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Agence de l'Environnement et de la Maîtrise de l'Energie

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Ministère de l'Écologie, du Développement et de l'Aménagement durables

Study for a simplified LCA methodology adapted to bioproducts

Etude d'une méthodologie simplifiée pour la réalisation des ACV des bioproduits

Final report

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Study performed for the ADEME by BIO Intelligence Service

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About the ADEME:

ADEME, the French Environment and Energy Management Agency, is a public agency overseen jointly by the Ministry for the Ecology, Energy Sustainable Development and Planning and the Ministry for Further Education and Research. It is involved in the implementation of public policy in the fields of the environment, energy and sustainable development. The agency provides expertise and consultancy services for businesses, local authorities, public bodies and the general public and assists them with the funding of projects in five areas: waste management, soil preservation, energy efficiency and renewable energies, air quality and noise reduction. It also helps them make progress with sustainable development initiatives.

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Abstract

Agricultural resources form a renewable stock of raw materials that can be used for various purposes: food supply, production of energy (including biofuels), bioproducts and bio-based construction materials. The use of agricultural resources to produce bioproducts is expanding in France and throughout the world, partly due to the presumed advantages of these products towards the environment.

In this context, ADEME (the French Environment and Energy Management Agency) commissioned a study for the **development of a methodological framework to evaluate the environmental impacts of bioproducts**. This study was also in charge of the identification of areas of improvement for the "Bilan Produit", an environmental assessment tool developed by ADEME, in order to allow a future integration of bioproducts.

The first step of this study consisted of a **comparative review of the existing bioproducts' LCA** (Life Cycle Assessment). This review underlined a **deep heterogeneity among the methodologies used**, as well as a lack of transparency in the results displayed.

In a second step of the project, **all the methodological issues in the evaluation of bioproducts were studied**, and recommendations for the resolution of each one of them have been proposed. These critical analyses are presented in individual factsheets, which detail the specific issues of each question, facts from the bibliographic review, the results of the tests conducted on three bioproducts, and finally the methodological recommendations to answer the question.

This project showed that some methodological **recommendations had to be specified depending on the objective of the LCA: eco-design, environmental labelling or comparative LCA**.

The work conducted also identified some **necessary improvements to the Bilan Produit tool**, which come under four categories: addition of the missing inventories, integration of metadata regarding the inventories, consideration for the specific end-of-life scenarios of bioproducts, and an updating of the characterization methods.

The study was carried out by **paying attention to its consistency with other methodological frameworks in development** in France, such as the **ADEME-AFNOR platform** or the **Biofuels repository**, and abroad, with the **PAS 2050**, for example.

Finally, further information should arise from the working groups in ADEME-AFNOR, and from the work performed on water assessment and other indicator issues.

Résumé

Les ressources agricoles constituent un gisement de matière première pour de nombreux usages: alimentation, production d'énergie (y compris sous forme de biocarburant), de bioproduits et de biomatériaux. L'utilisation de ces ressources pour la production de bioproduits se développe fortement en France et dans le monde, notamment en vertu des potentiels pressentis de ces produits par rapport à l'environnement.

Dans ce contexte, l'ADEME a souhaité développer un cadre **méthodologique pour l'évaluation environnementale de ces bioproduits**. Les axes d'amélioration de l'outil Bilan Produit de l'ADEME pour une intégration future des bioproduits devaient également être étudiés.

La première étape de cette étude a été de réaliser une **analyse comparative des ACV existantes pour les bioproduits**. Cette revue bibliographique a mis en évidence une **forte hétérogénéité dans les méthodologies utilisées**, ainsi qu'un manque de transparence dans la présentation des résultats.

Dans une seconde étape, cette étude a permis d'**étudier point par point toutes les questions méthodologiques liées à la réalisation d'ACV des bioproduits**, et de proposer des recommandations pour le traitement de chacune de ces questions. Ces analyses critiques sont présentées sous forme de fiche méthodologique, afin de détailler: les enjeux propres à chaque question, les éléments issus de l'étude bibliographique, les résultats des tests effectués (sur trois bioproduits) et les recommandations méthodologiques issues de cette étude.

Il est apparu que certaines recommandations méthodologiques devaient se décliner **selon l'objectif de l'utilisateur: éco-conception, affichage environnemental ou ACV comparative**.

Cette réflexion a aussi mis en avant les **améliorations nécessaires de l'outil Bilan Produit**, selon trois axes: rajout des inventaires manquants, intégration de métadonnées sur ces inventaires, prise en compte de la fin de vie spécifique des bioproduits et mise à jour des méthodes de caractérisation utilisées.

Ces travaux ont été effectués en veillant à la **cohérence avec les différents cadres méthodologiques en cours de développement**, aussi bien en France avec la **plateforme ADEME-AFNOR** ou le **référentiel Biocarburants** qu'à l'étranger, par exemple avec le **PAS 2050**, lors de l'élaboration d'un cadre méthodologique.

Enfin, des éléments complémentaires devraient être apportés par les travaux en cours au sein de l'ADEME-AFNOR ou par ceux des groupes de travail internationaux, sur l'indicateur eau notamment.

1. REVIEW OF THE FRAMEWORK OF THE STUDY

1.1. PURPOSES OF THE STUDY

This study was designed to have the following purposes:

- **Developing, if possible, a simplified and uniform method for assessing the environmental impacts of bioproducts**
- **Consolidating this method by means of actual tests**
- **Proposing adaptations of the ADEME Product Assessment tool in line with this method.**

These objectives were to be broken down according to the three approaches: eco-design, environmental labelling and comparative LCA, as well as seeking to identify recommendations applicable to all of these approaches where possible.

1.2. CONTEXT OF THE STUDY: THE DEVELOPMENT OF BIOPRODUCTS:

In France and worldwide, the use of farming resources to produce bioproducts has expanded considerably, due in particular to the envisaged potential of such products with respect to the environment.

Definition of bioproducts

There are a number of definitions for the concept of bioproduct. We have used the **definition offered by the European Commission**:

Bioproducts ("bio" referring to "renewable biological resources" and not to "biotechnologies") designates non-food products extracted from biomass (plants, algae, crops, trees, marine organisms and domestic organic waste, food production and animal production). Bioproducts include high-added-value chemical products from the field of fine chemicals such as medicines, cosmetics, food additives, etc. and raw materials produced in large volumes, including general biopolymers and chemical feedstocks The concept excludes traditional bioproducts such as pulp, paper and timber products, as well as biomass used as a source of energy, etc.

Bioproducts may be classified in the following categories:

- Bio-packaging/biopolymers
- Surfactants
- Biosolvents
- Lubricants and hydraulic fluids
- Chemical intermediates
- others

The term "bioproducts" does not refer to organically farmed products.

The development of such bioproducts has arisen due to a favourable context and growing interest in bioenergies and bioproducts:

- **In economic terms:** Competitiveness compared to fossil fuels, security of supply, new markets, innovative, "green growth" products
- **In social terms: a source of jobs and revenue in rural areas;**
- **In environmental terms:** reducing CO2 emissions, pollution, liquid and solid waste, as well as offering fossil substitution, eco-construction and eco-designed products;
- **In societal and political terms:** a response to increasing public awareness in Western countries of the issue of sustainable development as defined in the Kyoto protocol and expressed within Europe and in France (Grenelle environmental summit).

