect these data. If, during the course of the project such data would become available, we might reconsider this choice. For the time being, we will exclude it from our analyses.

- 1000 kg of edible yield of Shrimp produced on model farm “Y” in Thailand for consumption in the EU;
- 1000 kg of edible yield of Pangasius produced on model farm “Y” in Vietnam for consumption in the EU;
- 1000 kg of edible yield of Tilapia produced on model farm “Y” in China for consumption in the EU;

and simplified LCAs will be performed for:

- 1000 kg of edible yield of Shrimp produced on model farm “Y” in Bangladesh for consumption in the EU;
- 1000 kg of edible yield of Tilapia produced on model farm “Y” in Thailand for consumption in the EU;
- 1000 kg of edible yield of Shrimp produced on model farm “Y” in Vietnam for consumption in the EU;
- 1000 kg of edible yield of Shrimp produced on model farm “Y” in China for consumption in the EU.

For each functional unit listed above, model farm-systems will be identified per country and for each of these model farm-systems, LCA data and LCAs could be performed. Different farming systems and different technologies (from “average technology” to “best available technology”) will be covered in the scoping phase (WP2) of the SEAT project mapping their environmental performance as well as identifying options for reducing their impacts. As also mentioned in section 2.1.1, the precise finished products and systems and also the model farms to be studied will be identified in WP2. As this work package is not yet finished at the moment of writing this report, we cannot yet determine these finished products, systems and model farms in any more detail than above. One thing is certain, the outcome of WP2 will further specify and change the FUs listed above and will specify which model farms will be studied for each functional unit.

The selection of representative systems is one of the expected key issues and challenges of this LCA study. We do not need to cover a *statistically representative* (ample) sample of farms and related systems to substantiate statements on the environmental performance of the general aquaculture practice for Tilapia, Catfish, Shrimp and Prawns in Bangladesh, China, Vietnam and Thailand respectively. We do, however, have to cover a representative, as far as practically possible and feasible, range of model farms – from average to best available technology – in order to identify the key life cycle based environmental issues of aquaculture systems, and to identify main improvement options for these systems.

Having said this, we also need to take into account the practical limits of our study and the time and resource-needs of performing LCA studies. A detailed LCA study may easily take 100-200 days of work. Therefore, considering this time budget, the goals of the study and the numerous amounts of possible model-farm-systems that we could do LCAs on, we propose (as a general strategy for selecting model-farm-systems for which LCAs will be performed):

- to perform four detailed LCAs in total, i.e. one detailed LCA for one (most) representative species of each country (these are the *focus farm-systems*);
- to perform a number (to be determined later) of simplified LCAs on *adjacent farm-systems*.

As we would also like to perform sensitivity analysis on possible future trends of various farm-systems on top of mapping their environmental performance and

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[2] We use the term model farm here to indicate an “average” farm based on the practices and data of a number of individual, real-world farms.

identifying improvement options, it is essential that we have a number of as detailed as possible LCA studies. As these studies will be elaborate, we can do them only for a selected number of farm-systems, i.e. the four focus farm-systems. It would be advantageous if the four focus farm-systems would be equal for several WPs so that, for example, WP7 will also focus their more detailed analysis on these farms providing useful input data to the details LCAs of the same farm-systems. In this way, various WPs of the SEAT project could re-enforce each other. The focus-farms should ideally be visited and monitored for several years so that development trends can be identified, modeled and assessed.

3.3 *Short report on methods and data (sources) to be used in the detailed LCA*

This is a last step of the Scope definition. In this paragraph for every step of the next stages - the inventory analysis, the impact analysis and the interpretation- it will be indicated which methods and data will be used and which are the (main) choices being made.

Where possible the choices and methods described by Guinée *et al* (2002) will be used.

3.3.1 Inventory analysis

At this stage data are collected and interventions are attributed to the processes. Aggregation of all data finally results in a list of all environmental interventions of the product system: the inventory table.

3.3.1.1 Drawing up the flow charts

It is proposed by Guinée *et al* (2002) first to make a summarised version of the flow chart. In this summary a lot of aggregated processes are included such as ‘use of the Linoleum floor’ or ‘disposal’. These aggregated processes consist of a number of mutual tied processes. During the study these aggregated processes will be specified and the individual underlying processes will be assessed.

In Figure 2 a first draft flow chart for a generalized aquaculture system is given.

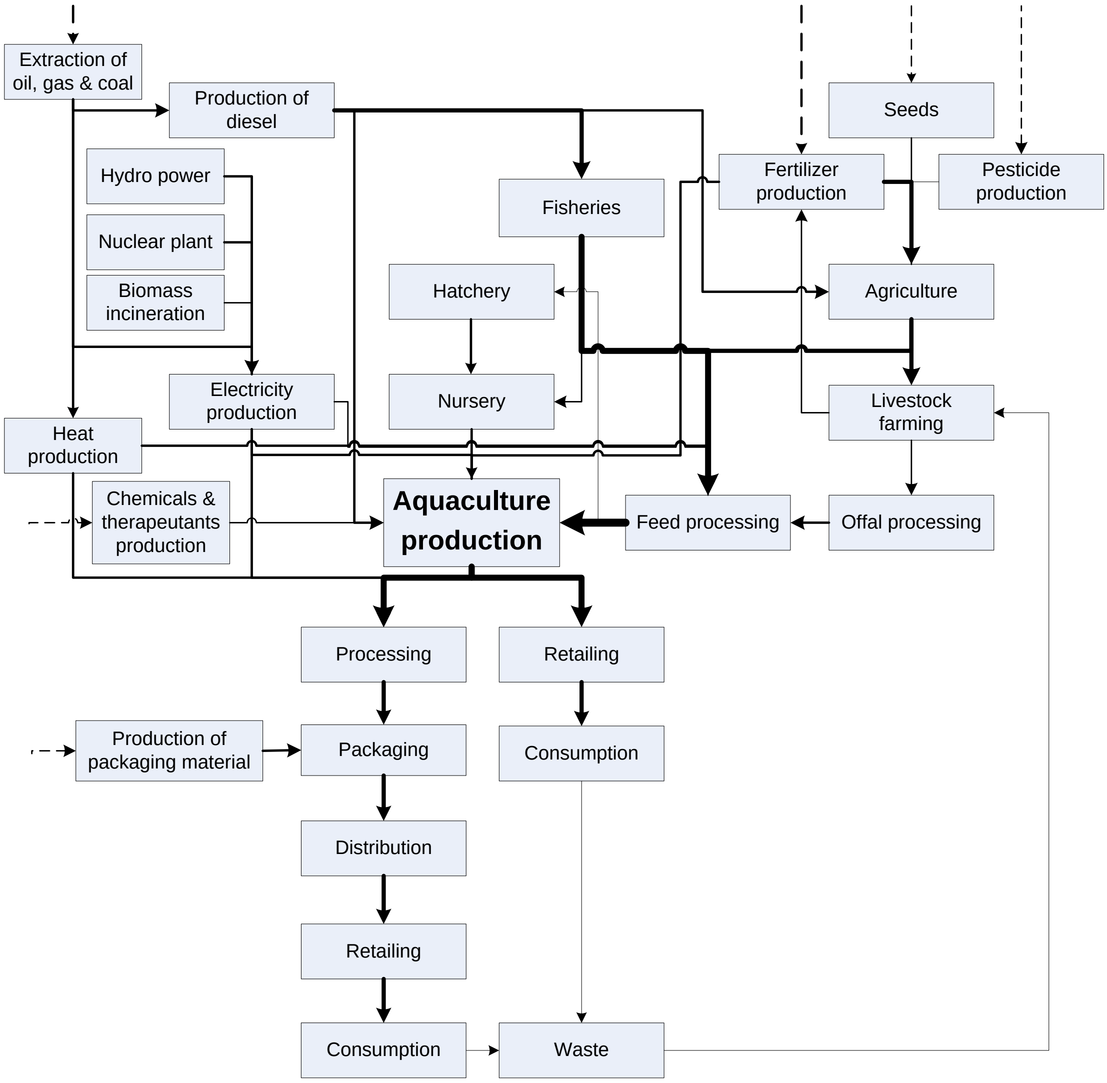

Figure 2: Generalized flow chart for aquaculture systems

3.3.1.2 System boundaries

As discussed above, the SEAT aquaculture LCAs will look from cradle (egg, seed) to grave (finished, consumable product). This sets part of the boundaries of the systems we will be analysing. However, there are three additional types of boundaries, that we will need to decide on, the boundary between:

1. the product system and the environment,
2. the processes that are part and are not part of the system,
3. the product system under investigation and other product systems.

Boundaries of type 1 (between the product system and the environment) may be an issue in fisheries, where fish is caught from nature (being a natural resource) but if it is also feed, then the feed is an economic input. Put in other terms: it has to be defined which flows cross this boundary and are environmental interventions. Well-known examples of confusion on this point are forests and other biological production systems (including aquaculture systems). Do they belong to the environment and is wood a resource coming into the physical economy (natural forest)? Or is the forest already part of the economy and are solar energy, CO_2, water and minerals to be regarded as the environmental interventions passing the boundary between environment and economy (forestry)? Another example concerns the other end of the life cycle: is a landfill to be regarded as part of the environment or still as part of the physical economy? In the first case all materials which are brought to the landfill have to be regarded as emissions into the environment; in the latter case this will only hold for the emissions from the landfill to air and groundwater. Our lead in solving this boundary problem will be the degree to which the processes involved are steered by human activities. Forestry can be regarded as part of the socio-economic system, while wood extracted from a natural forest will have to be regarded as a critical resource taken from the environment. Likewise a landfill, managed without any control measures is regarded as part of the environment, with all discarded materials to be regarded as emissions. If the landfill is a well controlled site, separated from groundwater and with cleaning of the percolation water, one may well regard this as part of the product system with only the emissions from the landfill to be considered as burdens to the environment. In aquaculture, similar situations will occur when particulate organic matter is collected in pond sediments and later used for building pond walls. In the scenarios assuming that sediments are flushed, the nutrients in the sediments will be considered as emissions; in scenarios assuming that sediments are used for building pond walls, the nutrients within the sediments would (initially, depending on leaching rates) remain within the technosphere.

