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SP9 – SUSTAINABILITY ANALYSIS FOR EUROBIOREF BIOREFINERY CONCEPT (ENVIRONMENTAL, ECONOMICAL, SOCIOECONOMICAL, POLICY RULES)

WP9.1 – DEVELOPMENT OF A LCA METHODOLOGY AND LC MANAGEMENT FOR THE INTEGRATED BIOREFINERY

Deliverable report

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Content

Executive summary

Description of the deliverable objective and content

The increasing awareness of the importance of sustainability and the potential environmental impact associated with products and services has sparked the innovation of methods to better understand, measure and reduce this impact. The leading tool for achieving this – and the only tool that can make a full evaluation of all sources and types of impact – is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 14040:2006, ISO 14044:2006).

LCA is an internationally recognized approach that evaluates the potential environmental and human health impact associated with products and services throughout their life cycle, beginning with raw material extraction and including transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts.

To begin building this foundational knowledge, EuroBioRef project has decided to perform LCA analyses on biorefinery activities. The global objective is to realize an LCA that will evaluate environmental burdens of the biorefinery (and chemicals) over their whole life cycle ("cradle to grave"). Due to the characteristics of a biorefinery, a specific LCA methodology is developed into the EuroBioRef project.
Based on ISO standards (ISO 14040:2006, ISO 14044:2006) and ILCD Handbook (European Commission 2010) recommendations, this deliverable states the LCA methodology to be used to assess the environmental impact of biorefineries within the EuroBioRef project.

This deliverable D9.1.3 named "New methodology for performing LCA of biorefineries" is linked to the Task 9.1.3 named "LCA Methodology".

Brief description of the state of the art

There is no internationally recognized LCA methodological guide focused on biorefinery activities. Nevertheless, the literature offers some interesting scientific articles focused on biorefining, some recognized standards and some useful general LCA guides.
The deliverable D1.2.3 named "Literature review establishing the state of the art of LCA applied to biorefineries, to be published in a peer reviewed scientific journal" presents a detailed literature review updated on M12, M24, M36 and M48.

Deviation from objectives and corrective actions

According to European Commission request, the EuroBioRef, Biocore and Suprabio FP7-funded biorefinery projects should be harmonised on certain aspects in terms of sustainability assessment. Environmental LCA is one of the key aspects to be harmonised.

This request was not included in the Description of Work (DoW) and can be considered as a deviation from objectives.

In order to ensure that the evaluation is based on a common ground, the inter-project working group on harmonisation of sustainability assessment was pre-formed on 18th June 2010 in Brussels (Belgium) and consists of representatives from IFEU (Biocore and Suprabio), Imperial and Quantis (EuroBioRef).
In September 2010, an interim report named "Harmonisation of sustainability assessment" (Boucher et al. 2010) was delivered to the European Commission.
In October 2011, an inter-project harmonisation meeting was organized in Verona (Italy) to discuss and organize the redaction of the final report about harmonisation of sustainability assessment.

In November 2011, a bilateral harmonisation meeting between IFEU and Quantis was organized in Heidelberg (Germany) to discuss about some specific LCA issues.
In January 2012, a meeting between the inter-project working group and the scientific officers was organized in Brussels (Belgium) to discuss the LCA harmonised approach. The official approval is expected for early 2012.

The methodology used in the EuroBioRef project shall be aligned with the environmental LCA part of the report delivered by the inter-project working group. For this reason, some parts of deliverable D9.1.3 “New methodology for performing LCA of biorefineries” might be changed after the release of the mentioned report.

Innovation brought and technological progress

The innovation promoted by this deliverable is intended in terms of LCA methodology. Indeed, it defines an adapted LCA approach in order to take into account the specificities of biorefineries. The assessment of a biorefinery should take into account its multi-inputs and multi-outputs nature considering many feedstock sources, different transformation processes and specific products at the end.

Some specific LCA choices are needed due to the degree of freedom offered by the internationally recognized LCA standards as ISO standards (ISO 14040:2006, ISO 14044:2006) and ILCD Handbook (European Commission 2010).
The developed methodology is aligned with the harmonisation works carried out by the inter-project working group representing the FP7-funded biorefinery projects: EuroBioRef, Biocore and Suprabio. This harmonisation work gives to the developed LCA methodology the possibility to be recognized at a larger level in a dynamic of progress in terms of environmental assessment of biorefinery activities.

Analysis of the results

Not applicable.

Impact of the results

The LCA methodology developed in this deliverable represents the framework for the further LCA activities of the EuroBioRef project. In the future, the LCA activities of the EuroBioRef project will be based on this methodology in order to guarantee a maximum degree of consistence.

Due to the harmonisation efforts among the three FP7-funded biorefinery projects (EuroBioRef, Biocore and Suprabio), the impact of this deliverable is expected to be larger than the EuroBioRef boundaries.

Related IPR

Not applicable.

Publishable information

This deliverable has a public dissemination level.

Conclusion

The EuroBioRef project adopted LCA as tool to consistently assess potential impacts related to biorefinery activities. This deliverable developed a specific LCA methodology accounting for the particularities of this specific industrial sector and strongly relying on ISO standards (ISO 14040:2006, ISO 14044:2006) and ILCD Handbook (European Commission 2010) recommendations.

The developed methodology is harmonised with the recommendations made by an ad-hoc created inter-project working group representing the FP7-funded biorefinery projects: EuroBioRef, Biocore and Suprabio. Addressing a request from the European Commission about sustainability assessment, it has been created to ensure that the sustainability assessment among the FP7 projects is based on a common ground.

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1. Introduction

The increasing awareness of the importance of sustainability and the potential environmental impact associated with products and services has sparked the innovation of methods to better understand, measure and reduce this impact. The leading tool for achieving this – and the only tool that can make a full evaluation of all sources and types of impact – is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 14040:2006, ISO 14044:2006).

LCA is an internationally recognized approach that evaluates the potential environmental and human health impact associated with products and services throughout their life cycle, beginning with raw material extraction and including transportation, production, use, and end-of-life treatment. Among other uses, LCA can identify opportunities to improve the environmental performance of products at various points in their life cycle, inform decision-making, and support marketing and communication efforts.

To begin building this foundational knowledge, EuroBioRef project has decided to perform LCA analysis on biorefinery activities. The global objective is to realize a LCA that will evaluate environmental burdens of the biorefinery (and chemicals) over their whole life cycle ("cradle to grave"). Due to the characteristics of a biorefinery, a specific LCA methodology is developed into the EuroBioRef project strongly based on ISO standards (ISO 14040:2006, ISO 14044:2006) and ILCD Handbook (European Commission 2010) recommendations.

1.1. Harmonisation

According to European Commission request, the EuroBioRef, Biocore and Suprabio FP7-funded biorefinery projects have be harmonised regarding the sustainability assessment. Environmental LCA is one of the key aspects to be harmonised.

LCA is normalized by internationally recognized standards such as (ISO 14040:2006) and (ISO 14044:2006). Nevertheless, the degree of freedom they offer in terms of methodological or data choices is too broad to ensure consistent evaluations between different projects.

In order to ensure that the evaluation is based on a common ground, the inter-project working group on harmonisation of sustainability assessment was pre-formed on 18th June 2010 in Brussels (Belgium) and consists of representatives from IFEU (Biocore and Suprabio), Imperial and Quantis (EuroBioRef). This deliverable is concerned by the environmental LCA harmonisation efforts (the social and economic aspects are not taken into account).
In September 2010, an interim report named "Harmonisation of sustainability assessment" (Boucher et al. 2010) was delivered to the European Commission.
In October 2011, an inter-project harmonisation meeting was organized in Verona (Italy) to discuss and organize the redaction of the final report about harmonisation of sustainability assessment. In November 2011, a bilateral harmonisation meeting between IFEU and Quantis was organized in Heidelberg (Germany) to discuss some specific LCA issues.
In January 2012, a meeting between the inter-project working group and the scientific officers was organized in Brussels (Belgium) to discuss the LCA harmonised approach. The official approval is expected for early 2012.