Bioproducts derived from green chemistry are promoted notably due to their many and various potential points of interest in terms of decreased environmental impact:

- use of renewable materials,
- design of auxiliary solvents and safer products, less toxic chemical syntheses,
- decrease in the number of byproducts,
- design of non-persistent substances,
- improvement of energy performance,
- reduced greenhouse gas emissions

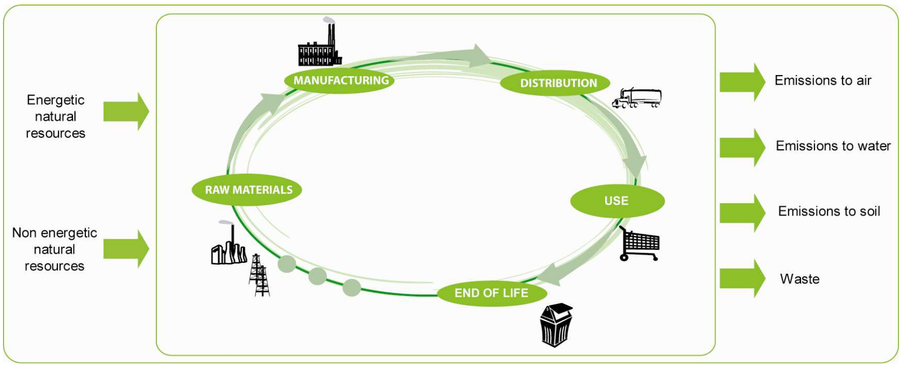
However, the renewable nature and advantages of bioproducts in terms of reduced greenhouse gas emissions require firmly established proof, whence the growing need to be able to carry out robust and uniform studies of this type of product. Life Cycle Assessments (LCAs) have proved to be one of the most appropriate tools to apprehend these impacts. The following section supplies a brief description of the general principles underlying these approaches.

1.3. Life Cycle Assessment (LCA)

1.3.1 General principles

Life Cycle Assessment (LCA), which emerged in the 1960s, makes it possible to quantify the impact of a given "product" (good, service or process) from the extraction of the raw materials of which it is composed through to its disposal via its distribution and use (the so-called **"cradle to grave"** analysis). Flows of input and output materials and energies at each stage of the life cycle are listed, and an exhaustive assessment of the consumption of energy and natural resources as well as of emissions into the environment (air, water and soil) is carried out. These assessments of input and output flows are called Life Cycle Inventories (LCIs).

Figure 1 – The Principle of Life Cycle Assessment



This consumption and emission data is processed to assess the potential impacts on the environment of the product under consideration: greenhouse effect, atmospheric acidification, exhaustion of natural resources, water eutrophication, and so on. Life Cycle Assessment is therefore a multi-criteria method:

1.3.1.1 Standardisation

The principles of LCA are defined in international norms in the ISO 14040 series. The ISO 14040 standard describes the essential characteristics of an LCA and best practices for conducting this type of study (methodological framework, requirement of transparency, applicable provisions for communication to third parties, etc.).

The three other standards refer more particularly to the four major stages of life cycle assessment:

- **Definition of the purpose and scope of the study: ISO 14041**

These two stages, which precede performance of an LCA, are indispensable in that they make it possible to identify the perimeter for data required to quantify environmental impacts.

- **Inventory of resource consumption and emissions: ISO 14041**

This stage consists in collecting the data required to complete the inventory of resource consumption and emissions into the environment.

- **Life cycle impact assessment: ISO 14042**

This standard establishes requirements regarding how the consumption of resources (for instance, 1 tonne of coal) and emissions into water, air and the ground (for instance, the emission of 1 kg of methane or 2 kg of CO_2) are converted into environmental impact indicators (for instance, global warming potential).

- **Life cycle interpretation: ISO 14043**

The ISO 14 043 standard explains how to summarise and comment on life cycle assessment information in order to present recommendations which are consistent with the purposes and scope of the study.

The ISO 14,041 - 14,043 standards have been compiled within the ISO 14 044 standard [ISO 14044].

1.3.1.2 Quantifying environmental impacts

The results of an LCA are presented in terms of potential impact indicators ("greenhouse effect, kg CO_2 equivalent ", "acidification, kg H+ equivalent", etc.) and physical flows ("non-renewable energy, mJ", "non-hazardous waste, kg", etc). The table below presents sample potential impact indicators which are often quantified in an LCA. A detailed description of these indicators (meaning and units) is presented in Appendix I.

Table 1– Example of environmental impacts and impact indicators

Impact	Impact indicator
Resource consumption	
Exhaustion of non-renewable natural resources	Abiotic resource depletion potential
Consumption of non-renewable primary energy	Non-renewable primary energy consumption potential
Water consumption	Water resource depletion potential
Climate change	
Greenhouse effect	Global warming potential
Air pollution	
Air acidification	Acidification potential
Photochemical oxidation	Photochemical ozone creation potential
Exhaustion of the ozone layer	Ozone layer depletion potential
Water pollution	
Eutrophication	Eutrophication potential (nutrification)
Toxic hazards	
For humans	Human toxicity potential
For aquatic ecosystems	Aquatic toxicity potential
For sedimentary ecosystems	Sediment toxicity potential
For terrestrial ecosystems	Terrestrial toxicity potential

These potential impact indicators are calculated on the basis of data from the life cycle inventory (LCI) and characterization models which allow these environmental impact indicators to be assessed on the basis of LCI data. For instance, the appropriate LCI data to calculate the "global warming" impact indicator comprises the atmospheric emissions of greenhouse gases (CO_2, CH_4, N_2O, etc.). In the example quoted above, the LCI provides the greenhouse gas emissions generated by the combustion of 1 litre of fuel (from extraction of crude oil through to combustion, via refining and transport). The characterization model used for the global warming potential impact indicator is generally that of the IPCC[1], which assigns a global warming potential (GWP) calculated in kg CO_2 equivalent.

Note: reference is frequently made to *potential* impact indicators, as opposed to *actual* impacts: This is because characterization models do not allow real impacts to be assessed, since these are dependent on actual local conditions of pollutant emission and dispersal.

1.3.1.3 Required documents and sources of data

The data required for life cycle assessment relates, firstly, to:

- **Activity data:** for instance, the quantity of fuel consumed in an industrial process, or the quantities in which a given molecule is emitted on the site in question. Generally, this data is supplied by the producer. This is called primary data, sometimes known as foreground data.

- **Complete inventories relating to the products consumed by these activities** (which will be referred to more simply here as Life Cycle inventories or LCIs). The example here shows all flows relating to making available the litre of fuel burned during the production being studied. This secondary or "background" data comes from databases such as EcoInvent (a database with European and international coverage), which contain inventories for changes in land use and which are relatively exhaustive in terms of the production of materials, chemicals, energy, agriculture, transport and waste processing. These databases are constantly expanding and cover increasingly complex industrial processes (for instance, electronics).

- **Environmental impact characterization factors,** which make it possible to calculate impact indicators on the basis of LCI data (for instance, by converting various greenhouse gas emissions, such as CO_2 and methane, into a global warming indicator). These are based on a characterization methods such as CML, developed in 1992 at the University of Leiden [CML 1992], for which the related databases are regularly revised, or IMPACT 2002+, or, for toxicity, the USETOX model, developed under the auspices of UNEP-SETAC (a joint programme run by the United Nations Environment Programme and the Society of Environmental Toxicology and Chemistry).

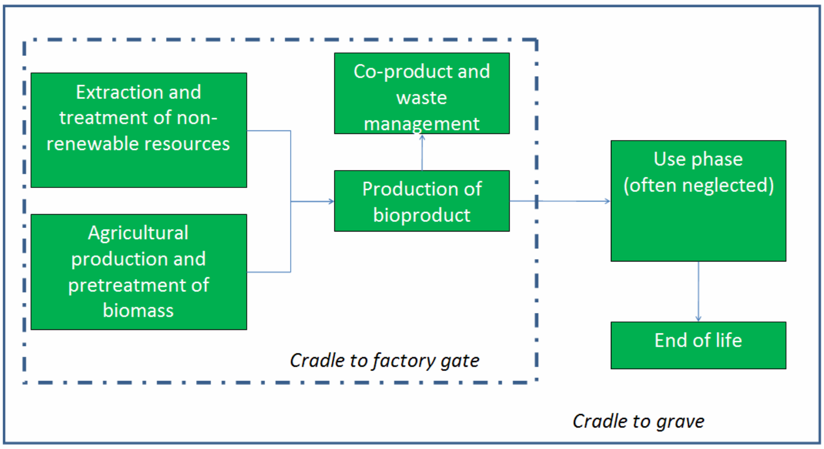
For certain data which is more specific to the study, data collection is generally carried out on a case-by-case basis, with collection from the industrial site, plus bibliographical research and rationed use of previous studies.