Boundaries of type 2 (between processes that are part and processes that are not part of the study) will be discussed in section 3.3.1.3 under the heading “cut-off”. Boundaries of type 3 (between the product system under investigation and other product systems) will be discussed in section 3.3.1.4 under the heading “allocation”

3.3.1.3 Process data and cut-off

When the processes are defined, the process data can be collected. Per process all the economical and environmental in- and outputs are described and quantified according to Figure 6 of Annex 1.

The Asian partners are responsible for process data referring to all processes based in their country (fisheries, feed production, farming etc. etc. as far as taking place in the country of the Asian partner). Local existing literature on these processes should be identified and field measurements and interviews should substantiate and replenish these literature sources. Main gaps in data should be identified and reported too, and the quality of data collected should be indicated (see below). Special issues to attend to include:

- CO_2, N_2O and CH_4 emissions from fish ponds;
- Use of pesticides and fertilizers in crop cultivation for feeds;
- Use of antibiotics, anti-fouling agents etc;
- feed production data;
- etc.

CML is responsible for data concerning all other processes situated outside the Asian countries, for example, soybean tilling in South America, fishmeal from the U.S., fertilizers from Europe etc. For this, CML will use public databases available at CML and public studies on similar aquaculture products.

As far as the quality of the data and validation is involved the ISO-guidelines will be followed. The uncertainty, completeness, variability, and representativeness of the process data must as far as possible be described. In the Interpretation phase of the

LCA the possible effects of the quality of the data (ranges of uncertainty, variability etc.) will be analysed. It is, however, expected that considering the state-of-knowledge lower quality data will have to be accepted for the time being.

In principle, an LCA should track all the processes in the life cycle of a given product system, from the cradle to the grave, and collect full data sets on each one of these. In practice this is impossible, however, and a number of flows must be either roughly estimated or cut-off and subsequently ignored. This often is the case for the production of capital goods. The root problem behind the cut-off issue is a lack of readily accessible data, implying disproportionate expenditure of funds and effort on data collection. Cut-off may substantially influence the outcome of an LCA study, however, and means that 'easy' LCAs come at a price. Guinée et al. (2002) have re-formulated cut-off as a problem of having to quantitatively estimate the environmental interventions associated with flows for which no readily accessible data are available using primarily environmentally extended Input-Output Analysis (EIOA). This is what we will also do in the aquaculture studies: when data are lacking and cannot be collected with reasonable efforts, the potential importance of these lacking data will be estimated by EIOA. We will use for this an updated E3IOT database (http://cml.leiden.edu/software/data-e3iot.html), which can be used in the CMLCA software (see section 3.3.1.5).

Collecting appropriate and complete process data sets for all selected systems is one of the key issues and challenges of this LCA study.

3.3.1.4 Allocation

When processes deliver more than one valuable product, the interventions of these multiple processes should be divided over the production system under investigation and other systems. This is called allocation.

There are three kinds of multiple processes:

- co-production: simultaneous production of economical valuable products,
- combined waste disposal: simultaneous processing of more than one stream of waste, with a negative value and'
- open loop recycling: processing a waste stream of one production process such that it can be reused in/for another useful material.

According to ISO, the following preference order of options for addressing the problem of multiple processes should be applied:

Step 1
If it is possible, one should try to avoid allocation by dividing the multiple processes in sub-processes or to enlarge the system under investigation such that also the co-products are involved.

Step 2
If it is not possible to do so, an allocation based upon causal physical relations is preferred; e.g. the amount of mercury (Hg) in the emission of a waste combustion installation can be attributed to every mercury containing product to be burned according to its content; the carbon dioxide emission can be attributed to a product according to the caloric value of the product.

Step 3

If it is not possible to attribute on the basis of a causal physical relationship, then other relations should be used such as: an allocation proportional to the economical value of the products.

In this study we follow the ISO steps as closely as possible with some adaptations as documented in Guinée et al. (2002; 2004). If allocation cannot be avoided, we will apply economic allocation (step 3) as a baseline method (cf. Guinée et al., 2004). For waste management processes – as far as relevant and important for aquaculture systems – allocation will be performed based on causal physical relations (step 2), because the emissions can be related to the composition of the waste.
As recommended by Guinée et al. (2002), sensitivity analyses will be performed for allocation, since it is impossible to determine the ultimate best solution accepted by everybody for a problem that is an artefact of wishing to isolate one function out of many.

Multiple processes will most likely be found in fisheries and by-catch, fish meal and feed stuff production, agricultural processes and processing (fish filet to EU, remainder to local market; see also Henriksson et al., *in prep.*).

Allocation is one of the expected key issues of this LCA study.

3.3.1.5 Scaling and aggregation

The result of the collection of data is a database with processes and accompanying interventions. These processes are being coupled on the basis of the functional unit. After aggregation of all data for the whole flow chart an inventory table will result.

For all LCA calculations, CML will use CMLCA[3] software. CMLCA is largely based on the ISO Standards and Guinée et al. (2002) allowing, amongst others, allocation scenario calculations, the use of different impact assessment methods and several types interpretation analysis (see section 3.3.3 and see Heijungs & Kleijn, 2001). CMLCA can export all results and input data to MS Excel spreadsheets, which can be used and reviewed by third parties without requiring any knowledge of CMLCA itself. Last but not least, as CMLCA has been developed and is continuously being extended and improved by CML itself, further adaptation of the software to specific requirements for this project are also possible.

3.3.2 Impact assessment

At this stage the potential effects of the interventions are identified and characterised.

3.3.2.1 Selection and definition of impact categories, models and indicators

[3] The CMLCA software tool program is publicly available, see: http://www.cmlca.eu/.

In this step it will be established which of the environment problems and impact categories will have to be taken into account and which methods are used in order to characterise the impact of inventory items.

In the LCAs for aquaculture systems we will apply the updated impact assessment method of Guinée *et al* (2002) as available from the CML website (http://www.leidenuniv.nl/cml/ssp/databases/cmlia/cmlia.zip) as baseline. This baseline list comprises of the impact categories listed in Table 3. Depending on the inventory results, indicator results will be calculated for each of these categories.

Table 3: Baseline impact categories

Impact category	Single baseline characterisation method available in the Guide?	Other characterisation method(s) available in the Guide?
Depletion of abiotic resources	yes	yes
Impacts of land use		
land competition	yes	yes
Climate change	yes	yes
Stratospheric ozone depletion	yes	yes
Human toxicity	yes	yes
Ecotoxicity		
freshwater aquatic ecotoxicity	yes	yes
marine aquatic ecotoxicity	yes	yes
terrestrial ecotoxicity	yes	yes
Photo-oxidant formation	yes	yes
Acidification	yes	yes
Eutrophication	yes	yes

For a more in-depth discussion of baseline impact categories, models, indicators and characterisation factors we here refer to Guinée *et al.* (2002).

This baseline list is not a complete list of all relevant impacts that can be expected from aquaculture systems. The following impact categories are missing in this list, although they may be of importance for this study:

1) Depletion of resources
    a. Depletion of biotic resources (e.g. fish stock exploitation)
    b. Water use
2) Impacts of land use
    a. loss of life support function
    b. loss of biodiversity
3) Impacts of ionising radiation
4) Odour
    a. malodourous air
    b. malodourous water
5) Noise
6) Waste heat
7) Casualties
8) Desiccation
9) Salination

The problem of these categories often was (and still is) that (accepted) methods and associated characterisation factors were missing. LCA has developed further since then and the EU identified a growing need of have quality-assured life cycle data, methods and studies for reliable decision support in public policy and in business. For this, the European Platform on LCA (EPLCA) was established by the European Commission in 2005. One of the EPLCA's tasks was to develop The International Reference Life Cycle Data System (ILCD) Handbook. The ILCD Handbook is a series of technical guidance documents in line with the ISO 14040 and 14044 standards for a number of archetype goal and scope situations. Along with this Handbook, a supporting tool on a best practice LCIA methods and data sets should be developed. The work on this LCIA supporting tool and the ILCD Handbook is in its final stage and if all data needed will be publicly available on time, we will adopt the LCIA data sets and apply them in our aquaculture LCAs (http://lct.jrc.ec.europa.eu/index_jrc).

ILCD LCIA methods and data are not available for all possible impact categories. For some categories it was concluded that additional research was necessary before a best practice could be identified and adopted. Therefore, we may need to develop new models for categories for which methods are lacking or immature as far as practically feasible within this project. Furthermore, it may be considered to adopt and develop spatially different (site-dependent) characterisation factors for some impact categories. Selection and proposals for new methods and for spatial differentiation will be made as part of D3.2 of the SEAT project and not in this deliverable.