- The inter-project working group on harmonisation of sustainability assessment consisting of representatives from IFEU (Biocore and Suprabio), Imperial and Quantis (EuroBioRef) will deliver a final report in early 2012 named “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects” (but, at the moment, it is not yet available).

- The methodology used in the EuroBioRef project shall be aligned with the environmental LCA part of the report delivered by the inter-project working group. For this reason some parts of deliverable D9.1.3 “New methodology for performing LCA of biorefineries” might be changed after the release of the mentioned report.

2. Life Cycle Assessment (LCA)

This chapter presents the LCA methodology and gives some details concerning the main standards taken into account in the EuroBioRef project.

2.1. The methodology

The International Organization for Standardization (ISO) defines LCA as follows: "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, p. 2).

Among the tools that Life Cycle Management (LCM) offers, LCA, or environmental balance, is one of the most comprehensive and high-performance methods. LCA is the only method that assesses with quantitative metrics the environmental impacts of a product or activity (a system of products) over its entire life cycle in a holistic approach.

The main goal of the method is to identify the hotspots through the life cycle of products and services to guide the decision-making process to lessen their environmental impacts.

2.2. The reference documents

LCA methodology is laid down in important regulatory frameworks. Many methods and guidance documents are available according to specific geographic zone or industrial sector.
LCA is structured, comprehensive and internationally standardised through ISO 14040-14044 standards (ISO 14040:2006, ISO 14044:2006). While these ISO standards are in place since the mid 1990ies, a new guidance document was been published in 2010 and it is taken into account in the EuroBioref project: ILCD Handbook (European Commission 2010). Both reference documents are presented below.

2.2.1. The ISO 14040-14044 standards

ISO standards define four phases in a LCA study:

1) goal and scope definition,
2) inventory analysis,
3) impact assessment, and
4) interpretation.

The first phase states the reason for carrying out the intended application and to whom they are communicated (goal) and the depth and the breadth of LCA, i.e. how the product system is set up and modelled (scope).

The Life Cycle Inventory (LCI) analysis phase collect and compute the input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.

The third phase focuses on the Life Cycle Impact Assessment (LCIA) phase. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance.

2.2.2. The ILCD Handbook

The ISO 14040-14044 standards provide the indispensable framework for LCA. This framework, however, leaves the individual practitioner with a range of choices, which can affect the legitimacy of the results of an LCA study. While flexibility is essential in responding to the large variety of questions addressed, further guidance is needed to support consistency and quality assurance. The International Reference Life Cycle Data System (ILCD) has therefore been developed by the European Commission (Joint Research Centre, JRC, of the Institute for Environment and Sustainability, IES) to provide guidance for consistent and quality assured LCA data and studies.

The ILCD Handbook consists of a set of documents that are in line with the ISO standards on LCA with the main goal to ensure quality and consistency of life cycle data, methods and assessments by providing stricter guidance than the ISO standards. Its main target audience is LCA practitioners, data providers, and reviewers.

EuroBioRef project will take into account the main requirements of the ILCD Handbook whenever possible. It is important to consider that the first volumes of ILCD Handbook documents were launched in March 2010.

3. Goal and scope definition

This chapter defines the goal and scope for the EuroBioRef project.

3.1. Goal

The aim of LCA activities in EuroBioRef are adapted from the objectives of WP 9.1 (EuroBioRef DoW, pp. 142-144):

a) to develop an appropriate LCA methodology,

b) to develop an LCA web tool:
- to perform LCA of biorefineries,
- to provide a tool and indicators for life cycle management,
- to consider the possibility of an environmental labelling of the bio-based products.

c) to evaluate the environmental performance of the value chains investigated within EuroBioRef

This document presents the appropriate LCA methodology developed in the EuroBioRef project.
In anticipation of the application of the methodology, the present chapter states some definitions following ISO standards and ILCD Handbook recommendations. These definitions should be stated on case-by-case basis when actually applying the methodology. Table 3-1 presents some examples that can be useful in the future applications of this methodology in a biorefinery context.

Table 3-1 Examples of some definitions to be stated applying the methodology developed in the EuroBioRef project.

Topic	Definition
Reasons for carrying out the study	The reasons for carrying out LCA activities in EuroBioRef project are related to the need to assess the environmental impacts of selected feedstock-to-product schemes within a biorefinery context.
Intended application *The ILCD Handbook lists many LCA applications, e.g., Identification of Key Environmental Performance Indicators (KEPI) of a product group for Ecodesign / simplified LCA, Comparison of specific goods or services, Development of Product Category Rules (PCR) or a similar specific guide for a product group, etc.*	The intended application of LCA activities in EuroBioRef project correspond to the objectives of WP 9.1 mentioned above, i.e.: a) to develop an appropriate LCA methodology (and test it on the value chains investigated within the EuroBioRef project), b) to develop an LCA web tool: - to perform LCA of biorefineries based on the developed methodology, - to provide a tool and indicators for life cycle management and improvement of the environmental performance of biorefineries, - to consider the possibility of an environmental labelling of the bio-based products resulting from the biorefinery (incl. chemicals, materials, fuels, etc.), c) to evaluate the environmental performance of the value chains investigated within EuroBioRef
Intended audience	The intended audience can be divided into internal stakeholders such as EuroBioRef partners and external stakeholders such as the European Commission team.
Limitations	LCA activities in the EuroBioRef project have some assumption-related limitations due to the fact that analysed systems are not yet implemented.
Commissioner of the study	The research led in the EuroBioRef project has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n° [241718].

3.1.1. Classifying the decision-context

According to the ILCD Handbook (European Commission 2010, pp. 36-50), the decision-context shall be identified during the goal definition.

Three different decision-context situations (A, B and C) of practical relevance in LCA can be differentiated considering the following aspects:

- Is the LCA study used to support a decision on the analysed system?
    - And, if so: what is the influence of changes that the decision implies in the analysed system and in other systems via market mechanisms? These can be small-scale (non-structural) – Situation A – or large-scale (structural) – Situation B.
    - And, if not so: is the study interested in interactions of the depicted system with other systems – Situation C ? Yes – Situation C1 – or not – Situation C2.

Table 3-2 Main aspects of the decision-context according to the ILCD Handbook (European Commission 2010, p. 38)

Decision support?		Kind of process-changes in background system / other systems	
		None or small-scale	Large-scale
	Yes	Situation A "Micro-level decision support"	Situation B "Meso/macro-level decision support"
	No	Situation C "Accounting" (with C1: including interactions with other systems, C2: excluding interactions with other systems)	

EuroBioRef LCA activities are classified in Situation B because the consequences of life cycle based decisions are considered as large-scale. Situation B refers to life cycle based decision support for strategies and typically refers to the mid-term (5 to 10 years from present) or long-term (beyond 10 years from present) future. Identifying best business opportunities and assessing the socio-economic and environmental impacts of selected feedstock-to-product schemes (which is the objective of SP 9), implies decisions to promote some options with large-scale consequences. According to ILCD Handbook definitions, large-scale consequences shall generally be assumed if the annual additional demand or supply that is triggered by the analysed decision exceeds the capacity of the annually replaced installed capacity that provides the additionally demanded process, product, or broader function, as applicable; if that percentage is over 5 %, 5 % should be assumed instead[1]. Although, as so far, it cannot be stated systematically if the biorefinery products (and co-products) will cover more than 5% of market share, the EuroBioRef project is for sure large-scale regarding the input (feedstock) side. In addition, biorefineries (based on the concept developed within the EuroBioRef project or any similar concept) are expected to develop significantly within the next 5 to 10 years in the European Union and it is believed that such a type of activity (biomass-to-products in a biorefinery context) is likely to represent a significant market share (on the feedstock side but also possibly on the product side) when the technologies reach maturity.