1.3.2 Application of LCAs to bioproducts

LCAs are highly relevant and appropriate in terms of the environmental assessment of bioproducts. They make it possible to take into account all the stages relating to the existence of this product (see diagram below) and thereby avoid oversimplified comparisons. Being multi-criteria in nature, they offer a broad picture of the impacts of these products, which is an important aspect in terms of clarifying the possible transfers of pollution between different environmental concerns (for instance, offering reduced CO_2 emissions but increasing eutrophication and water pollution as a result).

[1] Intergovernmental Panel on Climate Change

Figure 2 – Overall view of a bioproduct life cycle



As shown on this diagram, LCAs which relate to bioproducts may be either "*cradle to factory gate*", going no further than the bioproduct's production phase, or "*cradle to grave*", incorporating use and end of life. The usage phase is often disregarded, since it is often deemed to be similar for bioproducts and their fossil equivalents.

At each stage of the procedure, the flows to be measured consist of contributions of energy (electricity, fuel, natural gas, water vapour) and inputs/reagents, for both agricultural and industrial phases. In addition to these flows, which it is relatively easy to quantify, LCAs also have to incorporate emissions of all molecules with a proven impact on the environment (emissions into the air, water or ground), which it is often more difficult to quantify.

The specific nature of bioproducts means that the performance of LCAs for such products requires special care to be taken with respect to a number of points which are of prime methodological importance:

- Since the purpose is often the comparison of bioproduct assessments (often with fossil alternatives), the establishment of coherent parameters and functional units is necessary.
- The manufacture of bioproducts is often accompanied by the production of various types of co-product (corn gluten feed, wheat residue, lignocellulosic residue, etc.): this makes it vital to deal with allocations consistently.
- In the case of products derived from agricultural land, the issue of modelling this complex agricultural stage (emissions of nitrous oxide (N2O), a powerful greenhouse gas given off notably by soil bacteria, the degree of nitrate and plant protection products, etc.) is crucial. This means using the most recent and complete models available.
- Taking into account any changes in land use is another issue which must not be neglected when LCAs of this type are performed.
- Taking into account the wide variety of reactions during processing of biomass in the industrial phase (which uses innovative procedures for which little coverage exists in the literature), involves having access to all the cycle inventories for input and output products during this manufacture.

In short, performing LCAs for these products calls for these questions to be studied in greater depth in order to be able to supply a methodological framework which is uniform for all stakeholders wishing to address these issues.

1.4. DEFINITION OF THE SCOPE OF THE STUDY

1.4.1 PRODUCTS STUDIED

The scope of the study extends to all non-energy and non-food products derived from plant matter. This covers two major categories of product:

- Finished products: products which are regularly used by consumers (e.g.: biolubricants, bioplastics, etc.).
- Chemical intermediaries: platform molecules designed for the chemical processing and formulation industries.

Pursuant to the definition of bioproducts, it has been decided that products derived from traditional uses of timber (construction materials, paper, etc.) shall not form part of this study. More generally, it has been decided not to include construction materials within the field of bioproducts studied here since they require highly specific approaches and relate to highly specific contexts and industries.

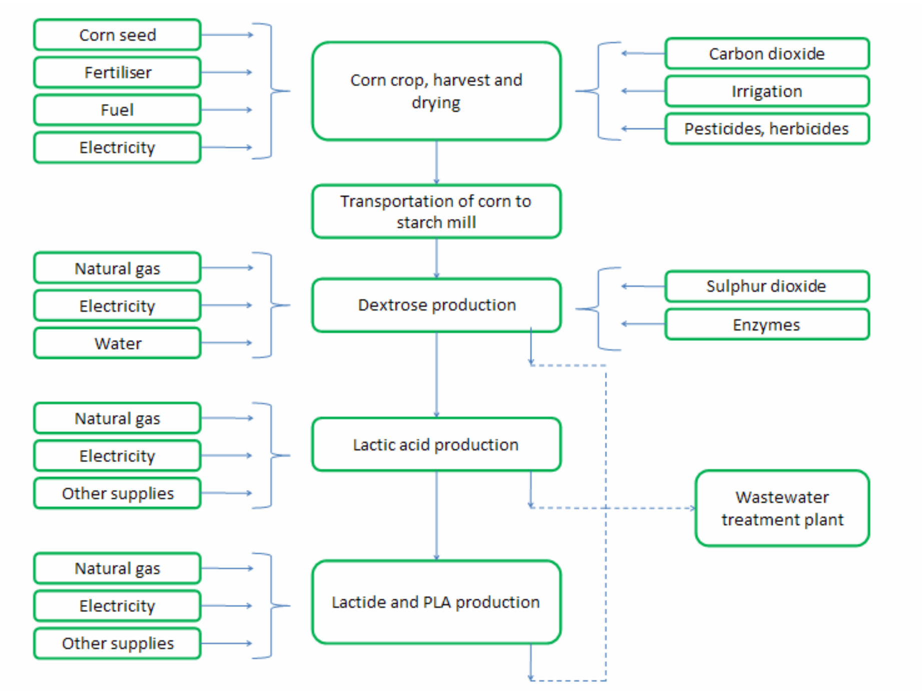
It should also be noted that enzymes and other products derived from "white biotechnology" should not be seen as falling within the scope of products under study, but may constitute a criterion to be taken into consideration as regards production procedures which may be used by bioproduct industries.

Despite this relatively restricted field of analysis, the range of products studied is highly diverse. However, a number of general principles may be applied to bioproducts:

- They derive, at least in part, from renewable resources;
- Their production process includes both agricultural production and industrial transformation stages, which require contributions of inputs and energy;
- They generate waste, which implies an end of life, and sometimes specific processing.

The box below provides an example showing the various stages of production for PLA (Polylactic acid).

Figure 3 – Example of a bioproduct production process: PLA (PolyLactic Acid)



This process can be divided into the upstream phase of agricultural production of corn and the downstream industrial phase, in which sugars are transformed into polylactic acid (PLA).

1.5. LCAs IN TERMS OF THEIR PURPOSE

With regard to the drafting of a simplified methodology for bioproduct LCAs, options and scenarios are directly related to the purposes of the LCA.

Three broad objectives may be identified:

- eco-design of a product,
- environmental labelling/display,
- comparison with fossil-based products.

Depending on the key issues, the specific purposes of the LCA and the consequences in terms of methodology will be different. Summary tables presenting these differences are shown below.

1.5.1 ECO-DESIGN

Purpose

Supplying orders of magnitude for the stages and items in terms of impact Forming a basis for a broad-based investigation of environmental integration
Methodological
The predominant role of the user. The desired level of detail will depend on their needs. People who are new to LCAs may be involved

1.5.2 ENVIRONMENTAL LABELLING/DISPLAY

Purpose
Having "building blocks" to establish labelling Positioning products with respect to others in terms of their environmental balance
Methodological
Attempt to provide overall consistency The need to have values in usable units Various levels of detail may be envisaged
At the current stage of development
Seeking results for a typical business Seeking robust, mean values

1.5.3 COMPARATIVE LCAS (COMPARISON WITH FOSSIL-BASED PRODUCTS)

Purpose
Positioning bioproducts in comparison with existing fossil equivalents
Methodological
Seeking consistency and uniformity between the areas being compared Issue of the key functional unit

Having a sufficiently sophisticated level of modelling

Simplification and approximation possible for identical stages

In the rest of this report, recommendations relating to simplified methodology will be detailed in terms of the three objectives set out above, in order to ensure that the potentially specific needs of these three types of LCA are properly taken into account. The principal objective remains that of determining **general recommendations** which enable all three possible issues to be addressed.