2.1.1.1 Classification

In this step the interventions will be attributed to the different impact categories. This will be done based on baseline list given by Guinée *et al* (2002) attributing interventions to impact categories.
Interventions that do attribute to more than one impact category will be categorised as follows:

- When there are serial and indirect effects, the interventions will be attributed to both impact categories.
- When there are parallel effects, the intervention will be distributed over the relevant impact categories, based on the best available knowledge. If it is not exactly known which part of the intervention has to be attributed to a certain impact category, the intervention will be attributed fully to all relevant categories.
- When there are combined effects (two compounds that do show a mutual influence) then the interventions are classified separately according to the assumptions made about the background concentration of the 'other compound' in the characterisation model adopted.

3.3.2.2 Characterisation

When the interventions are attributed to the impact categories, their contributions to the different impact categories are calculated applying the selected characterisation factors/methods (see section 3.3.2.1). The results will be aggregated per impact category. This will finally result in one indicator result per impact category. For many impact categories there is not one generally recognised list of characterisation factors available, which implies that different choices can be made here giving different results.

For this study we propose to work with the updated baseline (including latest GWPs, USEtox and other more recent (variants of baseline) methods and characterisation factors) methods and factors as summarised in the impact assessment spreadsheet published and downloadable from the CML website (http://www.leidenuniv.nl/cml/ssp/databases/cmlia/cmlia.zip), replenished by the ILCD LCIA methods and factors (http://lct.jrc.ec.europa.eu/publications).

3.3.2.3 Normalisation

In this step the indicator results for the functional unit are given as a fraction of the reference contribution of a certain region, in a certain time interval, to a certain impact category. Among these reference contributions (normalisation data) one might find: the annual contribution of the whole world, or only the Netherlands, to the impact categories under consideration (= environmental problems). This step enables comparing the contributions of the different impact categories, because now they are in the same dimensions: fraction of the annual world-wide (or Dutch) contribution to this category. Because so far most of the impact assessment methods are not regionalised yet, we will adopt normalisation on a global level as baseline.

As a step towards grouping and weighting, normalisation often is indispensable; therefore we suggest executing this step. However, the available data about the reference contributions of the whole world (or the Netherlands) are valid for a given period and need to be updated regularly. In the CML impact assessment spreadsheet mentioned above, the most recent normalisation data published by Wegener Sleeswijk et al. (2008) have been included, and these will be adopted here as baseline. We will thus as baseline perform a normalization for the global level for 2000 (for the related data, see http://www.leidenuniv.nl/cml/ssp/databases/cmlia/cmlia.zip).

3.3.2.4 Grouping and weighting

After normalisation the results per impact category might be grouped or even be weighted.

Grouping means that the categories are being grouped, sorted and if desired classified. As an example one might think of classifications based upon the spatial scale of a certain environmental problem (local, regional, global), or a classification based on a scale of ‘importance’. In this way results are presented in an orderly way.

Weighting is a step of impact assessment in which the (normalised) indicator results for each impact category assessed are assigned numerical factors according to their relative importance, multiplied by these factors and possibly aggregated; weighting is based on value-choices (e.g. monetary values, standards, expert panel). Weighting enables comparing different categories and calculating one final result for a specific LCA study. Currently, CML is finishing a study on weighting methods for the EC JRC-IES in Ispra, Italy (Huppes & Oers, 2009; Huppes & Oers, 2010). In this study several weighting methods are proposed as it is not possible to just define one overall method.

ISO does not permit weighting in case the results of an LCA will be used for comparative assertion. Grouping is allowed for comparative assertions.

Unfortunately, no practical methods are presently known to the authors of this study for grouping.

For the aquaculture LCAs, we therefore propose not to perform grouping, but to carry out a weighting, as a kind of exercise, using a number of (or all) practical and available methods identified by Huppes & Oers (2009, 2010). This may help interpret the results but also help identify the pitfalls of weighting for the EAFI. Note, however, that ISO would not allow weighting for comparative assertions and that an EAFI based on the weighting results of an LCA and used for labelling would thus conflict with this ISO requirement.

3.3.3 Interpretation

The definition of the goal and scope of a study provides the initial plan for conducting an LCA-study. The Inventory Analysis supplies the data on relevant processes and interventions on which the assessment will be based. In the Impact Assessment the interventions are translated into potential environmental impacts. In the interpretation the results of the life cycle inventory analysis and the life cycle impact assessment (LCIA), are summarised and discussed as a basis for conclusions, recommendations and decision making in accordance with the goal and scope definition" (ISO, 2006a). In ISO document 14044 (2006b) it is proposed to subdivide the interpretation into three steps:

- identification of the significant issues
- evaluation
- conclusions, recommendations and reporting.

This subdivision will also be followed in this study. The first two steps should be followed in a recursive process. Conclusions will have to be based on the combined results of the two preceding steps.
For the first two steps, one can apply procedural and numerical approaches. Procedural approaches includes discussion of data and results in relation to other sources of information through expert judgment ,comparisons with reports on similar products, intuition, reputation of data suppliers, etc. ISO 14044 provides several suggestions for procedural approaches, for examples different kinds of critical review.

Numerical approaches are, however, not provided by ISO 14040 and 14044. Only general descriptions are given like “the objective of the identification of significant issues is to structure the results from LCI or LCIA phases in order to help determine significant issues […]”. In addition to procedural approaches, we will apply a number of numerical to support the identification of significant issues and to support the evaluation in this study. Examples of numerical approaches that may be included in this study are:

- contribution analysis
- perturbation analysis
- uncertainty analysis
- comparative analysis
- discernibility analysis
- key issue analysis

As the goal of the aquaculture LCAs includes identifying the causes of environmental impact and starting points for improving the environmental performance of the aquaculture systems, with insights into the effects of choices in methods and data on the outcomes, the interpretation phase is of particular importance for these studies.

3.3.3.1 Identification of the significant issues

The aim of the identification of significant issues is to get preliminary answers to the questions defined in the goal and scope of the study. This process may include a.o.:

- Contribution/dominance analysis: remarkable or significant contributions to the total result are mapped e.g. by expressing the contribution of substances, processes, life cycle stages and/or impact categories in % of the total results.
- Anomaly Assessment: on basis of e.g. experience unusual or remarkable deviation from expected or normal results are determined or simply stated.

For the aquaculture LCAs, we propose to apply a contribution analysis and an anomaly assessment in order to be able to point out important processes and inputs that determine the environmental performance of the evaluated aquaculture products and to identify starting points for improvements.

3.3.3.2 Evaluation / Analyses

"The objectives of the evaluation are to establish and enhance the confidence in and the reliability of the result of the study" (ISO, 2006b). ISO mentions a completeness check, a sensitivity check, a consistency check, an uncertainty analysis and assessment of data quality as elements of the evaluation.

We will apply a completeness check and a consistency check as described in ISO 14044, clause 4.5.3.2 and 4.5.3.4. On top of that we will apply a

- perturbation analysis
- uncertainty analysis
- comparative analysis
- key issue analysis

Perturbation analysis (also known as marginal analysis or sensitivity analysis)
Inherently unstable elements are investigated by changing a data entry or factor with 1% and determining how much a result is changed. The result is expressed as a multiplier expressing the extent to which a perturbation of certain input parameter propagates into certain output result. If, for example, an increase of 1% of an input parameter leads to an increase of 2% of an output result, the multiplier is 2; if an output result decreases by 2%, the multiplier is -2. The results of a perturbation analysis may provide opportunities for redesign, prevention strategies, etc. It may also prioritize further data collection: more precise knowledge of data is more important for highest contributors, than for those that hardly contribute.

Uncertainty analysis
This is the systematic study of the propagation of input uncertainties into output uncertainties. There are several techniques for uncertainty analysis including numerical treatment (parameter variation; Monte Carlo analysis; fuzzy sets; Bayesian statistics; ...) and analytical treatment. In this study we will apply a selected number of Monte Carlo simulations.

<u>Monte Carlo simulations:</u>

- consider every input parameter as a stochastic variable with a specified probability distribution
- construct the LCA-model with one particular realization of every stochastic parameter
- calculate the LCA-results with this particular realization

- repeat this for a large number of realizations
- investigate statistical properties of the sample of LCA-results

Note that Monte-Carlo simulations can be quite time-consuming and that they presume that uncertainty parameters are available for all input parameters. As most LCA databases don't include such uncertainty data, the meaning of Monte Carlo simulation remains limited.

Comparative analysis
A comparative analysis is not related to uncertainty, but is only an analysis of the product alternatives simultaneously. It lists LCA results for different product alternatives simultaneously. It thus provides presentations of results on the basis of which different product alternatives can easily be compared. However, comparative is seductively simple and may even be dangerous, because it may easily induce claims without a proper analysis of robustness of these claims with respect to influence of uncertainties.

Discernibility analysis
Discernibility analysis is a special form of uncertainty analysis. It is actually a combination of comparative and uncertainty analysis, as it calculates results for one Monte Carlo realization for all product alternatives simultaneously, ranking if A is better than B or not. This approach effectively comes down to counting the number of times that the first product alternative has a higher score and the number of times that this is not the case. The results can be used to test if product A is statistically discernible from product B, or to rank product alternatives in statistically sound way (e.g., 'there is 95% chance that product A is better than product B').

Key issue analysis
Key issue analysis is a combination of uncertainty analysis and contribution analysis. It will provide information on, for example, the composition of the uncertainty in the results. Its results may be used for focusing the attention to those data sets for which improved data collection seems most important of for which improvements will be most efficient.

Building and depending on the results of all the analyses discussed above, or additional to these analyses, several other sensitivity analyses may be performed:

- different methods for allocation and impact assessment;
- different farm types and intensities for a specific fish species-country combination;
- determining the variability in the process data from different sources, if available;
- etc.