[1] An example according to ILCD Handbook (European Commission 2010, p. 42): the installed capacity for production of the globally traded material X, that might be required in consequence of the analysed decision to produce product Y, might be e.g. 10 Mio tonnes. The plants for producing material X might have a lifetime of 25 years (i.e. 4 % of this are replaced annually and on average). In that case, an annual demand of more than 0.04*10*10^6 t = 400,000 t of material X shall be assumed to have the large-scale consequence of triggering additional installation of capacity beyond the replacement of old plants.

According to the report "Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects":

- Proposal 1: Situation B is considered to apply for the main pathways of all projects.
- Proposal 2: The focus is on mature, full industrial plants. Other development statuses may be added.
- Proposal 3: 2025 is chosen as the harmonised time frame for mature, full industrial plants. Other timeframes (e.g. 2015) may be added.

3.2. Scope

The ILCD Handbook (European Commission 2010, pp. 51-69), based on LCA ISO standards (ISO 14040:2006, p. 11-13), states that the object of the LCA study is identified and defined in detail during the scope definition phase.

The following definitions are structured according to ILCD Handbook recommendations.

3.2.1. Type of deliverables

The appropriate type of deliverable is derived from the goal of the study, especially the intended applications.

EuroBioRef deliverables are clearly defined in the DoW. The present document corresponds to the deliverable D9.1.3 named "New methodology for performing LCA of biorefineries".

3.2.2. System studied and its functional unit

The functional unit (FU) quantifies the performance of a product system and is used as a reference unit for which the LCA study is performed and the results are presented.

Two approaches are taken into account in the EuroBioRef project with the following functional units:

- the "biorefinery approach": 1 kg of feedstock (dry matter) transformed in the biorefinery;
- the "product approach": 1 kg of product exiting the biorefinery.

Both functional unit definitions allow to communicate the results per kg of dry matter leaving the field, which is the functional unit proposed by the harmonisation works. Although the biorefinery capacities concerned are very large (i.e. 50 kt and 500 kt), the functional units refer to 1 kg in order to facilitate the results communication.

The two approaches are defined in section "3.2.4 System boundaries".

According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”:

- Proposal 4: The proposed functional unit is 1 kg of dry matter leaving the field. For side streams other functional units depending on the questions to be answered might be needed and may be added accordingly.

3.2.3. LCI modelling framework

Two main decisions are to be made concerning LCI modelling framework:

- Attributional or consequential modelling;
- Solving multifunctionality: allocation or system expansion / substitution approaches. This latter decision at least in part depends on the former.

These decisions, which are to be made in accordance with the goal of the study, have implications for many of the later choices, including which inventory data are to be collected or obtained.

ILCD Handbook (European Commission 2010, pp. 71-72) gives definition of these two type of modelling:

- Attributional modelling
  The life cycle model depicts its actual or forecasted / specific or average supply-chain plus its use and end-of-life value chain. The existing or forecasted system is embedded into a static technosphere.

- Consequential modelling
  The life cycle model depicts the generic supply-chain as it is theoretically expected in consequence of the analysed decision. The system interacts with the markets and those changes are depicted that an additional demand for the analysed system is expected to have in a dynamic technosphere that is reacting to this additional demand.

The discussion about attributional and consequential modelling in the biofuel context is still a debated topic as confirmed by literature such as (Brander et al. 2009).

As stated before, EuroBioRef LCA activities are classified in Situation B. According to ILCD Handbook Situation B shall apply the LCI modelling guidance of Situation A with one exception: processes that have been identified as being affected by big changes (large-scale consequences) as consequence of the analysed decision shall be modelled as mix of the long-term marginal processes (see sub-section “Identifying processes in consequential modelling” for more details).

To determine which processes are to be considered affected by big changes, all main inputs (feedstocks) and outputs (co-products) shall be systematically examined. At this stage of the EuroBioRef project, primary data are not available to define the large-scale processes. This task will be treated in the next steps of the project.

LCI modelling in the EuroBioRef project shall be aligned with ILCD Handbook provisions detailed in section “6.5.4 LCI modelling provisions for Situations A, B and C” (European Commission 2010, pp. 81-92). For processes that are affected by big changes in Situation B, the relevant modelling approach is consequential. In those cases, the chapter “7.2.4 Identifying processes in consequential modelling” (European Commission 2010, pp.164-182) is required to be applied in its detail.
Providing the details of these provisions is beyond the objective of the present deliverable and one shall refer to the corresponding section in the ILCD Handbook.

According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”:

- Proposal 6: Consequential modelling will be applied.

Identifying processes in consequential modelling

In the consequential approach, the relevant consequences and the related processes are to be identified.
One important aspect of consequential modelling is that it is not depicting the actual processes of a system, but it is modelling the forecasted consequences of decisions. These consequences are those processes that are assumed to be operated as reaction to the named decision. To identify the detailed consequences and marginal (or affected) processes, expertise of technology development forecasting, scenario development, market cost and market forecasting, technology cost modelling, general-equilibrium modelling and partial equilibrium modelling is required (European Commission 2010, p. 165).

The aim of this sub-section is not to detail each step of modelling the consequences for the consequential approach, but rather to present an overview according to ILCD Handbook recommendations.
The first step towards identifying the marginal processes that provide the function and the superseded (displaced) processes is to identify which primary and secondary consequences (also known as “rebound effects”) and constraints are to be integrated in the model. The next step is the identification of the processes that are operated or displaced due to the identified consequences. Analysing the considered consequences and taking into account the selected constraints, the processes are identified and the consequential life cycle is modelled stepwise starting from the analysed decision in the foreground system. Not a single, short-term or long-term marginal process should be modelled but a mix of the most likely marginal processes, which the ILCD Handbook assumes results in much more robust models. In Situation B, processes that have been identified as being affected by big changes (large-scale consequences) as consequence of the analysed decision shall be modelled as mix of the long-term marginal processes.

The case of indirect land use change (ILUC)

Indirect land use change (ILUC) is an aspect under consequential modelling and it refers to the situation that an additional demand for land means that the actual land use has to be carried out elsewhere, i.e. it is displaced. ILCD handbook (European Commission 2010, p. 173) signals that the appropriate way to integrate ILUC is to be developed for the specific case. Indeed, as no widely accepted provisions exist for this topic, no specific provisions are made in the first edition of the ILCD handbook (it is indicated that such provisions might be part of a future supplement).

The present document recommends to deal with ILUC issues according to the causal descriptive approach described by (E4tech 2010). This approach uses information on agricultural markets to determine what fraction of additional agricultural land use will be met by intensification (increase in use of fertilizers) and what fraction will be based on actual indirect land use. Modelling ILUC using causal descriptive approach requires mapping out all the impacts an increased demand for a certain biofuel (or bioproduct) has on the broader agricultural and land use systems. The land use change impacts can be established by comparing the worldwide land use when the concerned feedstock is produced to the worldwide land use with no additional demand for this feedstock, i.e. the difference between the baseline and the biofuels (or bioproduct) projection.