1.6. THE PRODUCT ASSESSMENT ("BILAN PRODUIT") WORKTOOL

The Product Assessment ("Bilan Produit") worktool was set up a number of years ago by ADEME in order to simplify the use of the LCA-type approach. It provides a framework which facilitates the performance of an assessment and makes life cycle inventories from major databases (principally ECOINVENT) available to users.

Designed to offer industrial stakeholders and researchers an **eco-design software utility**, ADEME is considering extending the software's features to include preparations for environmental certification and labelling. **Support for comparison between plant-based and mineral-based processes,** while not a priority, has not been ruled out.

It should also be noted that this study deals only with the **expression of proposals** for proper integration of methodological recommendations in this worktool. The scope of these proposals is open, given that the Product Assessment is liable to be upgraded.

1.1. CONDUCT OF THE STUDY

This study has been conducted in coordination with ADEME (the French Environment and Energy Management Agency), with the assistance of a steering committee (representing ADEME and the other public agencies involved in this project) and a technical committee made up of industrial stakeholders and representatives of non-profit organisations[2].

[2] ACDV (Plant Chemical Association) AFT Plasturgie, ARD, Arvalis -- Institut du Végétal, BASF France SAS, CCFD Terre Solidaire, CLCV, FCD, Fibres Recherche Développement, groupe TEREOS, IFP, Novamont, PROLEA-SOFIPROTEOL, RHODIA, ROQUETTE Frères, USIPA

2. UPDATING LCA KNOWLEDGE REGARDING BIOPRODUCTS

2.1. PRESENTATION OF RELEVANT STUDIES

The bibliographical research stage has made it possible to identify many publications relating to the environmental impacts of bioproducts. However, these publications differ widely in terms of transparency, levels of clarity and the hypotheses adopted. Few products have been studied by more than one team.

The list of relevant studies with respect to this project is presented below. This is not an exhaustive list of all studies examined, but a selection of the studies which have contributed to the work on developing a methodology.

Table 2- LCA studies with relevance for bioproducts

Etude	Auteur	Date	Bioproduit
Life Cycle Assessment (LCA) of biopolymers for single-use Carrier bags	Murphy, Davis, Payne	2008	sacs en biopolymeres à base d'amidon Mater-Bi
			sacs Octopus en mix de PLA (Cargill Dow et Basf)
Producing bio based bulk chemicals using industrial biotechnology saves energy and combats climate change	Hermann et Patel	2007	15 molécules chimiques plateformes
Applying distance-to-target weighing methodology to evaluate the environmental performance of bio-based energy, fuels, and materials	Weiss & Patel	2007	divers produits (films plastiques, biohuiles, assiettes en plastique…)
Life cycle assessment of wood-fibre-reinforced polypropylene composites	Xu and Jayaraman	2007	biopolymères
Synthèse d'études ACV sur les plastiques de différentes origines	BIO Intelligence Service	2007	bioplastiques
Evaluation des besoins en labellisation et étiquetage de produits incorporant des matières d'origine renouvelable et comparaison des méthodes existantes. Promotion des bioproduits et biomatériaux	BIO Intelligence Service	2007	bioproduits
Medium and Long term opportunities and risks of the bio-technological production of bulk chemicals from renewable resources	BREW project	2006	différentes molécules chimiques plateformes
Cradle to gate Environmental assessment of enzyme products produced industrially in Denmark by Novozymes A/S	Nielsen	2006	5 enzymes

Table 3 – LCA studies with relevance for bioproducts (cont'd)

Etude	Auteur	Date	Bioproduit
Applying distance to target weighing methodology to evaluate the environmental performance of bio-based energy, fuels, and materials	Weiss & Patel	2006	divers bioproduits
Life cycle assessment study of biopolymers (Polyhydroxyalkanoates) derived from no-tilled corn	Kim and Dale	2005	PHA à partir de maïs
Comparing the Land requirements, Energy savings and Greenhouse gases emissions reductions of biobased polymers and Bioenergy	Dornburg	2004	biopolymères
Cumulative Energy and Global Warming Impact from the production of biomass for bio based products	Kim and Dale	2004	biomasse
Environmental assessment of bio-based polymers and natural fibres	Patel	2003	divers biopolymères et bioproduits, à partir de 11 autres études
Applications of life cycle assessment to NatureWorksTM polylactide (PLA) production	Vink	2002	PLA
Life cycle assessment of biofibres replacing glass fibres as reinforcement in plastics	Corbières	2001	palettes en polypropylène renforcé par des fibres de miscanthus (China reed)
Life-Cycle Assessment of Mineral and Rapeseed Oil in Mobile Hydraulic Systems	McMannus	2001	huile hydraulique
Lupranol Balance - Ecoefficiency analysis	Muller (BASF)	2001	lupranol (un polyol) à partir d'huile de ricin
Resource flow and product chain analysis as practical tools to promote cleaner production initiatives	Narayanaswamy	2000	amidon de blé

2.2. CONCLUSIONS OF THE BIBLIOGRAPHICAL SUMMARY

The summary of this bibliographical phase has given rise to the following observations:

- Studies relating to bioproducts deal with a broad range of products, which reflects the broad diversity of businesses concerned

- The level of detail supplied by these publications is extremely varied, and generally, relatively poor: only one study presents a detailed report running to over 200 pages, offering sufficient elements to enable the methodology and calculations to be properly apprehended. Most of the LCAs examined consist of summary reports running to 5-10 pages, which are of relatively little use in terms of determining their exact choices and calculations.

- Many different options have been adopted in terms of functional units, impact indicators and the scope of study, with no consistent pattern.

- Where studied, product end-of-life scenarios vary widely: incineration, landfill, composting and recycling. These choices may entail significant differences in the final results.

- Comparisons between bioproducts and fossil-based products make use of diverse fossil references, with no uniformity across the studies. Most of the time, very little detail regarding the chosen fossil-based products is supplied.

3. DEVELOPMENT OF A SIMPLIFIED METHODOLOGY FOR BIOPRODUCT LCAS

3.1. IDENTIFIED KEY METHODOLOGICAL POINTS

Performing LCAs for bioproducts raises a number of methodological questions which are crucial for the results of the assessments. Different options are adopted by different studies, which can make comparison between the studies difficult.

This chapter, which is at the heart of the study, analyses the principal methodological questions with respect to the performance of LCAs for bioproducts. The analysis takes the form of a summary sheet for each key issue. These sheets are broken down into the observations derived from bibliographical research, issues which are specific to the question of methodology, the results obtained in the test phase and recommendations following these tests and the investigative phase. The sheets supply details of the methodological recommendations based on the specific characteristics of bioproducts.

The various analyses incorporate tests performed by BIO on the basis of LCAs carried out for three products:

- A gateway molecule: Roquette's isosorbide
- a bioplastic: Materbi by Novamont
- A biolubricant from Novance

The ensuing methodological recommendations also make use of work done by other working groups on the issue of assessment and environmental display: the ADEME-AFNOR platform and PAS 2050.

Recommendations are also related to the planned establishment of an LCI database by ADEME by 2011. This database, of which the structure and development plan are currently being examined, will offer LCIs per kilogram of product, particularly for farming industries. An agribusiness database is also to be established within the next three years (on the basis of cooperation between the French Agricultural Research Institute INRA and other partners).