Last but not least, further up-scaling of aquaculture practices will be qualitatively analysed in terms of consequences for land use, biodiversity and competition with land use for food and biofuel production etc., comparable to problems identified in biofuel studies.

3.3.3.3 Conclusions and presentation of the results

Final conclusions concerning the interpretation of the results are drawn on the basis of the outcomes of the significance and the sensitivity/uncertainty analysis.

We propose to present the results both in tabular and in graphical way, as far as useful. Furthermore, the public and private data sources used (with protection of proprietary data if necessary) and the assumptions and choices made will be reported.

In the inventory two types of flows can be discerned that cannot be attributed to impact categories: (i) flows not followed up to system boundaries (as a result of cut-off) and (ii) inventories not assigned to an impact category (because it is not known to what extent these interventions contribute to the impact categories). These two groups are presented together with the final results.

Discussing the LCA results we will as accurately as possible indicate which statements can be made and which statements cannot be made on the basis of the study's results.

3.4 Review

An internal review of the case study results will be made by the SEAT partners ensuring that (ISO, 2006b):

- the methods used to carry out the LCA are consistent with this ISO 14040 and 14044;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

An internal review does not comply fully with ISO requirements on comparative assertions. However, as explained in section 2.1.2, the LCAs performed as part of the SEAT project will not be used to directly compare different aquaculture systems amongst each other. In this project comparative assertion is not at stake yet. However, if, after the SEAT project, the results are used for this, an external panel of interested parties should review the case study results to ensure compliance with ISO comparative assertion requirements.

3.5 Acknowledgement

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Annex 1: Brief summary of the key characteristics of the Dutch LCA Handbook

Short history

Life Cycle Assessment (LCA) originated in the early seventies. In this initial period studies were performed in a number of countries, in particular Sweden, the UK, Switzerland and the USA. The products which got primary attention were beverage containers, a topic which has dominated the LCA discussions for a long time (cf. Udo de Haes, 1993). During the seventies and the eighties numerous studies were performed, using different methods and without a common theoretical framework. The consequences were quite negative, because LCA was directly applied in practice by firms in order to substantiate market claims. The obtained results differed greatly, although the objects of the study were often the same, thus preventing LCA from becoming a more generally accepted and applied analytical tool.

Since about 1990 a number of changes have occurred in this situation. Under the coordination of the Society of Environmental Toxicology and Chemistry (SETAC) exchange between LCA experts has greatly increased, and efforts are being made to harmonise the methodology. The SETAC "Code of Practice" is up to now the most outspoken outcome of this process (Consoli *et al.*, 1993). Complementary to the efforts in the framework of SETAC, since 1994 also the International Organization for Standardization (ISO) plays a role (Technical Committee 207, Subcommittee 5). Whereas SETAC has primarily a scientific task, focused at methodology development, ISO has the formal task of methodology standardisation which to date has resulted in two standards:

- ISO 14040 (2006E): 'Environmental management – Life cycle assessment – Principles and framework';
- ISO 14044 (2006E): 'Environmental management – Life cycle assessment – Requirements and guidelines'.

The significance of LCA lies in its highly structured type of analysis. The methods for this are becoming more and more sophisticated, in line with the development of software and databases. Another recent development is the requirement of an independent peer review on the results of an LCA study, which is of crucial importance for the credibility of the results.

ISO Standards and new LCA Handbook

The ISO International Standards are important in providing an international reference with respect to principles, framework and terminology for conducting and reporting LCA studies. The ISO standards do not, however, provide a 'cookbook' of step-by-step operational guidelines for conducting an LCA study. Although the ISO Standards contain steps that shall or should be considered when conducting an LCA, these are not ordered in stepwise fashion.

Therefore, the Dutch Ministry of Housing, Spatial Planning and Environment (VROM), the Ministry of Economic Affairs (EZ), the Ministry of Agriculture, Nature Management and Fisheries (LNV) and the Ministry of Transport, Public Works and Water Management (V&W) commissioned CML to draft a new LCA Handbook in 1996.
The general aim of the new Handbook was to provide a stepwise "cookbook" with operational guidelines for conducting an LCA study step-by-step, based on the ISO

14040 Standards. The different ISO elements and requirements are made operational to the "best available practice" for each step. This general aim is achieved by renewing the guide of Heijungs *et al.* (1992) to all relevant developments that have taken place since. Starting point were the ISO 14040 Standards with particular reference to the work within the SETAC LCA community, in particular the various working groups established (on Inventory Analysis, Impact Assessment, etc.). In some instances the ISO 14040 Standards are a straightforward affair and the options indicated by the ISO standards only had to be worked out in more detail. In other instances, a further interpretation of the ISO Standards was needed.

Definition and applications
As defined in ISO 14040 (2006a), Life Cycle Assessment is a "compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system[4] throughout its life cycle". According to ISO 14040 and 14044 (2006a+b, p. 4) a product system is 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". As stated before, products also include services which provide a given function. In the following we will speak however of a product as pars-pro-toto for all objects of LCA, if not specified differently.

The terms 'economic process' or 'economic activity' are often used as synonyms alongside 'unit process' to refer to any kind of process producing an economically valuable material, component or product, or providing an economically valuable service such as transport or waste management. Economic or unit processes (often abbreviated to 'processes') are the smallest portions of a product system for which data are collected during execution of an LCA. They are linked to one another by flows of intermediate products and/or waste for treatment, to other product systems by product flows, and to the environment by elementary flows ("material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation"; ISO 14040 and 14044, 2006a+b), i.e. inputs from and outputs to the environment, also referred to as environmental interventions[5]. These environmental interventions may have impacts on the environment by way of environmental processes.

LCA takes as its starting point the function fulfilled by a product system. In principle, it encompasses all the environmental impacts of resource use, land use and emissions associated with all the processes required by this product system to fulfil this function - from resource extraction, through materials production and processing and use of the product during fulfilment of its function, to waste processing of the discarded product. This means that ultimately all environmental impacts are related to this function, being the basis for comparisons to be made.

LCA as defined here deals only with the *environmental* impacts of a product (system), thus ignoring financial, political, social and other factors (e.g. costs, regulatory matters or Third World issues). This does not, of course, imply that these

[4] Here, 'product system' is synonymous with 'function system'.
[5] 'Environmental interventions' is the preferred term in this paper, this being considered broader than the ISO term 'elementary flow'. From the ISO definition of the latter (see ISO 14040, 2006), it is unclear whether 'elementary flow' also covers land use, while land use is becoming an increasingly important issue under this heading. Environmental interventions thus include both environmental flows and land use.

other aspects are less relevant for the overall evaluation of a product, but merely delimits the scope of LCA as discussed in this paper.

The prime purpose of LCA, as we see it, is to support the choice of different (technological) options for fulfilling a certain function by compiling and evaluating the environmental consequences of these options. It should indicate the effects of choices in a way that prevents problem shifting. Problem shifting can occur when analysing only one activity, one area, one substance, one environmental pr*oblem or effects over a limited period of time. So the LCA model tries to cover all activities related to a product or function; stating effects anywhere in the world; covering all relevant substances and environmental themes; and having a long time horizon. This encompassing nature of LCA in place, time and effect mechanisms has as a corollary that the model used should be simple.

LCA can be applied at quite different levels. On the one hand, LCA can be used at an *operational level* for product improvement, product design and product comparison. The latter is for instance at stake in the underpinning of ecolabeling programmes or purchase preference schemes (cf. European Commission, 1997). On the other hand, LCA can be used at a *strategic level*, either by companies or authorities. Within firms LCA may give the guidance for business strategies, including decisions which types of products to develop, which types of resources to purchase and which type of investments to make for waste management. For authorities an application of increasing importance is the comparison between contrasting environmental policy options, for instance in the field of waste management, of energy policy or of transportation. A recent example concerns the proposal of "overall business impact assessment" (OBIA), being an LCA for a company as a whole (Taylor, 1996). Finally, LCAs are often experienced as educationally beneficiary, learning e.g. a company about its activities in relation to environmental burden and about what they can do about it themselves (see e.g. Baumann, 1998).

Methodological framework

The complexity of LCA requires a fixed protocol for performing an LCA study. Such a protocol has been established by the International Standards Organisation, ISO and is generally referred to as the methodological framework. ISO distinguishes four phases of an LCA study (see Figure 3):

- Goal and scope definition;
- Inventory analysis;
- Impact assessment;
- Interpretation.

From Figure 3, it is apparent that LCA is not a linear process, starting with the first and ending with the last phase. Instead it follows an iterative procedure, in which the level of detail may subsequently be increased. Despite the iterative character of LCA, the key methodological aspects of the different phases and steps within these phases will be discussed in a sequential mode below. For illustrating the different steps of LCA methodology, the Handbook on LCA (Guinée *et al.*, 2002) and a hypothetical example system of PE throw-away bags taken from that Handbook will be used.