Solving multifunctionality

The biorefinery is a complex concept that can integrate a large variety of available biomass feedstocks matched with a large variety of processes to obtain multiple products. Each process that provides more than one function is termed “multifunctional”.

In LCA studies, different approaches are used for solving multifunctionality.

According to LCA ISO standards (ISO 14044:2006, pp. 14-16), wherever possible, allocation should be avoided by either (1) dividing the multifunctional unit process into two or more sub-processes and collecting the input and output data related to these sub-processes or (2) expanding the product system to include the additional functions related to the co-products. Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them. Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them; for example in proportion to the economic value of the products.

ILCD Handbook (European Commission 2010, pp. 72-93) treats multifunctionality issues based on the decision-context situations (A, B or C).
To solve multifunctionality in Situation B, the LCI modelling guidance of Situation A shall be applied, with one exception: processes that have been identified as being affected by big changes (large-scale consequences) as consequence of the analysed decision shall be modelled as mix of the long-term marginal processes.
For solving multifunctionality in Situation A, subdivision or virtual subdivision shall be used in priority. Where this is not possible, some type of substitutions are suggested and are stated as priority before allocation choice. In any case, the appropriate LCI method approaches shall be aligned with the options detailed in the section “6.5.4.2.2 LCI modelling provisions” of the ILCD Handbook (European Commission 2010, pp. 82-85).
Multifunctionality in consequential modelling, Situation B, is solved in a two-step procedure next to subdivision or virtual subdivision (somewhat similarly as in attributional modelling). In the case subdivision and virtual subdivision are not possible or feasible, the next step depends on the question whether the multifunctional process is a case of combined production or of joint production. Combined production refers to situation where the amount of the co-functions can be entirely independently varied without changing the production facilities (e.g. multi-waste incineration). If this is not the case, this is called joint production (e.g. NaOH and Cl_2 production by electrolysis of NaCl). For combined production, the determining physical causality, which is the first of the two steps of allocation under attributional modelling, equally applies. For joint production, substitution (system expansion) is the solution to solve multifunctionality with the following considerations in mind: determining and non-determining co-products are not treated the same way, and how the superseded processes are chosen need to be described.

In a sensitivity analysis, according to EuroBioRef DoW, various methods of allocation are considered in the “product approach” to attribute the appropriate impact to the selected product (i.e. allocation based on physical, e.g. mass or energy content, or economic relationship). This choice is not aligned to consequential approach requested by ILCD Handbook, but it makes it possible to provide environmental profiles of individual products that all contain parts of the impact of biorefinery. This is a limitation in terms of methodology, and it is considered only in a sensitivity analysis way.

According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”:

- Proposal 7: To evaluate biorefinery concepts as multi-output systems, the projects will go for substitution. At least for some main scenarios all projects will apply the substitution approach (straw & short rotation coppice). Additionally, allocation (mass, energy, economic, RED) will be applied for sensitivity studies, depending on the specific research questions to be answered.

3.2.4. System boundaries

According to LCA ISO standards (ISO 14040:2006, p. 12), the system boundaries define the unit processes to be included in the analysed system.

ILCD Handbook (European Commission 2010, p. 94) states that the system boundaries definition is important to ensure that all attributable or consequential processes are included in the modelled system in order to cover all relevant potential impacts on the environment.

EuroBioRef LCA activities cover the entire value chain, including biomass feedstock source, transports, chemical conversion routes, use phase and end-of-life (EuroBioRef DoW, p. 142). The following figures summarize the system boundaries considered in this study according to the two approaches.

The “biorefinery approach” focuses on the biorefinery system (including all products), referring to 1 kg of biomass (dry matter) transformed in a biorefinery. This approach allows to have a global vision of the biorefinery system.

The “product approach” focuses on one selected product of the biorefinery. The functional unit considers 1 kg of the selected product leaving the biorefinery. This approach enables results to be provided for individual products of the biorefinery.

For both approaches, the multifunctionality is solved as described above and illustrated in Figure 3-1 and Figure 3-2.

According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”:

- Proposal 5: Infrastructure will not be included in the inventory, except for background data (indeed generic LCI databases such as ecoinvent may include infrastructure with no possibility to exclude it). It’s up to the partners to include infrastructure in sensitivity studies to show significance. There will be a short explanation in the reports why infrastructure is excluded.

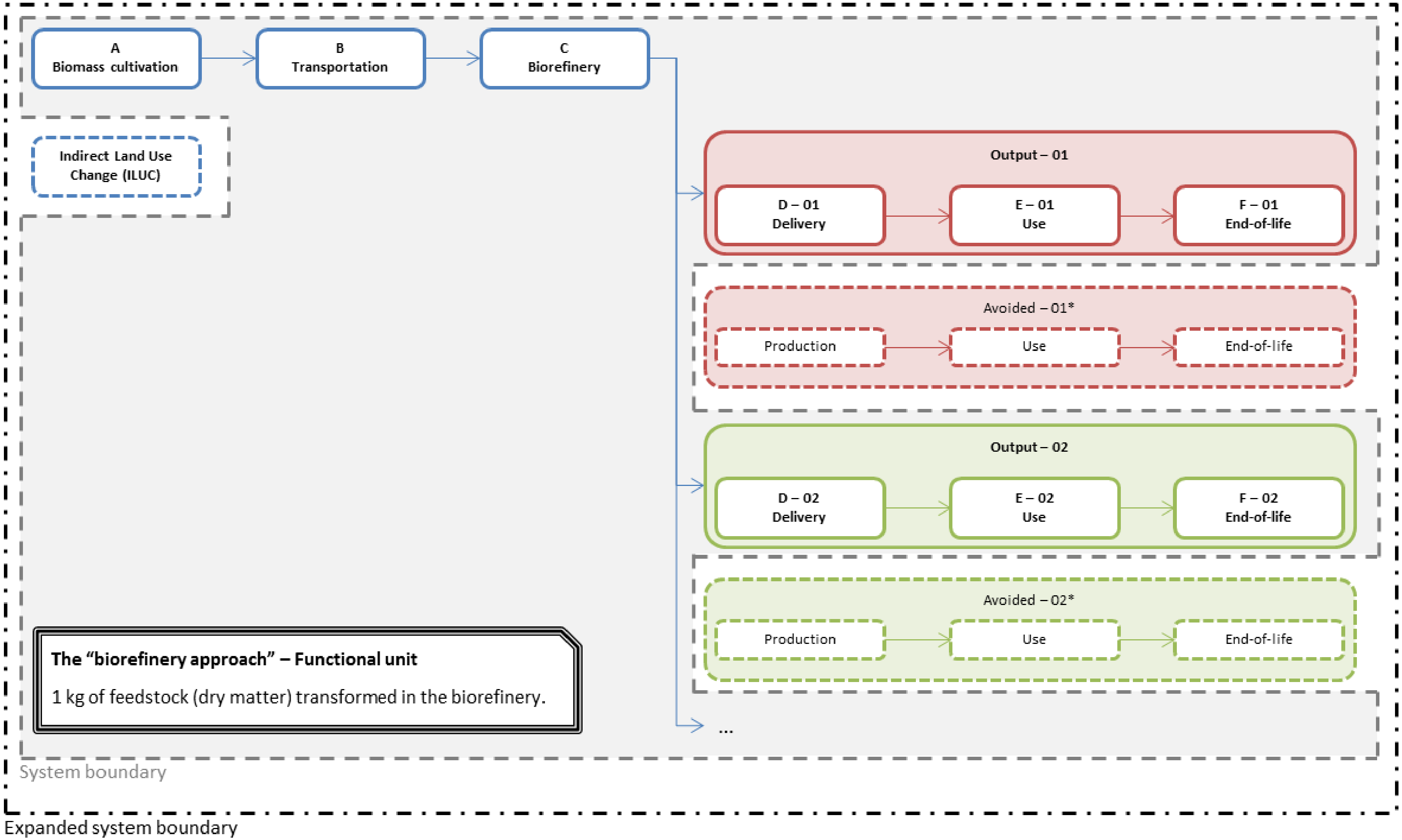

Figure 3-1 System boundaries considered in the “biorefinery approach”.