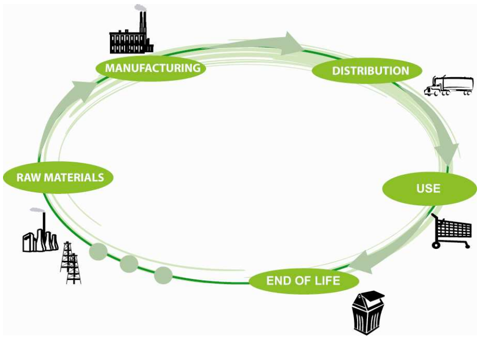
Lastly, wherever potential simplifications have been identified and acknowledged as being appropriate, they are presented with the general methodological recommendations in the form of a box at the end of these recommendations. All these simplifications are then tested in order to check their total impact on the product life cycle.

3.2. THE SCOPE OF THE STUDY

Life cycle assessment may be performed from "*cradle to grave*" or from "*cradle to factory gate*".

In the second instance, the product end of life stage is not measured (nor is distribution and use), which may affect product performance, depending on the possibilities of energy recovery (incineration), recycling, composting or landfill.

Figure 4 – The principle of life cycle assessment



3.2.1 IN THE BIBLIOGRAPHY

In most of the studies, the field of study is restricted to "*cradle to gate*". Only the phases of agricultural production and conversion into a bioproduct are considered. This methodological option can be justified as follows:

- There are many unknown factors regarding product end of life, as well as regarding discrepancies between potential end of life and those which actually occur.
- Bioproducts may be platform molecules which are subsequently transformed into a very wide variety of derivative products.
- Several databases relating to product production phases exist, making it possible to envisage comparisons between these phases.
- A few studies consider the entire lifecycle of products, but adopt highly disparate methodological options subsequently.

3.2.2 KEY ISSUES

End of life

The "cradle to gate" approach disregards the positive and negative impacts arising from different end-of-life scenarios:

Landfill disposal of products rich in organic carbon (as is potentially the case for bioproducts) generates methane emissions due to aerobic digestion of the molecules.

Incineration of waste may be associated with energy recovery for the generation of heat and/or electricity (cogeneration); any such generation then represents an impact credit with respect to generation of an equivalent amount of energy by another process. What is more, incineration may be a non-negligible source of emissions (CO_2, NOx, VOCs or HCl) in competing processes and in the case of some polymers.

Recycling bioproducts, particularly biopolymers, can be envisaged, although the quality of the product decreases through recycling.

Composting, **which is possible for bioproducts,** creates resources (which can be used as organic fertilisers); these can replace synthetic and mineral fertilisers. In this case, an impact credit is allocated to the composted bioproduct. This end of life is not yet properly applied, but it is likely to be developed in the future and should already be anticipated.

Biogas production is another avenue which can be envisaged for end of life for packaging and other products containing biodegradable materials, combined with other types of fermentable waste.

Above all, bioproducts contain **biogenic carbon**; carbon of renewable origin which is fixed during plant growth. Unlike fossil carbon emitted during combustion of a fossil equivalent, it is not counted at the end-of-life phase. This is often an element which differentiates between renewable and fossil processes and consequently it cannot be disregarded.

Taking into account biogenic CO_2.

Biogenic CO_2 is CO_2 sequestered by biomass or emitted during the natural decomposition or combustion of this biomass.

CO_2 has the same effect on our climate irrespective of whether it is biogenic or fossil in origin. However, carbon from biomass comes from carbon sequestered by the plant during growth, over a much shorter timescale than through the formation of coal or oil. Three approaches are used in the literature to take biogenic CO_2 into account specifically:

- Biogenic CO_2 is not taken into account in the greenhouse gas assessment. The assumption is made that biomass is constant over time and that all gas sequestered will be emitted. On this basis, the flows cancel each other out.

- Measurement: As for other flows, all the elementary flows of biogenic carbon are counted. In principle, this provides data about the CO_2 sequestered by the plant during growth and the quantity contained in the part which is used; in other words, about what happens to this carbon throughout the plant's life cycle.

- Sequestration: Rather than measuring the flow, the difference between sequestration and emission is measured by measuring the amount of biogenic carbon sequestered long-term in products and the carbon which is sequestered in biomass. The result obtained is the same as that using the previous method; only the values for each stage change.

3.2.3 Test results

The purpose of this test is to illustrate the impact of taking into account end of life on the overall product assessment.

Two end-of-life tests were performed on these three products:

- a comparison of results with and without end of life, in order to identify the end-of-life contribution to the overall result;
- a comparison of assessments which did and did not take into account the biogenic carbon content of products in calculation of their end-of-life impacts.

Test 1 – The table below shows the relative share of the end-of-life stage in the life cycle of each of the products.

Table 4 – Relative share of end of life in the global cycle of the 3 bioproducts tested

Impact indicators	Non renewable primary energy (MJ/kg)	Exhaustion of natural resources (kg Sb eq/kg)	Greenhouse gas emissions (kg CO2 eq/kg)	Human toxicity (kg 1,4-DB eq/kg)	Eutrophication (kg PO4- eq/kg)
Isosorbide					
Relative share of end of life	0,4%	0,5%	5,2%	13,8%	14,7%
Materbi					
Relative share of end of life	-9,8%	-9,0%	15,5%	0,8%	8,2%
Biolubricant					
Relative share of end of life	3,2%	3,3%	3,7%	27,6%	7,5%

This table shows that for the "Primary Energy", "Exhaustion of Natural Resources" and "Greenhouse Gas Emissions" indicators, this stage makes up a limited but non-negligible share of the total assessment.

The toxicity indicators (human toxicity and eutrophication) are particularly affected, due to emissions arising from combustion of the materials.

Test 2 – The second test relates to the effect of taking into account the product's biogenic carbon content at product end of life. Content in terms of carbon with a renewable origin represents an advantage for bioproducts. When the end of these products' life is incineration, only the proportion of fossil carbon contained in the product is counted, where this exists.

End-of-life calculations have been performed in two ways:

- counting only fossil-origin CO_2 emissions, and not counting biogenic-origin CO_2 emissions, since these are offset by the absorption of the same quantity of CO_2 by plants;
- counting all CO_2 emissions, i.e. considering the end of life of an equivalent fossil-origin product.

Table 5 – The effects of taking into account biogenic carbon in end of life

Greenhouse gas emissions for 1 kg of bioproduct	End of life	Whole life cycle
Isosorbide		
reference value	100%	100%
balance, considering the end of life of an equivalent fossil-origin product	450,3%	117,3%
Materbi		
reference value	100%	100%
balance, considering the end of life of an equivalent fossil-origin product	215,3%	115,5%
Biolubrifiant		
reference value	100%	100%
balance, considering the end of life of an equivalent fossil-origin product	3995,2%	239,1%

As the above table shows, taking into account biogenic carbon is a non-negligible factor for bioproducts.

There is an even greater impact on biolubricant life cycles:

- this oil is rich in carbon,
- the overall biolubricant balance is lower than for other products, so the relative effect is greater.

There is less of an effect on the Materbi balance, which is consistent with the mixed nature of this product, composed of raw materials of both fossil and renewable origins.

Isosorbide is also less affected.

This test indicates that if analysis does not include end of life, it is difficult to identify certain specific properties of bioproducts, particularly products' biogenic carbon content: this is only apparent if the biogenic share of end-of-life emissions is not counted. Consequently, products' biogenic carbon content must be identified in other ways: for instance, for the purposes of establishing building blocks with a view to environmental display, by specifying this biogenic carbon content to users of the product (as for gateway molecules such as isosorbide).

3.2.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

ADEME-AFNOR: Display of life-cycle impacts "from cradle to grave", including the usage phase.

PAS 2050: Incorporation of usage and end-of-life phases wherever possible.