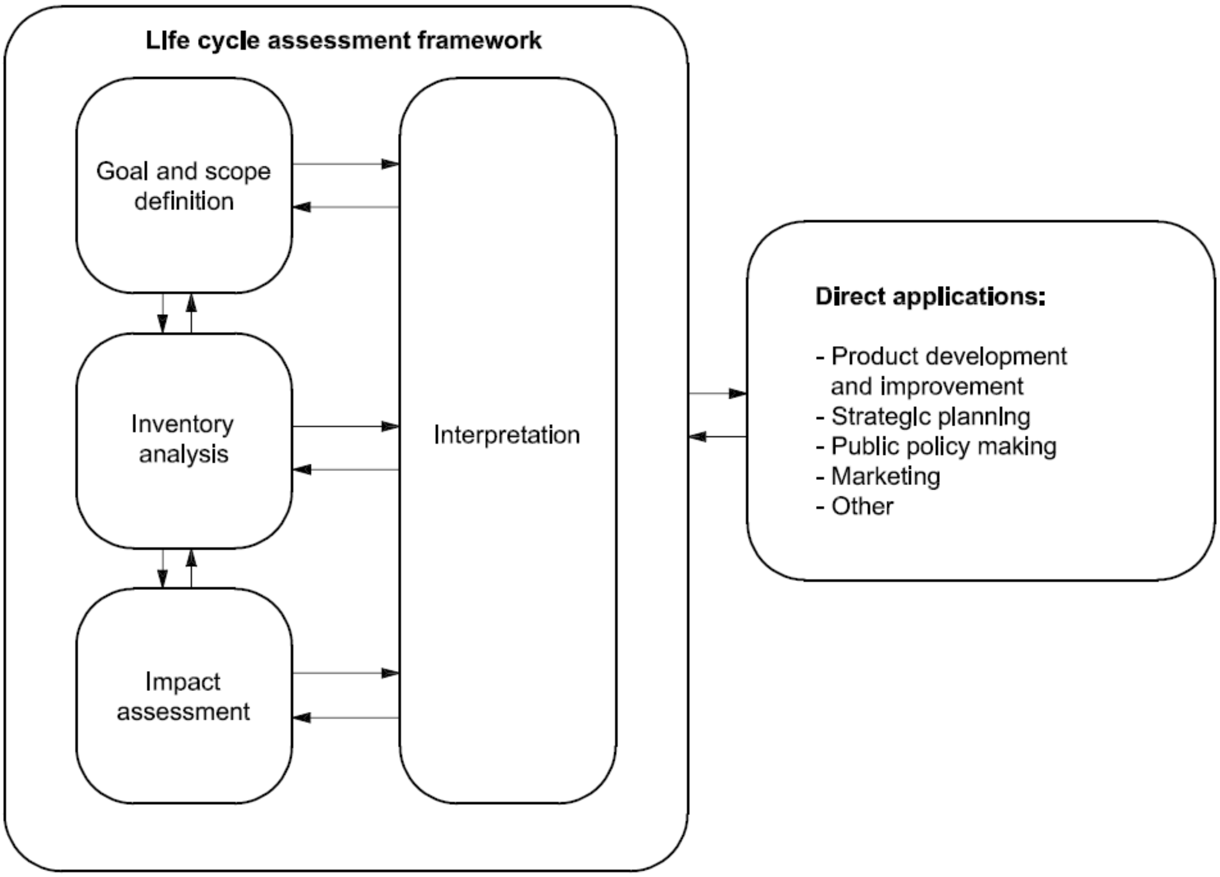

Figure 3: Methodological framework of LCA: phases of an LCA (source: ISO, 2006a).

Goal and Scope Definition

The Goal and Scope Definition phase is the first phase of an LCA, establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim. In the new Handbook, it includes the following steps:

- Goal definition;
- Scope definition;
- Function, functional unit, alternatives and reference flows.

In the first step of Goal and scope definition the *goal* of the LCA study is stated and justified, explaining the goal (aim or objective) of the study and specifying the intended use of the results (application), the initiator (and commissioner) of the study, the practitioner, the stakeholders and for whom the study results are intended (target audience).

In the *scope definition* step the main characteristics of an intended LCA study are established, covering such issues as temporal, geographical and technology coverage, the mode of analysis employed and the overall level of sophistication of the study.
Particularly two points need further explanation here: mode of analysis and level of sophistication.

For the mode of analysis discussion, we here refer to section 2.2 of the main text. The other point concerns level of sophistication. In the new Handbook, guidelines are given for two *levels of sophistication* of LCA: a simplified and a detailed level. The simplified level has been introduced for making faster and cheaper LCAs compared to detailed level LCAs. The simplified level may be good enough for certain

> Example of the scope definition for the hypothetical system of PE throw-away bags
> "The LCA is carried out to identify hot spots for improvement of processes in the Netherlands; therefore data should be representative of the present state of technology in that country. In this study, we used the most recent data that were available, mainly from 1999.
> The purpose is in agreement with the scope of structural change-oriented LCA, and simplified guidelines will suffice for most steps.
> Total size of the study is 8 man-months. A large amount of this time will be devoted to the collection of representative data of the most important production, recycling and upgrading processes."

applications. The guidelines for simplified LCA largely comply with the ISO standards but not completely; for example, the allocation procedure recommended for simplified LCA does not comply with the stepwise ISO procedure as described in ISO 14044. The guidelines given for detailed LCA fully comply with the various ISO Standards as mentioned.

The final step of the Goal and scope definition phase concerns the definition of the *function, functional unit, alternatives and reference flows*. The functional unit describes the primary function(s) fulfilled by a (product) system, and indicates how much of this function is to be considered in the intended LCA study. It will be used as a basis for selecting one or more alternative (product) systems that might provide these function(s). The functional unit enables different systems to be treated as functionally equivalent and allows reference flows to be determined for each of them. For instance, one could define functional unit for wall colouring in terms of the area to be covered, the type of wall, the ability of the paint to hide the underlying surface and its useful life. In a real example, then, the functional unit of a wall covering would be "20 m^2 wall covering with a thermal resistance of 2 m^2 K/W, with a coloured surface of 98% opacity, not requiring any other colouring for 5 years."

On the basis of the functional unit, a number of alternative product systems may be declared functionally equivalent and reference flows will be determined for these systems. The reference flow is a measure of the needed outputs from processes in a given (product) system which are required to fulfil the function expressed by the functional unit. For example, the above functional unit for wall covering might be fulfilled by 20 m^2 wall covered with paint A and this is therefore the reference flow for the product system that corresponds to paint A. The fact that 10 litre of paint is needed for this, is not a part of goal definition, but rather of process data.

Inventory Analysis

The inventory analysis is the second phase of an LCA, compiling and quantifying, as far as possible, the relevant inputs and outputs of the product system(s) under study throughout the life cycle. In the new Handbook, it includes the following steps:

- economy - environment system boundary;
- flow diagram;
- format and data categories;
- data quality;

- data collection and relating data to unit processes;
- data validation;
- cut-off and data estimation;
- multi-functionality and allocation;
- calculation method.

Firstly, the *system boundaries* have to be defined between the product system (as part of the physical economy) and the environment. Or put in other terms: it has to be defined which flows cross this boundary and are environmental interventions. Examples of confusion on this point are forests and other biological production systems (see Figure 4). Do they belong to the environment and is wood a resource coming into the physical economy (natural forest)? Or is the forest already part of the economy and are solar energy, CO_2, water and minerals to be regarded as the environmental interventions passing the boundary between environment and economy (forestry)? Another example concerns the other end of the life cycle: is a landfill to be regarded as part of the environment or still as part of the physical economy? In the first case all materials which are brought to the landfill have to be regarded as emissions into the environment; in the latter case this will only hold for the emissions from the landfill to air and groundwater. In order to make the results of different studies comparable there is a great need for harmonisation here. An element may well be the degree to which the processes involved are steered by human activities. Forestry can be regarded as part of the socio-economic system. But wood extracted from a natural forest will have to be regarded as a critical resource taken from the environment. Likewise a landfill, managed without any control measures should be regarded as part of the environment, with all discarded materials to be regarded as emissions. If the landfill is a well controlled site, separated from groundwater and with cleaning of the percolation water, one may well regard this as part of the product system with only the emissions from the landfill to be considered as burdens to the environment.

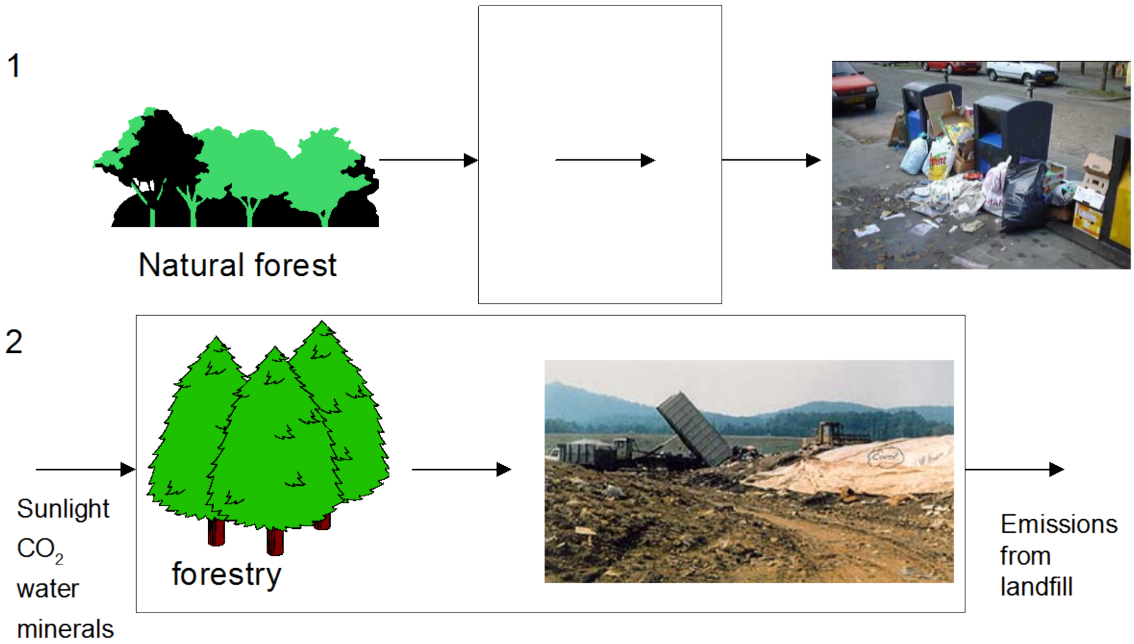

Figure 4 : Two ways of defining system boundaries between physical economy and environment in LCA; a) with narrow system boundaries, b) with extended boundaries.