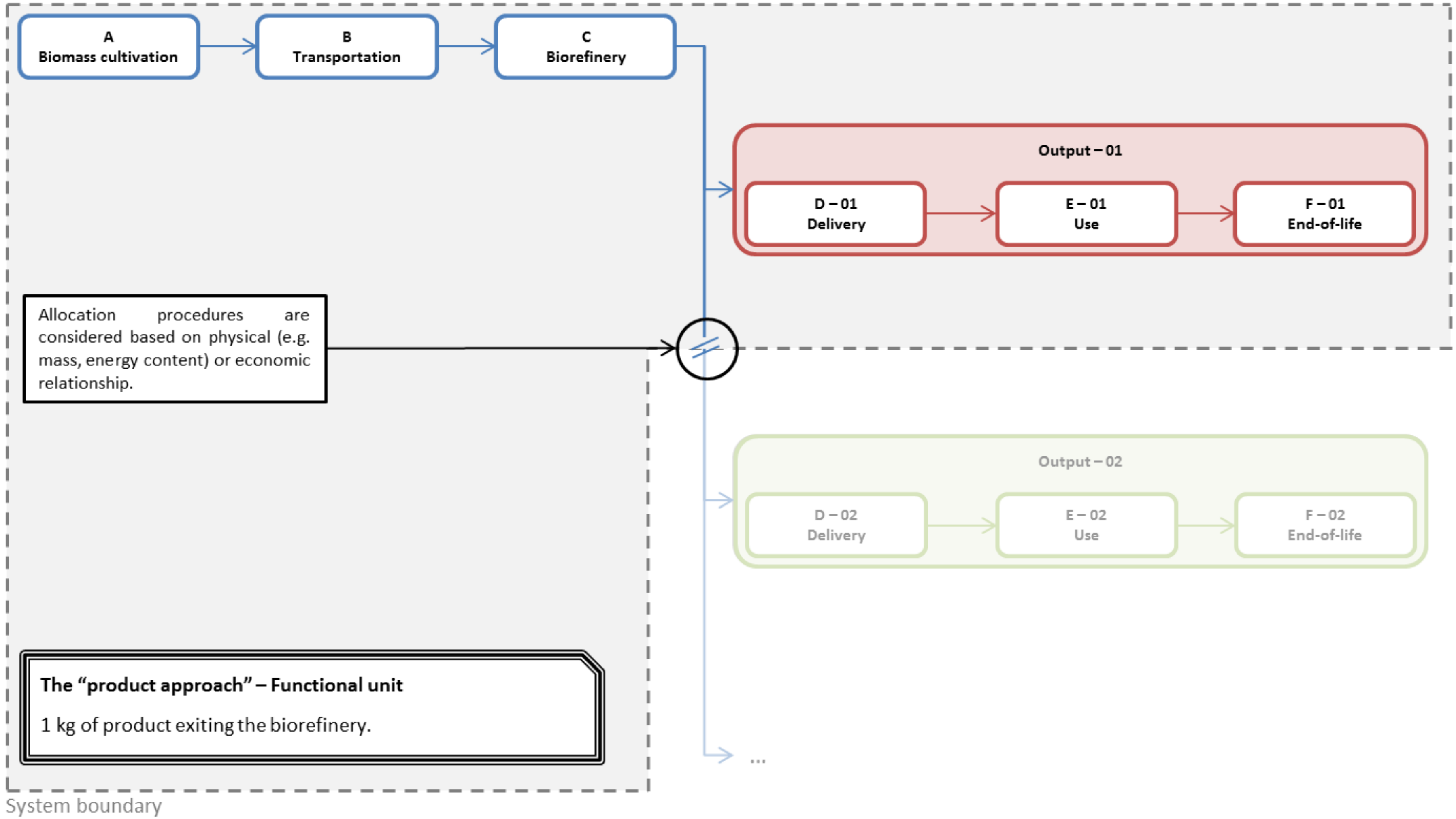

Figure 3-2 System boundaries considered in the "product approach".

3.2.5. Critical review

No critical review by an independent external panel will be performed. For this reason, communication outside EuroBioRef partners should be conducted with caution and accompanied by a statement that the findings are not peer reviewed.

Harmonisation:

- According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”, no critical review by an independent external panel will be performed.

4. Life Cycle Inventory (LCI)

The LCI analysis phase inventories the input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.
ISO standards (ISO 14040:2006, p. 2) define LCI analysis as the phase of LCA involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

The following chapters treat some specific methodological points linked to LCI analysis in the EuroBioRef project.

4.1. LCI databases

The data related to the biorefinery activities can be structured into three categories:

a) the auxiliary inputs used at each stage along the life cycle;
b) the direct emissions occurring at each stage along the life cycle;
c) the indirect resources and emissions associated with the supply chain of the auxiliary inputs recorded under a).

In the EuroBioRef project, the LCI is performed using different sources of data.

For the categories a) and b), primary data provided directly by partners are considered first; scientific literature data are used to complete missing data.

Concerning the data of the category c), sometimes called secondary data (which refer to data that are not based on direct measurements or calculation for the concerned process), the following sources are considered (in order of priority):

1) the generic LCI database ecoinvent V2.2 (ecoinvent 2010);
2) Quantis own internal database;
3) datasets from relevant literature or provided through expert judgment and assumptions.

The ecoinvent database is the world's leading database with consistent and transparent, up-to-date LCI data. With more than 4'000 LCI datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment, it offers one of the most comprehensive international LCI databases. High-quality generic LCI datasets are based on industrial data and have been compiled by internationally renowned research institutes and LCA consultants.

Another generic LCI database investigated during the EuroBioRef project is the European Reference Life Cycle Database (ELCD). Nevertheless, ELCD database is not used in EuroBioRef project because according to European Commission – Joint Research Centre website (EC JRC website 2011) the actual version of ELCD database is not considered as official reference:
"Disclaimer: Please note that so far mostly only internally reviewed and only partly harmonised LCI data sets are provided in this second version of the ELCD core database. All process data sets are in line with ISO 14040 and 14044 as stated by their owners/providers, but are not to be considered as official reference data sets of the European Commission or its JRC. The data sets are provided "as they are". A further methodological harmonisation and independent external review are foreseen."

Harmonisation:

- According to the report "Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects", all projects will use the ecoinvent V2.2 database as the principal source of secondary data.

4.2. Agricultural models

Direct and indirect field emissions arising from agricultural activities (including emissions of greenhouse gases such as N_2O or CO_2, but also emissions of NH_3 and NO_X to the air, emissions of NO_3^{2-}, PO_4^{3-} and P in water, etc.) are generally significant contributors to the environmental impacts of biomass systems.

Some agricultural models are available in order to assess the fate of fertilizers used during biomass cultivation. The following paragraphs state the approach used in the EuroBioRef project for each type of direct emissions arising from fertilizer and pesticides application during agricultural activities. Some default values are indicated in the following equations in order to define each parameter. In the future, these default values could be change according to data availability.

Modelling of ammonia (NH_3) emissions to air

The NH_3 emissions to air due to the losses during the spreading of farmyard manure are calculated with the models given by (Katz 1996) and (Menzi et al. 1997).