3.2.5 RECOMMENDATIONS

The test results and particularities of bioproducts discussed in the paragraph dealing with the key issues have led us to make the following recommendations:

When impact indicators based on airborne or waterborne pollutant emissions are calculated, such as eutrophication, air acidification and human toxicity, it is vital for the end-of-life stage to be taken into account. For the purposes of simplification, mean values for the various possible ends of life may be suggested and used during studies.

If only energy consumption and greenhouse gas emission indicators are taken into account, the end-of-life impact is much less significant. This is because CO_2 emissions during end-of-life combustion are not taken into account (or barely so) because they are of renewable origin (or partially so).

If these recommendations are applied to questions of environmental labelling and eco-design, the following conclusions may be drawn:

If the purpose relates to **eco-design**, **total life cycle assessment** should be performed wherever possible, even if the incorporation of the end of life requires the use of mean values.

If the purpose relates to **labelling**, as required, the LCA may end at the **factory gate** (establishing the building blocks to carry out complete LCAs by the downstream producer) or **at end of life**, depending on the nature and use of the product. For instance, for gateway molecules, displays should halt at the factory gate, in order for downstream users to incorporate these results into their own assessments. In this case, **the product's biogenic carbon content should be specified**, in order to enable proper end-of-life modelling subsequently. Alternative solutions to identify the advantage of bioproducts for LCAs halting at the factory gate have not been considered. The biogenic carbon content could perhaps be expressed as an absolute value and as a percentage of the product's total mass.

Recommendation for simplified methodology:

Where there is no specific data for the end of life of the product, use may be made of mean end-of-life data.

3.2.6 RESPONSES AND DISCUSSION

During meetings of the technical committee, it was specified that taking into account end of life for bioproducts remained a delicate notion. Indeed, the end-of-life possibilities which give advantages to bioproducts (notably composting) are not yet applied in reality. Consequently, the recommendation to incorporate end of life should include different end-of-life possibilities for bioproducts as potential options.

Furthermore, some products within the field of bioproducts are intermediaries which may have a wide number of applications (e.g. PDO or 1.3-propanediol). The environmental assessment should therefore be performed as far as the factory gate; a comparison with the same fossil-derived molecule is possible.

Particular care should be taken with future developments relating to the quantification of products' biogenic carbon content.

Update regarding bioproduct end of life

An agreement concerning biodegradable dustbin bags was signed on November 19, 2009 by the French Ministry for Ecology, Energy, Sustainable Development and the Sea, the French Mayors' Association, the French Retailers' Federation and representatives of the plastics industry. Its principal aim is to "develop the recovery of organic waste through composting and biogas production".

3.3. FUNCTIONAL UNITS

The functional unit is a common unit which serves as a reference to express a product's environmental assessment. It makes it possible to quantify the results of an LCA study with respect to the service provided. In order to compare bioproducts to their fossil-based equivalents, it is necessary to take the basis of an equivalent service provided, taking into account any differences in properties[3].

3.3.1 IN THE BIBLIOGRAPHY

For comparison between bioproducts, the functional unit adopted may be based on the raw material produced or on the service provided. These selected functional units vary widely between studies, as the table of examples below shows.

Figure 5 – Non-exhaustive list of functional units encountered during the bibliographical study

'Raw material' functional unit	'Service provided' functional unit	Other
"1 kg of PLA pellets", "1 kg of plastic film", "1 kg of fibre"	"1 kg of filler product", "1 kg of car parts", "1 kg of transport pallet", etc	"1 hectare of crops"

Recommending a single functional unit for the performance of bioproduct LCAs therefore appears to be impossible. Indeed, the services performed are highly varied depending on the products and their uses.

The bibliographical summary reveals a distinct preference for simple functional units of the type "1 kg of material".

3.3.2 KEY ISSUES

Environmental impacts relating to bioproduct life cycles may be calculated on the basis of many units, from the simplest (kilogram of bioplastic pellets) to the most complex (carrying XX litres of shopping from a supermarket to the user's home in biopolymer bags). However, choosing an appropriate functional unit is a vital condition in terms of enabling robust comparisons with fossil-origin equivalents.

This is because two equivalent products (a bioproduct and a fossil-origin product) may sometimes not provide the same service for an equivalent amount of mass. It is therefore crucial to determine **what function the product performs** and what **intrinsic characteristics** this relies on **upstream**

[3] For instance, composites made of natural fibres are generally lighter than their fibreglass equivalents. For the performance of an equivalent service, the quantities of the products in question will therefore be different.

from the study. For instance, for a bio-oil, depending on the final use, characteristics of viscosity and siccative power[4] or degree of purity would be priority considerations in defining the functional unit.

One of the issues which are specific to some bioproducts (notably chemical intermediaries) is the wide variety of uses for a single product once it leaves the factory. In such instances, the potential difference in services provided will emerge only when this intermediary is used. If the LCA stops at the intermediary's factory gate, it needs to do no more than study the product using a simple, clear unit. For this type of LCA, a functional unit such as "supplying 1 kg of product at the factory gate" appears to be the most appropriate.

3.3.3 TEST RESULTS

No tests were performed with regard to this parameter.

3.3.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

ADEME-AFNOR and **PAS 2050** make no particular recommendations with respect to the choice of functional unit.

3.3.5 RECOMMENDATIONS

Generally speaking, the choice of functional unit should relate to the service provided by the product. Generally, traditional units of weight and volume provide adequate descriptions of the product, but not always. It is therefore appropriate to start by examining the issue of the service. What is more, units of weight or volume make it possible to take into account the fact that many bioproducts are chemical intermediaries, which do not provide a single, unique service.

The need to consider this question is all the greater if the LCA is designed to provide a comparison with another equivalent product. It is in such circumstances that the need for a fair comparison of the service provided becomes acute.

In most cases, it would appear that an **LCA performed for 1 kg of product** can be envisaged. In particular, this unit may be appropriate for LCAs intended for display or eco-design. For comparative LCAs, establishing more sophisticated functional units appears to be called for if the differences in the service rendered by the two products being compared are both measurable and different by more than a few percent. However, this precaution assumes that standardised methods exist in order to enable robust testing of the service performed to be carried out.

Whichever functional unit is chosen, it is crucial to **specify whether it refers to dry matter weight, gross weight,** etc.

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[4] The siccative power of an oil refers to its capacity to dry when exposed to air and is determined by its iodine content.

3.3.6 RESPONSES AND DISCUSSION

The issue of **choosing a functional unit** does not appear to be problematic. Indeed, this unit must be simple, and the issue of whether it enables genuine comparison with equivalent products of conventional origin to be made must have been verified beforehand.

However, the selected unit must be explicit as to the product's characteristics. For instance, in the case of a kilogram of product, it must be clearly specified whether this is dry matter weight or gross weight.

Lastly, for **products based on plant fibre**, the product's advantages in terms of volume mass will not be reflected in the assessment if the functional unit chosen is "1 kg of product" or similar. For instance, transport of fibre-based products will have less of an impact than that of a heavier but otherwise equivalent product. However, in this instance **raw material life cycle analysis** is being considered (fibre-based bioproducts) and not finished product LCAs (for instance, for a vehicle component). Consequently, the advantages of fibres compared to fossil equivalents emerge much more clearly during the usage phase of the finished product (in this example, during the vehicle life cycle).

3.4. IMPACT INDICATORS – THE CASE OF TOXICITY

Human activity creates various types of disturbance to the environment. This is generally the case for all types of production. To apprehend this type of issue, LCAs take a multi-criteria approach to a broad range of **impact categories** (i.e. specific environmental problems such as climate change, resource depletion, toxicity, etc). They provide a measure of the impact of the product under study with regard to these various issues. These environmental issues are summarised by means of one or more indicators known as *impact indicators*. These are based on models representing the problem under consideration in order to provide a simplified unit showing all the various flows emitted which have an effect on each issue.