Next step concerns drawing the *flow diagram* of the system studied. It constitutes the basis for the whole analysis and it identifies all relevant processes of the product system with their interconnections. The functional unit delivered by the system is the central element; starting from here, the processes ramify "upstream" up to the different resources used, and "downstream" to the different ways of waste management involved.

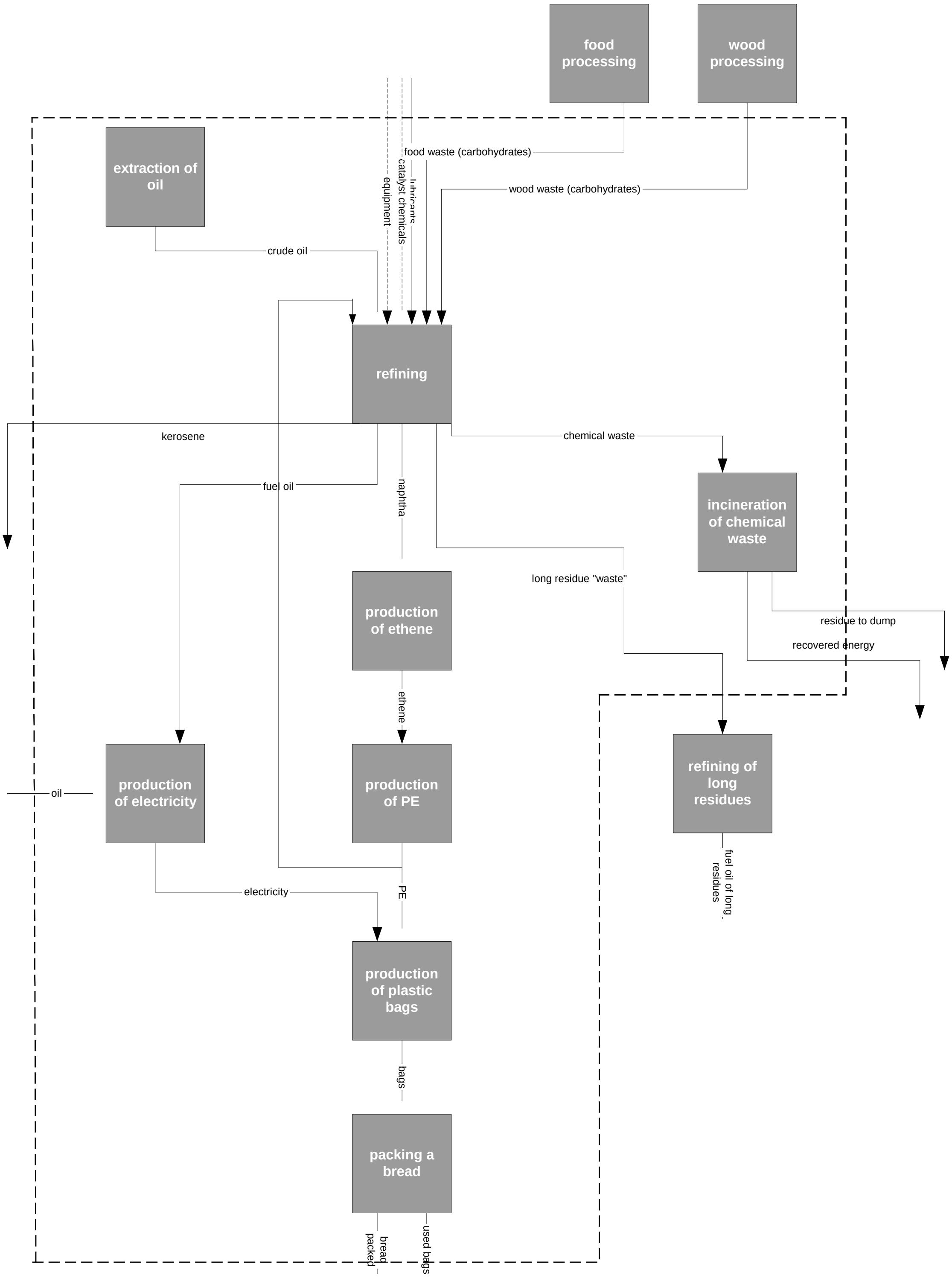

Figure 5 : Simplified flow diagram for the hypothetical system of PE throw-away bags.

The next steps concern *data collection and its quality assessment*. Data collection is a core issue in LCA. In this step data for all relevant data categories on the unit processes are collected and all flows connecting unit processes to each other are quantified. In the new Handbook various data categories are distinguished (see Figure 6).

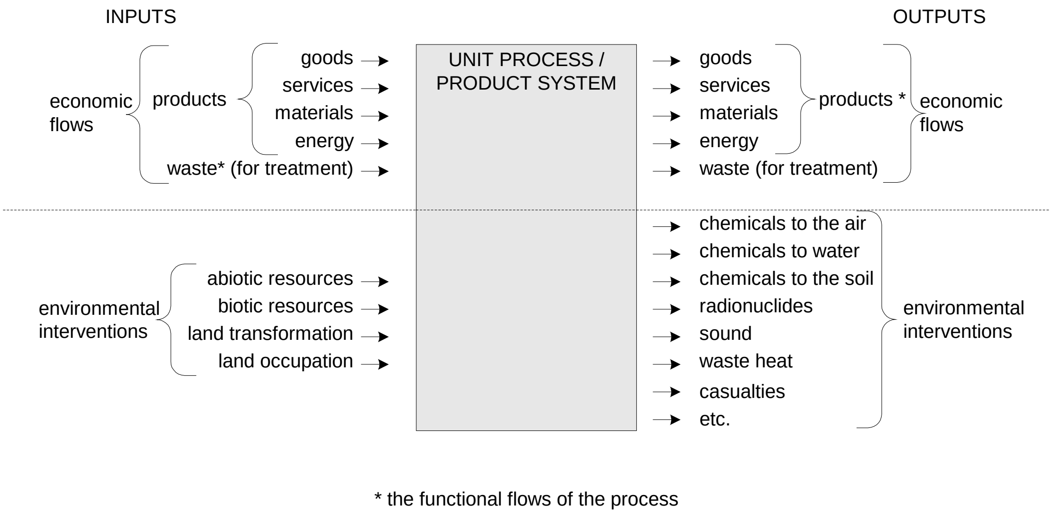

Figure 6 : Data categories distinguished in the new Handbook (Guinée *et al.*, 2002)

There are several generic databases and written references available for supporting data collection, but for a specific case-study it may also be very relevant to collect primary data for a number of (foreground) processes.
For LCA models, like any other model, it holds that “garbage in = garbage out”. In other words, data quality has a major influence on results and proper evaluation of data quality is therefore an important step in every LCA. The data used in a given case study should, for instance, be representative for that particular study. Various partial methods are available for data quality assessment in LCA, but a standardised method for overall assessment of data quality is lacking as yet.

The next step concerns *cut-off and data estimation*. In principle, an LCA should track all the processes in the life cycle of a given product system, from the cradle to the grave. In practice this is impossible, however, and a number of flows must be either roughly estimated or cut-off and subsequently ignored. The root problem behind the cut-off issue is a lack of readily accessible data, implying disproportionate expenditure of funds and effort on data collection. Cut-off may substantially influence the outcome of an LCA study, however, and means that ‘easy’ LCAs come at a price. In the new Handbook the cut-off problem has been re-formulated as a problem of having to quantitatively estimate the environmental interventions associated with flows for which no readily accessible data are available using primarily environmentally extended Input-Output Analysis (see for further details, e.g., Suh et al., 2006 and Hendrickson et al., 2006).

A next important issue concerns the boundaries between the product system under study and other product systems. In part this concerns simple decisions which processes belong to which product system and which not. The problem lies in processes which are part of more than one product system, the so-called *"multiple processes"* (see Figure 3). How should the environmental impacts of these processes be *allocated* to the different product systems involved? Up to now the procedures used are rather arbitrary, using rules based on mass or energy data, whereas they may have great influence on the final results of the study. There are three basic types of multifunctional processes that require partitioning (Figure 7): multi-output processes (co-production), multi-input processes (combined waste processing) and input-output processes which cross system boundaries (recycling).