The emissions during the spreading of slurry and liquid manure are calculated according to the following formula.

$$NH_{3s} = 17/14 * (-9.5 + 19.4 * TAN + 1.1 * SD_m) * (0.0214 * S + 0.358) * A_s \qquad \textbf{Eq. 1}$$

With:

NH_{3s}	= emissions of NH_3 from slurry or liquid manure [kg NH_3 /(ha.yr)]
TAN	= total content of ammonium-N in the slurry or liquid manure [kg NH_4-N/m^3]; as default value according to (Walther et al. 2001, p.63) 1 kg N/t is considered (= 1 kg NH_4-N/m^3 with a density of 1'000 kg/m^3)
SD_m	= saturation deficit of the air in month m; as default value an average value of 3.5 is considered (Quantis assumption
S	= quantity of slurry spread [m^3/(ha of fertilised surface.yr)], including the dilution water; as default values according to (Nemecek et al. 2007, p. 28) if S_{in} < 40 --> S = 40 and $A_s = S_{in}/40$ and if S_{in} > 40 --> S = S_{in} and A_s = 1." With S_{in} = amount of slurry input in m^3
A_s	= fraction of the total area, where slurry is spread (%/100)

The emissions during the application of solid manure (from cattle and pigs) are calculated according to the following formula.

$NH_{3M} = 17/14 * (0.787 * TAN * M + 0.757) * 0.75 * A_M$	**Eq. 2**

With:

NH_{3M} = emissions of NH_3 from solid manure [kg NH_3 /(ha.yr)]
TAN = total content of ammonium-N in the manure [kg NH_4-N/t]; as default value according to (Walther et al. 2001, p. 57) 2 kg N/t is considered (= 2 kg NH_4-N/m^3 with a density of 1'000 kg/m^3)
M = quantity of solid manure spread [t/(ha of fertilised surface.yr)]
A_M = fraction of the total area, where solid manure is spread (%/100); as default value according to (Nemecek et al. 2007, p. 28) if M_{in} < 16 --> M = 16 and $A_M = M_{in}/16$ and if M_{in} > 16 --> M = M_{in} and A_M = 1 with M_{in} = amount of manure input in t

Mineral fertilisers emissions are modelled according to (Nemecek et al. 2007, p. 29) based on the emission factors given by (Asman 1992). The values considered are listed below. N content are based on (Nemecek et al. 2007, pp. 84-88) except for multinutrient fertilisers (Quantis assumption).

Table 4-1 NH_3 mineral fertilisers emissions.

Fertilizer	Emission factor for NH_3-N	N content
ammonium nitrate	2.0%	35%
calcium ammonium nitrate	2.0%	27%
ammonium sulphate	8.0%	21%
urea	15.0%	46%
multinutrient fertilisers[2]	4.0%	28%
urea ammonium nitrate	8.5%	32%

It would be worth making a sensitivity analysis on these data, if their contribution is high to impact results. Data provided by (FAO-IFA 2001) will be investigated.

Modelling of direct and indirect nitrous oxide (N_2O) emissions to air

The N_2O emissions to air are calculated according to (Emmenegger et al. 2009, p. 35) based on (Nemecek et al. 2007) and (IPCC 2006).

$N_2O = 44/28 * (EF_1 * (N_{av} – 14/17 * NH_3 + N_{cr}) + EF_4 * 14/17 * NH_3 + EF_5 * 14/62 * NO_3^-\text{-N})$	**Eq. 3**

With:

N_2O = emissions of N_2O [kg N_2O/(ha.yr)]
EF_1 = 0.01 (IPCC 2006, p. 11.11)
N_{av} = total N input from synthetic and organic fertilizers [kg N/(ha.yr)] (100% of nitrogen applied is assumed available)
N_{cr} = nitrogen contained in the crop residues [kg N/(ha.yr)]
EF_4 = 0.01 (IPCC 2006, p. 11.24)
NH_3 = losses of nitrogen in the form of ammonia [kg NH_3/(ha.yr)]; calculated according to Eq. 1, Eq. 2 and Table 4-1
EF_5 = 0.0075 (IPCC 2006, p. 11.24)
NO_3^--N = nitrate loss through leaching [kg N / (ha.yr)]; calculated according to Eq. 14

EF parameters can vary a lot across a geographic region because the climate varies. Especially, the N_2O emissions are influenced by humidity. In case data are available, specific EF should be taken into account.

[2] NPK-, NP-, NK-fertilisers

Modelling of nitrogen oxides (NOx) emissions to air

The NO_x emissions to air are calculated according to (Nemecek et al. 2007, p. 36).

$NO_x = 0.21 * N_2O$	**Eq. 4**

With:
NO_x = emission of NOx [kg NO_x/(ha.yr)]
N_2O = emissions of N_2O [kg N_2O/(ha.yr)]; calculated according to Eq. 3

It would be worth making a sensitivity analysis on these data, if their contribution is high to impact results. Data provided by (FAO-IFA 2001) will be investigated.

Modelling of carbon dioxide (CO_2) emissions to air

CO_2 emissions are calculated taking into account three contribution according to Eq. 5.

$CO_2 = CO_2^{LUC} + CO_2^{LIM} + CO_2^{UREA}$	**Eq. 5**

With:
CO_2^{LUC} = CO_2 emissions from soil due to the land use change [kg CO_2/(ha.yr)]
CO_2^{LIM} = CO_2 emissions from lime application [kg CO_2/(ha.yr)]
CO_2^{UREA} = CO_2 emissions from urea application [kg CO_2/(ha.yr)]

Calculation of CO_2 emissions from land transformation is carried out according to specific annex of ILCD handbook (European Commission 2010, pp. 337-342) based on (IPCC 2006). Emissions are defined by calculating the difference of the steady-state soil carbon content between the land use before and after transformation (converting C differences stoechiometrically to CO_2 flows).

Many aspects influence emissions from land transformations. The native soil carbon stock (which depends on climatic conditions in the region and soil type) is modified as a result of changes in land use (land use type, temperature regime, and moisture regime), land management (specific land management for cropland and for grassland), and in the level of related input (as a function of the above named land management types). These aspects and resulting factors are derived from the most recent available related IPCC reports.

The CO_2 emission to air due to the land use change is calculated according to the following equation.

$CO_2^{LUC} = (SOC_i - SOC_f) * 44/12$	**Eq. 6**

With:
CO_2^{LUC} = CO_2 emissions from soil due to the land use change [kg CO_2/(ha.yr)]
SOC_i = initial soil organic carbon stock of initial land use "1" [kg C/(ha.yr)]; as defined by Eq. 11
SOC_f = final soil organic carbon stock of land use "2", i.e. after transformation [kg C/(ha.yr)] as defined by Eq. 12

The soil organic carbon stock of the initial land use is calculated according to the following equation.

$$SOC_i = SOC_n * LUF_1 * LMF_1 * IL_1 \quad \textbf{Eq. 7}$$

With:
SOC_i = initial soil organic carbon stock of initial land use "1" [kg C/(ha.yr)]
SOC_n = native soil organic carbon stock (climate region, soil type) [kg C/(ha.yr)]
LUF_1 = land use factor [-]
LMF_1 = land management factor [-]
IL_1 = input level factor [-]

The values of SOC_n, LUF, LMF and IL are given in (European Commission 2010, pp. 337-342) based on (IPCC 2006).