For instance, the following impact categories are generally relevant as regards bioproducts:

- Consumption of natural resources and consumption of non-renewable energy
- Greenhouse Gas Emissions
- Human toxicity potential
- Photochemical oxidation potential (also known as "ozone precursors")
- Eutrophication Potential
- Potable water consumption

A more detailed description of these impact categories, related models and examples of values are to be found in an appendix to this report.

3.4.1 IN THE BIBLIOGRAPHY

The two indicators which have been the subject of most study in relation to bioproduct LCAs are **non-renewable energy consumption and greenhouse gas emissions.** This observation applies to all LCAs, not just to bioproducts.

Some studies also consider other indicators (eutrophication, acidification, etc), which rely on a fairly limited number of impact assessment methods (generally, CML).

Change in land use has as yet been rarely considered, although it is a non-negligible issue in the event of a decrease in farmland.

3.4.2 KEY ISSUES

Impact indicators are not or equal in terms of the reliability of the measurement used or in terms of the frequency with which they are used in studies. These differences are summarised in the table below.

Figure 6 – Reliability and frequency of use of various indicators for LCAs concerning

bioproducts

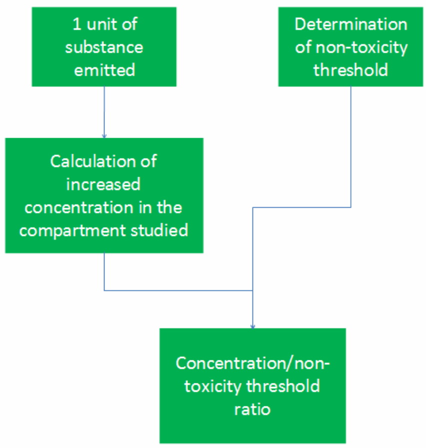
Impact indicator	Geographical scale	Reliability	Frequency in LCAs
Non-renewable energy consumption	Global/regional	++++	High
Climate change	Global	+++	High
Decrease in stratospheric ozone	Global	++	Medium
Eco-toxicity	Regional/local	+	Low
Photo-oxidant formation	Regional/local	++	Low
Air acidification	Regional/local	++	Medium
Eutrophication	Regional/local	++	Medium
Human toxicity	Global/regional/local	+	Low
Land use	Regional/local	++	Medium

Human toxicity is one of the most difficult indicators to model.

Assessment methodologies for human toxicity and eco-toxicity are still in the development phase. One of the first methods used to assess impacts on human toxicity was that of **critical volumes**. This consists in calculating the volume of air or water required to dilute the calculated emitted quantity of a polluting substance for it to fall beneath the thresholds specified in legislation in force. All the partial critical volumes (for a single emission) are then added together in order to obtain the total critical volume for a given product. This makes it possible to compare total air and water pollution for different emissions in different products. This method is still in use via standard NFP 01.

Other methods have been developed (CML, USEtox, EcoIndicateur 99, ReCiPe, IMPACT 2002+) in order to model what happens to substances and their impact in terms of human toxicity and eco-toxicity. They are based on the same principle, described by the European Commission and represented in the following diagram.

Figure 7 – Outline diagram of the principle for calculating a toxicity indicator



A number of different calculation methods have emerged on the basis of this outline. Three examples are presented below.

Figure 8 – Summary of the strengths and weaknesses of three methods of assessing toxicity

Method	Strengths	Weaknesses
CML	Approved model, updated, frequently used	Requires improvements regarding pesticides and heavy metals
Impact2002+	Improved model, updated and used	Requires improvements for metals and trace elements
USEtox	Based on a model developed by the UNEP and SETAC (Society of Environmental Toxicology and Chemistry) Best method of calculation for TD50[5] and non-carcinogenic pollutants. Method which incorporates the most molecules (> 1250).	Under development: presents a number of factors for approximately 1000 molecules. Gives factors for toxicity only (eco-toxicity and human toxicity)

While these models concentrate a remarkable degree of information regarding toxicity and the modelling of what happens to molecules, they are nonetheless fragile due to the complexity of the subject and the modelling options adopted. Comparative studies on their use have demonstrated that the estimated level of impact, and the respective share of the different toxin families in the result, may change significantly depending on the model used, rendering the use of these results highly delicate.

[5] TD 50 (Toxic Dose 50): represents the dose or concentration of toxic substance which provokes the harmful effect being studied in 50% of the subjects.

These, then, are methods under construction, which should be used with caution and in full awareness of their limits (particularly as regards trace elements and pesticides). The USEtox method, as yet not very widely circulated, appears to be the most complete.

In the light of these limits as to the reliability of results, significant discrepancies (of the order of a factor of 100) should be obtained before considering that a global effect has been observed during the course of comparative LCAs.

3.4.3 TEST RESULTS

Test 1 – An initial test was performed to illustrate the importance of the characterization method in the results for various indicators.

Indicators for greenhouse gas emissions, human toxicity and ozone layer depletion were calculated using the following:

- The CML method, used throughout the study
- The more recent ReCiPe method, which incorporates CML data alongside other approaches.
- The results of the test are shown below for each of the products.