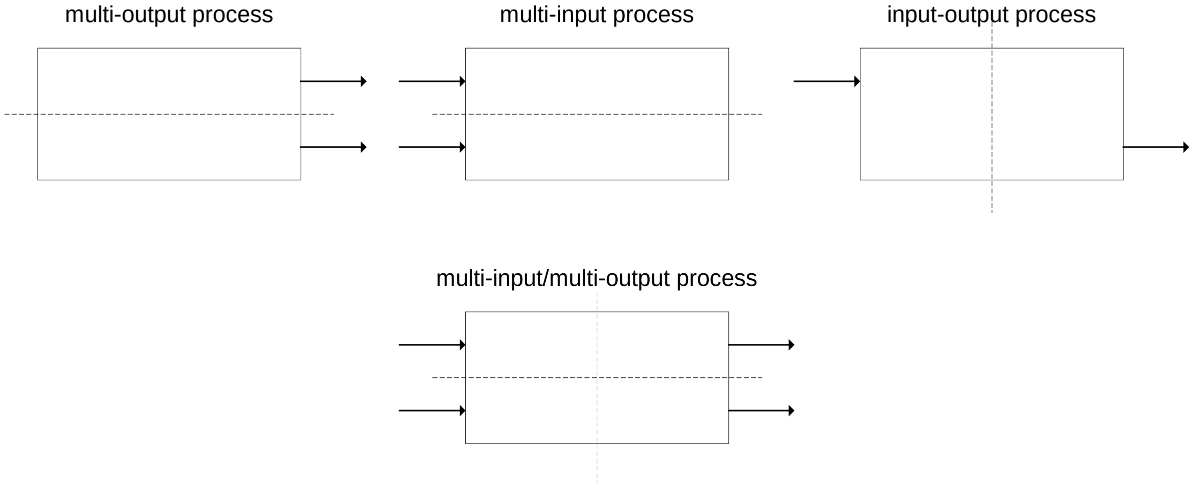

Figure 7: Basic types of multifunctional processes, and their combination. Functional flows to which all other flows are to be allocated are shown as arrows. Other flows have been omitted from the figure. System boundaries are depicted as dotted lines.

Co-production means that one unit process produces more than one functional output. The question is how should the environmental burdens (the environmental interventions from and to the environment) be allocated to these different functional outputs? Traditionally this is done on a mass basis. But the example of diamond production which goes together with the production of a great bulk of stones as a by-product shows that this may not be equitable: all burdens would be allocated to the stones and not to the diamonds, although the latter are the reasons for the existence of the mine. Another principle concerns allocation on basis of economic value, as the key steering factor for all production processes. It may be noted that it is also an economic principle which determines what has to be allocated to what: as wastes have to be allocated to products, only an economic principle can decide which output is waste and which is product or by-product.

With combined waste treatment the problem is that emissions from an incineration plant will contain a broad spectrum of materials, which will definitely not be included in a great deal of the burned wastes. Allocating the emission of cadmium to the waste management of a polyethylene (PE) bottle again is not equitable. The procedure should begin here with a causality principle linking as far as possible materials to different fractions of the waste.

With recycling we can distinguish between closed loop and open loop situations. In a fully closed loop situation there is no allocation problem, because there is only one product at stake. Generally loops will in part or in total be open: the wastes from one product system will be used as a secondary resource for another. In this situation we deal with a multiple process for which an allocation rule has to be defined. In present practice often a "50% rule" is used, giving an equal share to the two product systems involved, but also more sophisticated logic may be applied. In addition to this, one may also want to allocate part of the resource needs for product system A to product system B, because the latter makes also use of the resources, and part of the wastes from product system B to product system A, because system B also solves the waste problem for system A.

Allocation is a crucial issue. the allocation method selected may significantly influence the results of a specific LCA-study. ISO has proposed a preference order of different options to be checked on their applicability one after the other. In short, this preference order consists of the following steps:

- check whether allocation can be avoided by dividing processes into sub-processes
- check whether allocation can be avoided by expanding the boundaries of the system;
- apply principles of physical causality for allocation of the burdens;
- apply other principles of causality, for instance economic value.

The interpretation of this preference order is another thing and differs between practitioners. In the new Handbook preference has been given to economic allocation as a methodology which can be applied consistently for all types of allocation situations (cf. Guinée *et al.*, 2002).

The inventory analysis is concluded with the *calculation* of the inventory results, the total list of environmental interventions (the extractions and emissions) connected with the product systems investigated. In the computation process care must be taken that loops of flows are taken into account properly; for instance: electricity production requires steel and v.v. In Table 4 the inventory results are shown for the hypothetical system of PE throw-away bags.

Table 4: Inventory results for the hypothetical system of PE throw-away bags.

intervention	product system
resources	
crude oil	8.1 kg
emissions to air	
1-butene	7.8E–7 kg
benzene	9.9E–7 kg
carbon dioxide	2.2 kg
dioxins (unspecified)	8.1E–14 kg
ethylene	1.2E–4 kg
nitrogen oxides	3.7E–3 kg
sulphur dioxide	2.0E–2 kg
emissions to water	
benzene	1.2E–9 kg
cadmium	4.4E–8 kg
lead	3.0E–9 kg
mercury	2.8E–9 kg
phenol	2.4E–8 kg
economic inflows not followed to the system boundary	
lubricants	2.4 kg
economic outflows not followed to the system boundary	
used plastic bag	1000
residue to dump	0.08 kg
recovered energy	0.0008 MJ

Apart from the quantitative entries, the inventory results may also include qualitative issues and flags, points which cannot be dealt with in a quantitative way but which have to be considered in the final appraisal of the results.

Impact Assessment

Impact assessment is the third phase of an LCA understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study. In the new Handbook, impact assessment includes the following steps:

- selection of impact categories;
- selection of characterisation methods: category indicators, characterisation models and factors;
- classification (assignment of inventory results to impact categories);
- characterisation;
- normalisation;
- grouping;
- weighting.

In the Impact assessment phase the results of the Inventory analysis are translated into contributions to relevant *impact categories*, such as depletion of abiotic resources, climate change, acidification, etc. To this end, relevant impact categories must be identified. In the new Handbook a default list of impact categories has here been elaborated to facilitate the work of practitioners, thereby distinguishing between 'baseline' impact categories, 'study-specific' impact categories and 'other' impact categories (Table 5)[6].

Table 5: Default list of impact categories and subcategories

impact category	single baseline characterisation method provided in the new Handbook?	other characterisation method(s) available in the new Handbook?
A. Baseline impact categories		
Depletion of abiotic resources	yes	yes
Impacts of land use		
land competition	yes	yes
Climate change	yes	yes
Stratospheric ozone depletion	yes	yes
Human toxicity	yes	yes
Ecotoxicity		
freshwater aquatic ecotoxicity	yes	yes
marine aquatic ecotoxicity	yes	yes
terrestrial ecotoxicity	yes	yes
Photo-oxidant formation	yes	yes
Acidification	yes	yes
Eutrophication	yes	yes
B. Study-specific impact categories		
Impacts of land use		
loss of life support functions	no	yes
loss of biodiversity	no	yes

[6] 'Baseline impact categories' comprises impact categories for which a baseline characterization method has been selected in the new Handbook. Baseline impact categories are included in almost all LCA studies. 'Study-specific impact categories' comprises impact categories that may merit inclusion, depending on the Goal and scope of the LCA study and whether appropriate data are available, and for which a baseline and/or alternative characterization method has been proposed. 'Other impact categories' comprises the impact categories for which no baseline characterization method is proposed in the new Handbook.

impact category	single baseline characterisation method provided in the new Handbook?	other characterisation method(s) available in the new Handbook?
Ecotoxicity		
freshwater sediment ecotoxicity	yes	yes
marine sediment ecotoxicity	yes	yes
Impacts of ionising radiation	yes	yes
Odour		
malodourous air	yes	no
Noise	yes	no
Waste heat	yes	no
Casualties	yes	no
C. Other impact categories		
Depletion of biotic resources	no	yes
Desiccation	no	no
Odour		
malodourous water	no	no
...	...	...

This default list is based on a so-called midpoint approach. There are, however, other types of impact category lists, based on more endpoint-oriented approaches. The key difference between midpoint and endpoint approaches is the point in the environmental mechanism[7] at which the category indicators are defined. They may be defined close to the intervention (the midpoint, or problem-oriented approach, a.o. Heijungs *et al*., 1992). Alternatively, they may be defined at the level of category endpoints (the endpoint, or damage approach, a.o. EPS (Steen, 1999) and Eco-indicator 99 (Goedkoop & Spriensma, 1999)). In our view, the damage approach does not employ comprehensive and reliable endpoint indicators for all relevant impacts yet and has a number of other shortcomings. As things stand, therefore, we recommend the problem-oriented approach in the new Handbook, with impact categories defined at the midpoint level.

Subsequently, the interventions recorded in the inventory table are quantified in terms of a common category indicator. To this end *characterisation models* are used, from which characterisation factors are derived for individual pollutants and so on. For a each impact category listed in Table 5, a characterisation method comprising a category indicator, a characterisation model and characterisation factors derived from the model, should be developed.

For the impact category climate change, a characterisation method may resemble the following :

impact category	climate change
LCI results	emissions of greenhouse gases to air (in kg)
characterisation model	the model as developed by the Intergovernmental Panel on Climate Change (IPCC) defining the global warming potential of different greenhouse gases
category indicator	infrared radiative forcing (W/m^2)
characterisation	global warming potential for time horizon of 100 years

[7] Environmental mechanism is for a given impact category, the chain of environmental processes linking interventions to impacts; modelled in LCA (usually only partially) to one or more category endpoints by means of a characterisation model.

factor	(GWP100) for each greenhouse gas emission to air (in kg carbon dioxide/kg emission)
unit of indicator result	kg (carbon dioxide eq)

Examples of characterisation factors and models for a number of baseline impact categories thus may include the following:

impact category	characterisation factor	characterisation model
Abiotic depletion	ADP	-
Climate change	GWP	IPCC model
Stratospheric ozone depletion	ODP	WMO model
Human toxicity	HTP	Multimedia model, e.g. EUSES, CalTox
Ecotoxicity (aquatic, terrestrial etc.)	AETP, TETP, etc.	Multimedia model, e.g. EUSES, CalTox
Photo-oxidant formation	POCP	UNECE Trajectory model
Acidification	AP	RAINS
Etc.	...	...