The soil organic carbon stock of final land use is calculated according to the following equation.

$$SOC_f = SOC_n * LUF_2 * LMF_2 * IL_2 \quad \textbf{Eq. 8}$$

With:
SOC_f = final soil organic carbon stock of land use "2", i.e. after transformation [kg C/(ha.yr)]
SOC_n = native soil organic carbon stock (climate region, soil type) [kg C/(ha.yr)]
LUF_2 = land use factor [-]
LMF_2 = land management factor [-]
IL_2 = input level factor [-]

The values of SOC_n, $LUF_{1,2}$, $LMF_{1,2}$ and $IL_{1,2}$ are given in (European Commission 2010, pp. 337-342) based on (IPCC 2006).

According to (IPCC 2006, pp. 11.26-11.31), liming is used to reduce soil acidity and improve plant growth in managed systems. Adding carbonates to soils in the form of lime leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate which evolves into CO_2 and water.

CO_2 emissions due to liming are calculate according to the Tier 1 of (IPCC 2006, pp. 11.26-11.31)[3].

$$CO_2^{LIM} = [(M_{Limestone} * EF_{Limestone}) + (M_{Dolomite} * EF_{Dolomite})] * 44/12 \quad \textbf{Eq. 9}$$

With:
CO_2^{LIM} = CO_2 emissions from lime application [kg CO_2/(ha.yr)]
$M_{...}$ = amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$) [kg/(ha.yr)]
$EF_{...}$ = emission factor of 0.12 [kg of C/kg] for limestone and 0.13 [kg of C/kg] for dolomite

According to (IPCC 2006, pp. 11.32-11.36), adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4^+), hydroxyl ion (OH^-) and bicarbonate (HCO_3^-), in the presence of water and urease enzymes. Similar to the soil reaction following addition of lime, bicarbonate that is formed evolves into CO_2 and water.

CO_2 emissions due to adding urea are calculate according to the Tier 1 of (IPCC 2006, pp. 11.32-11.36)[4].

[3] Inventories can be developed using Tier 1, 2 or 3 approaches, with each successive Tier requiring more detail and resources than the previous one.
[4] Inventories can be developed using Tier 1, 2 or 3 approaches, with each successive Tier requiring more detail and resources than the previous one.

$CO_2^{UREA} = (M * EF) * 44/12$ **Eq. 10**

With:
CO_2^{UREA} = CO_2 emissions from ura application [kg CO_2/(ha.yr)]
M = amount of urea fertilisation [kg/(ha.yr)]
EF = emission factor of 0.20 for urea [kg of C/kg]

Modelling of phosphorus (P) and phosphate (PO_4^{3-}) emissions to water

The P and PO_4^{3-} emissions to water are calculated according to SALCA model developed by Agroscope Reckenholz-Tänikon Research Station (ART) (Prasuhn 2006). Three different kinds of phosphorus emissions to water are considered:

- leaching of soluble phosphate to ground water (inventoried as “phosphate, to ground water”),
- run-off of soluble phosphate to surface water (inventoried as “phosphate, to river”),
- erosion of soil particles containing phosphorus (inventoried as “phosphorus, to river”).

P leaching to the ground water is estimated as an average leaching, corrected by P-fertilisation.

$P_{gw} = P_{gwl} * F_{gw}$ **Eq. 11**

With:
P_{gw} = quantity of P leached to ground water [kg P/(ha.yr)]
P_{gwl} = average quantity of P leached to ground water for a land use category [kg P/(ha.a)], which is
0.07 [kg P/(ha.yr)] for arable land and
0.06 [kg P/(ha.yr)] for permanent pastures and meadows
F_{gw} = correction factor for fertilisation by slurry
F_{gw} = 1 + 0.2/80 * P_2O_{5sl}
P_2O_{5sl} = quantity of P_2O_5 contained in the slurry or liquid sewage sludge [kg/(ha.yr)] according to (Walther et al. 2001).

P run-off to surface waters is calculated in a similar way to leaching to ground water.

$P_{ro} = P_{rol} * F_{ro}$ **Eq. 12**

With:
P_{ro} = quantity of P lost through run-off to rivers [kg P/(ha.yr)]
P_{rol} = average quantity of P lost through run-off for a land use category [kg P/(ha.yr)], which is
0.175 [kg P/(ha.yr)] for open arable land,
0.25 [kg P/(ha.yr)] for intensive permanent pastures and meadows and
0.15 [kg P/(ha.yr)] for extensive permanent pastures and meadows
F_{ro} = correction factor for fertilisation with P
F_{ro} = 1 + 0.2/80 * P_2O_{5min} + 0.7/80 * P_2O_{5sl} + 0.4/80 * P_2O_{5man}
P_2O_{5min} = quantity of P_2O_5 contained in mineral fertilisers [kg/(ha.yr)]
P_2O_{5sl} = quantity of P_2O_5 contained in slurry or liquid sewage sludge [kg/(ha.yr)] according to Walther et al. (2001)
P_2O_{5man} = quantity of P_2O_5 contained in solid manure [kg/(ha.yr)] according to Walther et al. (2001)

P emissions through erosion to surface waters are calculated as described below.

$$P_{er} = S_{er} * P_{cs} * F_r * F_{erw}$$ **Eq. 13**

With:
P_{er} = quantity of P emitted through erosion to rivers [kg P/(ha.yr)]
S_{er} = quantity of soil eroded [kg/(ha.yr)] according to (Oberholzer et al. 2006, Appendix A4.1)
P_{cs} = P content in the top soil [kg P/kg soil]; the average value of 0.00095 kg/kg is used
F_r = enrichment factor for P; the average value of 1.86 is used according to (Wilke et al.1996) This factor takes account of the fact that the eroded soil particles contain more P than the average soil.
F_{erw} = fraction of the eroded soil that reaches the river; the average value of 0.2 is used

Modelling of nitrate (NO_3^-) emissions to water

The NO_3^- leaching to ground water is calculated according to (Emmenegger et al. 2009, pp. 71-83) mainly based on (De Willigen 2000) and (Roy 2003).

NO_3^- leaching to ground water is calculated as described below.

$$NO_3^--N = \{ 21.37 + [P / (c * L)] * [0.0037 * S + 0.0000601 * C_{org} – 0.00362 * U]\} * (1/1000)$$ **Eq. 14**

With:
NO_3^--N = nitrate loss through leaching [kg N / (ha.yr)]
P = annual precipitation and irrigation [mm/yr]
c = clay content [%]
L = root depth [m]
S = nitrogen supply [kg N / ha]
C_{org} = organic carbon content [%]
U = nitrogen uptake [kg N / ha]

The values of these parameters are given in the original references according to the context. For example, P and c depend on the ecozone, whereas L depends on the considered feedstock.

Modelling of further emissions in agriculture

For the pesticides emissions, a simplified modelling is used based on (Jungbluth et al. 2007). It is assumed that all inputs of pesticides are emitted in the nature. Therefore the emissions of the specific pesticides are equal to the inputs of pesticides.

For the heavy metal emissions in soil, the calculation is based on (Freiermuth 2006) according to (Nemecek et al. 2007). The difference between input of heavy metals with fertilizer and seeds and the output with the plant is assumed to be equal to the emissions in soil. The heavy metal content of plants and products is taken from (Nemecek et al. 2007).

The models for pesticides and heavy metal emissions could be refined and assessed in a sensitivity analysis.

4.3. Land use

According to IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry – GPG-LULUCF (IPCC 2003) land use is the type of activity being carried out on a unit of land.
Two topics are linked to feedstock cultivation in a biorefinery context: the direct land use change (LUC) and the indirect land use change (ILUC).

Considering biorefinery context, direct land use change occurs when biomass for biorefinery purposes displace a prior land use. According to (Emmenegger et al. 2009, p. 23), a direct land use change is given whenever the additional demand for more land is not caused by other displacements and the land transformed has not been used for the intended production of feedstock's, i.e. did not yield an annual, monetary profit.
The emissions of greenhouse gases related to the LUC are taken into account according to Eq. 6.