ADP = abiotic depletion potential GWP = global warming potential
ODP = ozone depletion potential HTP = human toxicity potential
AETP = aquatic ecotoxicity potential TETP = terrestrial ecotoxicity potential
AP = acidification potential POCP = photochemical ozone creation potential

It is generally recognised today that characterisation methods for assessing chemical releases should include a measure of both fate (including exposure/intake where relevant) and effect of the substances. The fate aspect involves the distribution over and persistence within the different environmental media. For toxic releases, fate may be modelled by e.g. multimedia models and effect may be expressed by e.g. a so-called PNEC (Predicted No-Effect Concentration) or similar effect indicator. Most characterisation methods are globally oriented but refinements are possible here, of course. This is not necessary for global categories, including the two mentioned above, but may be relevant for categories like acidification and eutrophication. Another refinement concerns the possible inclusion of anthropogenic background levels. This may for instance be relevant for the assessment of toxic releases and is already used in the assessment of photo-oxidant forming releases. It should be noted however that this process is by no means without obstacles. Due to the fact that many categories are quite heterogeneous with respect to their underlying mechanisms, such characterisation factors cannot be defined on scientific knowledge alone, but will to a smaller or larger extent also be based on value judgements. In fact, this is also the case with the well accepted GWP values (see Hertwich *et al.*, 2001).

In the *classification* step the environmental interventions qualified and quantified in the Inventory analysis are assigned on a purely qualitative basis to the various pre-selected impact categories. Thus, CH_4 and CO2 are for example assigned to climate change.

In the *characterisation* step the environmental interventions assigned qualitatively to a particular impact category in classification are quantified in terms of a common unit for that category by their respective characterisation factors, allowing aggregation into a single score: the indicator result. The resulting number for one particular impact category is referred to as a category indictor result, and the complete set of category indicator results as the environmental profile. For example, if the GWP of CO_2 equals 1 and the GWP of CH_4 equals 11, the indicator result for an emission of 2 kg CO_2 and an emission of 3 kg CH_4 for climate change using the GWP characterisation factors would be :

1 x 2 + 11 x 3 = 35 kg CO2 - equivalents

In Table 6 the environmental profile is shown for the hypothetical system of PE throw-away bags.

Table 6: Environmental profile for the hypothetical system of PE throw-away bags.

Impact category	Value
indicator results	
depletion of abiotic resources	3.5 kg antimony eq
photo-oxidant formation	$1.2 \cdot 10^{-4}$ kg ethene eq
climate change	2.2 kg CO2 eq
freshwater aquatic ecotoxicity	0.013 kg 14DCB eq
terrestrial ecotoxicity	$2.6 \cdot 10^{-6}$ kg 14DCB eq
human toxicity	0.0088 kg 14DCB eq
acidification	0.033 kg SO2 eq
eutrophication	$4.8 \cdot 10^{-4}$ kg PO4 eq
interventions of which characterisation factors are lacking	
emission to air: dioxins (unspecified)	$8.1 \cdot 10^{-14}$ kg
economic outflows not followed to system boundary	
used plastic bag	1000
residue to dump	0.08 kg
recovered energy	0.0008 MJ

Normalisation is a step of Impact assessment in which the indicator results are expressed relative to well-defined reference information. The reference information may relate to a given community (e.g. The Netherlands, Europe or the world), person (e.g. a Danish citizen) or other system, over a given period of time. Other reference information may also be adopted, of course, such as a future target situation. The main aim of normalising the category indicator results is to better understand the relative importance and magnitude of these results for each product system under study. Normalisation can also be used to check for inconsistencies, to provide and communicate information on the relative significance of the category indicator results and to prepare for additional procedures such as weighting or Interpretation. In Table 7 the normalised environmental profile is shown for the hypothetical system of PE throw-away bags.

Table 7: Normalised environmental profile for the hypothetical system of PE throw-away bags.

Impact category	Value
normalised indicator results	
depletion of abiotic resources	2.2E–11 yr
photo-oxidant formation	2.6E–15 yr
climate change	5.7E–14 yr
freshwater aquatic ecotoxicity	6.7E–15 yr
terrestrial ecotoxicity	6.8E–18 yr
human toxicity	1.8E–16 yr
acidification	1.1E–13 yr
eutrophication	3.7E–15 yr

interventions of which characterisation factors are lacking	
emission to air: dioxins (unspecified)	8.1E–14 kg
economic outflows not followed to system boundary	
used plastic bag	1000
residue to dump	0.08 kg
recovered energy	0.0008 MJ

Grouping is a step of Impact assessment in which impact categories are aggregated in one or more sets defined in the Goal and scope definition phase. It may take the form of sorting - whereby impact categories are sorted on a nominal basis, e.g. by characteristics such as emissions and resource use, or global, regional and local spatial scales -, and/or ranking - whereby impact categories are hierarchically ranked (e.g. high, medium, and low priority), applying value choices. Little work has yet been done to make this step operational.

Finally, *weighting* is a step of Impact assessment in which the (normalised) indicator results for each impact category assessed are assigned numerical factors according to their relative importance, multiplied by these factors and possibly aggregated. This may include a formalised weighting procedure, resulting in one environmental index. The weighting can be done case by case, or on basis of a generally applicable set of weighting factors. For the latter, three different lines can be distinguished, which are in part interconnected and which may to some extent be combined: a monetary approach, in which a translation into monetary values is being performed; a distance-to-target approach, in which the weighting factors are in some way related to given reference levels; and societal approach, in which the weighting factors are set in a authoritative procedure, comparable to the setting of standards.
Although all steps of LCA contain value choices, weighting par excellence is based on value-choices. Therefore, ISO states that “Weighting […] shall not be used in LCA studies intended to be used in comparative assertions intended to be disclosed to the public.”. Outside ISO, however, weighting methods have received extensive attention since 1992.

In Table 8 weighting results using a further unspecified weighting method are shown for the hypothetical system of PE throw-away bags.

Table 8: Weighting results for the hypothetical system of PE throw-away bags.

Impact category	**Weight**	**Value**
weighted indicator results		
depletion of abiotic resources	0.01	2.2E–13 yr
photo-oxidant formation	0.8	2.1E–15 yr
climate change	2.4	1.4E–13 yr
freshwater aquatic ecotoxicity	0.2	1.3E–15 yr
terrestrial ecotoxicity	0.4	3.9E–18 yr
human toxicity	1.1	1.9E–16 yr
acidification	1.3	1.4E–13 yr
eutrophication	1.0	3.7E–15 yr
weighting result		
total	–	***5.1E–13 yr***
interventions of which characterisation factors are lacking		
emission to air: dioxins (unspecified)		8.1E–14 kg
economic outflows not followed to system boundary		
used plastic bag	–	1000
residue to dump	–	0.08 kg
recovered energy	–	0.0008 MJ

Interpretation
Interpretation is the fourth phase of an LCA, interpreting the results of the Inventory analysis and/or Impact assessment in the light of the Goal and scope definition (e.g. by means of contribution, perturbation and uncertainty analysis, comparison with other studies) in order to draw up conclusions and recommendations. In the new Handbook, Interpretation includes the following steps:

- consistency check;
- completeness check;
- contribution analysis;
- perturbation analysis;
- sensitivity and uncertainty analysis;
- conclusions and recommendations.

Interpretation is the phase in which the results of the analysis and all choices and assumptions that are made during the course of the analysis are judged as to soundness, robustness, and overall conclusion. The main elements of the Interpretation are an evaluation of results (as to consistency and completeness), an analysis of results (for instance, as to robustness), and a pronunciation of the conclusions and recommendations of the study.
Interpretation is a relatively new phase of LCA and has not yet received as much attention as the other LCA phases. In the new Handbook, preliminary proposals for making the above listed Interpretation steps operational have been elaborated (see Guinée *et al.*, 2002).

In Table 9 the results of a contribution analysis for the emission of cadmium to fresh water yielding a decomposition into the main contributing processes, are shown for the hypothetical system of PE throw-away bags.

Table 9: Main contributing processes to the emission of cadmium to fresh water for the hypothetical system of PE throw-away bags[8].

Process	Contribution
Electricity production	56%
Refining; allocated to naphtha	25%
Incineration of chemical waste	19%

[8] Thus, a large part (56 per cent) of the emission of cadmium to surface water is caused by electricity production. Note that the contribution of 25 per cent by refining is only the part that is allocated to production of naphtha, and that this excludes the production of fuel oil and other co-products. If the emission of cadmium to surface water is a major concern in the study, it is clear that the process data for the electricity production should be checked carefully.

Annex 2: Terms & abbreviations

CALCAS	Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability
EC	European Commission
EIOA	Environmentally extended Input-Output Analysis
EU	European Union
EZ	(Dutch) Ministry of Economic Affairs
FP	Framework Programme
GWP	Global Warming Potential
IA	Impact Assessment
ILCD	International Reference Life Cycle Data System
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JRC	Joint Research Centre
JRC-IES	Joint Research Centre - Institute for Environment and Sustainability
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Analysis
LNV	(Dutch) Ministry of Agriculture, Nature Management and Fisheries
MSME	Micro, Small and Medium Enterprise
RA	Risk Assessment
SEAT	Sustaining Ethical Aquatic Trade
SETAC	Society for Environmental Toxicology and Chemistry
UK	United Kingdom
UNEP	United Nations Environment Programme
UNEP-SETAC	United Nations Environment Programme - Society for Environmental Toxicology and Chemistry
WP	Work Package
V&W	(Dutch) Ministry of Transport, Public Works and Water Management
VROM	(Dutch) Ministry of Housing, Spatial Planning and Environment