ILUC is addressed as stated in the section "3.2.3 LCI modelling framework".

4.4. Biogenic carbon

By default, biogenic carbon is not considered in the LCA related to global warming (i.e., intake by plants, storage and release during degradation/consumption). Because the uptake and the emission of CO_2 from biological sources cancel out (unless the emission occurs in a different molecular form, e.g. CH_4). The recommendation of the Publicly Available Standard (PAS) 2050 (BSI 2008) product carbon footprinting guidance is to not considering either the uptake or emission of CO_2 from biological systems (except where the CO_2 arises from land use change). Ecoinvent code of practice (Weidema et al. 2007) recommends to make the LCIA under exclusion of biogenic CO_2. According to these references, the LCA in the EuroBioRef project does not consider biogenic carbon during LCIA stage.

Nevertheless, for specific cases where release of biogenic carbon can be significantly longer after its capture (e.g., biopolymers stored in landfill, wood used for construction, etc.), the benefit from storing carbon during a certain time should be considered in the analysis. Because some biorefinery co-products could be concerned by this fact, biogenic carbon is inventoried at the LCI stage for the next steps of the EuroBioRef project. According to ILCD handbook (European Commission 2010) uptake of "carbon dioxide" by plants is inventoried under "Resources from air".

Harmonisation:

- According to the report "Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects", biogenic carbon shall be reported separately.

5. Life Cycle Impact Assessment (LCIA)

According to LCA ISO standards (ISO 14044:2006, pp. 16-23), the LCIA phase, which is the phase where the inputs and outputs of elementary flows are translated into impact indicator results, consists of mandatory and optional elements:

- Mandatory elements:
  - selection of impact categories, category indicators and characterization models;
  - classification: assignment of LCI results to the selected impact categories;
  - characterization: calculation of category indicator results.

- Optional elements:
  - normalization: calculating the magnitude of category indicator results relative to reference information;
  - grouping: sorting and possibly ranking of the impact categories;
  - weighting: converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available;
  - data quality analysis: better understanding the reliability of the collection of indicator results, the LCIA profile.

According to (EuroBioRef DoW, p. 143) this deliverable shall define environmental impacts to consider in EuroBioRef project. A midpoint and endpoint approach is used applying IMPACT 2002+ LCIA methodology (Jolliet et al. 2003) (Humbert et al. 2011). The details for the midpoint indicators of IMPACT 2002+ are listed in the Table 5-1.

Another LCIA methodology is considered in the EuroBioRef project. The ReCiPe LCIA methodology (Goedkoop et al. 2008) is used for some impact categories according to the harmonisation works.

Table 5-1 Details of midpoint indicators of IMPACT 2002+ methodology.

Impact category	LCIA methodology	Details
Climate change	IMPACT 2002+ (v2.2)	Based on IPCC 2001 and IPCC 2007 for CH_4, N_2O and CO, with a 100-year time horizon; CH_4, fossil = 27.75 kg CO_2-eq/kg; CH4, biogenic = 25 kg CO_2-eq/kg]. Unit: [kg CO2-eq into air]
Ozone depletion	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000) and US EPA Ozone Depletion Potential List. Unit: [kg CFC-11-eq into air]
Human toxicity	IMPACT 2002+ (v2.2)	Original method based on (Pennington et al. 2005; Pennington et al. 2006). Unit: [kg chloroethylene-eq into air]
Respiratory inorganics	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000; Hofstetter 1998). Unit: [kg PM2.5-eq into air]
Ionising radiation	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000). Unit: [Bq Carbon-14-eq into air]
Photochemical oxidation	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000). Unit: [kg ethylene-eq into air]
Aquatic acidification	IMPACT 2002+ (v2.2)	Based on CML (Guinée et al. 2002) and (Tachet et al. 2000). Unit: [kg SO2-eq into air]
Terrestrial acidification and nutrification	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000). Unit: [kg SO2-eq into air]
Aquatic eutrophication	IMPACT 2002+ (v2.2)	Based on CML (Guinée et al. 2002) and (Tachet et al. 2000). Unit: [kg PO43–eq into water]
Aquatic ecotoxicity	IMPACT 2002+ (v2.2)	Original method based on (Pennington et al. 2005; Pennington et al. 2006). Unit: [kg triethylene glycol-eq into water]
Terrestrial ecotoxicity	IMPACT 2002+ (v2.2)	Original method based on (Pennington et al. 2005; Pennington et al. 2006). Unit: [kg triethylene glycol-eq into soil]
Land use	IMPACT 2002+ (v2.2)	Based on Eco-indicator 99 (Goedkoop and Spriensma 2000) with only land occupation being considered. Unit: [m2 organic arable land-eq .year]
Turbined water use	IMPACT 2002+ (v2.2)	Based on volumes (m3 of water turbined). Unit: [m3 of water turbined]
Water withdrawal	IMPACT 2002+ (v2.2)	Based on volume (m3 of water withdrawn). Unit: [m3 of water withdrawn]
Water consumption	IMPACT 2002+ (v2.2)	Based on volumes (m3 of water consumed)] Unit: [m3 of water consumed]
Resource depletion: energy	IMPACT 2002+ (v2.2)	Non-renewable energy consumption, based on ecoinvent (Frischknecht et al. 2003) Unit: [MJ total primary non-renewable energy]
Resource depletion: minerals	IMPACT 2002+ (v2.2)	Mineral extraction, based on Eco-indicator 99 (Goedkoop and Spriensma 2000) Unit: [MJ additional energy]

According to the report "Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects":

- Proposal 8: Regarding impact assessment methods and environmental impact categories, harmonization will be limited to a minimum set of midpoint impact categories and associated methods. This is the main focus of the assessments. In individual projects, partners are free to: 1) complete the harmonized set of impact categories with additional ones; 2) perform an end-point evaluation (in addition of the midpoint approach); 3) use alternative impact evaluation methods in addition to the one(s) agreed upon.

- Proposal 9: No weighting will be applied.

6. Conclusion

The EuroBioRef project adopted LCA as tool to consistently assess potential impacts related to biorefinery activities. This deliverable developed a specific LCA methodology accounting for the particularities of this specific industrial sector and strongly relying on ISO standards (ISO 14040:2006, ISO 14044:2006) and ILCD Handbook (European Commission 2010) recommendations.

The developed methodology is harmonised with the recommendations made by an ad-hoc created inter-project working group representing the FP7-funded biorefinery projects: EuroBioRef, Biocore and Suprabio. Addressing a request from the European Commission about sustainability assessment, it has been created to ensure that the sustainability assessment among the FP7 projects is based on a common ground.

According to the report “Harmonisation of life cycle assessment (LCA) between the FP7-funded biorefinery projects”:

- Proposal 10: The assessment will rely on the ILCD Handbook version published in March 2010. Future developments of the ILCD will be discussed within the harmonization group. They will not be taken into account if they imply any methodological restructuring, because the actual environmental assessment already started and most methodological settings are fixed.
- Proposal 11: No specific LCI datasets will be delivered to the ICLD Data Network.

7. References

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8. Abbreviations and acronyms

DALY	Disabilities Adjusted Life Years
DoW	Description of Work
ELCD	European Reference Life Cycle Database
FU	Functional Unit
GWP	Global Warming Potential
ILCD	International Reference Life Cycle Data System
ISO	International Standardization Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment (method)
PDF	Potentially Disappeared Fraction of species
RER	Europe (in ecoinvent)
UCTE	Union for the Co-ordination of Transmission of Electricity