Figure 9 – Test result for isosorbide

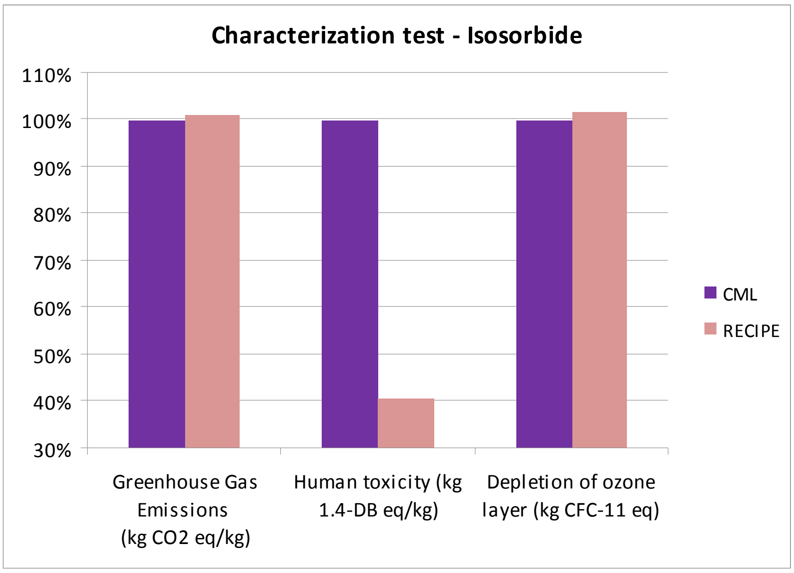


Figure 10 – Test result for Materbi

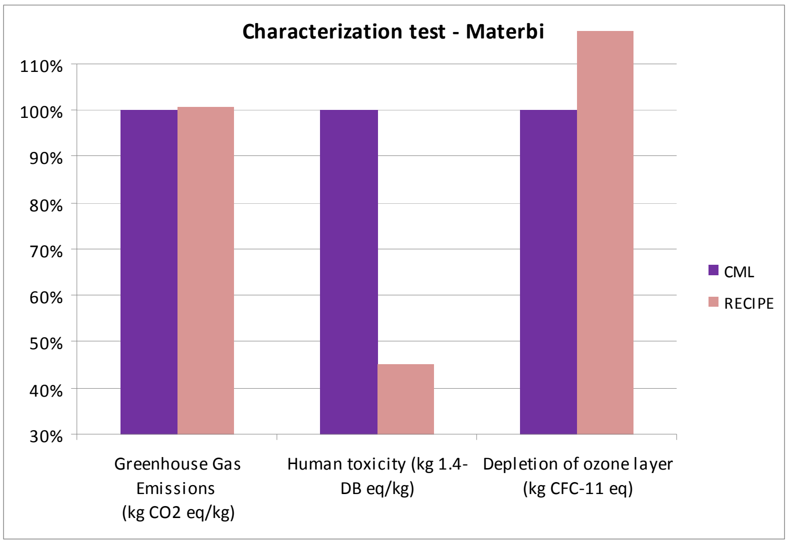
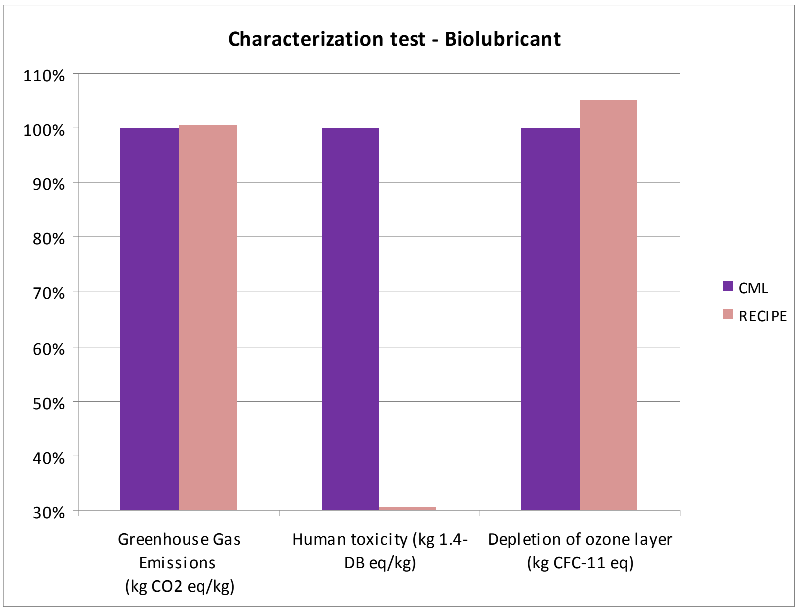


Figure 11 – Test result for the bio-lubricant



The charts above indicate the following:

- the toxicity indicator is highly sensitive to the method being used. Indeed, depending on the approach, the molecules counted and the related emissions factors differ extremely significantly (by factors of between 1 to 100 in some cases).

- the results for greenhouse gas emissions are less method-dependent, with international standards which are already used framing the calculations (IPCC).

Test 2 – At the request of the technical committee, a **second test** was performed **to determine the relevance of the "Exhaustion of Non-renewable Resources" indicator**. This indicator evaluates the quantity of non-renewable resources which are extracted and used during the product life cycle. During calculations, it became apparent that this indicator progressed exactly in line with the "non-renewable energy consumption" indicator because of the share of fossil resource consumption in resource consumption as a whole. In the light of its greater degree of complexity in terms of construction and apprehension with regard to non-renewable energy consumption, suggesting it as part of a simplified working methodology has not been deemed a priority. However, authors of LCAs may of course choose to integrate this indicator within their study.

3.4.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

The **ADEME-AFNOR** and **PAS 2050** are to propose indicators grouped by product category. However, since the working party dedicated to these products has not yet been convened, no recommendation as to the relevant impact indicators for the environmental assessment of bioproducts exists as yet.

As to toxicity for ecosystems, existing working parties have discussed USETox and VCDTox. During the "Methodology" working party meeting on December 11, 2009, a number of methods were presented:

- classification and labelling of substances regulated by REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and GHS (Global Harmonized System).
- EC Directive 91/414/EEC dated July 15, 1991 concerning the marketing of phytopharmaceutical products (EU directive)
- The VCDTOX method ('Volume Critique de Dilution Toxicité', Critical Dilution Volume toxicity) used to assess eco-labelled products
- the USEtox method, developed by UNEP (United Nations Environment Programme) and SETAC (Society of Environmental Toxicology and Chemistry).

As yet, there is no consensus as to the best methodology to be envisaged for the purposes of environmental display. The choice should be one of the methodologies listed above, selected here for their robustness and their recognition by institutions at the national or international level. The choice should be based on the availability of data in the short to medium term, the simplicity of application and the purposes of the display.

3.4.5 RECOMMENDATIONS

The various indicators do not all suggest the same impacts on the environment for a given product, depending on the compartments and ecosystems under consideration. Performing an environmental assessment with the aid of more than one indicator is therefore appropriate.

While greenhouse gas emissions and non-renewable energy consumption are the most frequently used indicators for Life Cycle Assessments, it may be necessary to add toxicity indicators, such as eutrophication or human toxicity, whilst bearing in mind that these indicators are less reliable.

In order to overcome the uncertainty relating to toxicity measurement methods, it is suggested that LCA reports should include **the list of the flows monitored and the quantity of emissions**. These flows enable comparison of one product to another, with no intermediate stages of aggregation or conversion into a single unit, (these often differ depending on the method used). What is more, this approach eliminates the bias introduced by certain toxicity calculation methods, which may favour either fossil-origin products or renewable-origin products depending on the model. However, it provides a plethora of information which does not communicate much to the general public (with one type of product being responsible for twice as many VOCs as another, etc.).

In order to determine which molecules should be monitored (in the light of the huge number of molecules studied), the common database of toxic substances used for ICPE (Installation Classified for the Protection of the Environment, French classification) regulations may be used. Industrial sites already have emissions values as part of this, or data from impact studies performed before the installation existed. In addition, a factor of 100 has been validated by the technical committee as being the minimum value for genuine differences of impact in terms of toxicity to be established.

Recommendation for simplified methodology:

Airborne emissions data may be gathered on the basis of ICPE data from industrial sites. However, this simplification is possible only for existing factories, or factories for which authorisation request dossiers have been prepared.

3.4.6 Responses and discussion

- **Allocation of pollutant flows**

Representatives of industry present at technical committee meetings raised the question of how pollutant emissions could be re-allocated to incinerated products and bioproducts, particularly as regards phthalates. Although waste has differing origins and composition, it is all incinerated in the form of a mixture, rendering it impossible to trace the origin of incineration plant emissions.

- **Water consumption**

The issue of the relevance of a "water consumption" indicator for bioproducts was raised in the technical committee. However, discussions showed that this indicator, which quantifies only water samples, is inadequate to describe the "water" aspects of the issue, because the qualitative dimensions and possibilities of recycling/purification/application are not taken into account. This is despite the fact that these possibilities represent an asset for bioproducts which is not highlighted by this method. Foreign working parties are studying better ways of modelling water flows, which could subsequently be recommended as part of this simplified methodology. The UNEP-SETAC working party, "Assessment of Water use with LCA[6]" has enabled this issue to be discussed by a large number of stakeholders involved in the development of environmental assessment methods. The work of other groups on the subject may also be monitored: ETH (Zurich, Switzerland), CIRAIG (Montreal, Canada), ESU Services (Zurich, Switzerland), Radbout University (Nijmengen, the Netherlands), etc.

[6] http://fr1.estis.net/builder/includes/page.asp?site=lcinit&page_id=2AAEA21D-4907-4E16-BF28-A63C072B6BF7

- **Exhaustion of non-renewable resources**

The technical committee requested that the behaviour of this impact indicator, which is more general than the depletion of fossil energy resources, be studied. Following analysis of the results for three indicators, it has emerged that is the non-renewable resource exhaustion indicator, calculated in kg antimony equivalent, is highly affected by the consumption of non-renewable energy. Consequently, these two indicators are very close and apparently redundant. However, if necessary, the indicator may easily be incorporated into studies. In a comparative approach, this indicator may provide additional information, provided that the results are not due mostly to energy flows.

3.5. QUANTIFIED FLOWS AND SOURCES OF DATA

Investigation of the flows to be monitored, the available sources of data and their degree of precision is the next step after adopting a position on the issues relating to indicators. Emphasis will be placed on different flows and levels of precision depending on the selected indicators. This can be clearly seen in the case of the toxicity indicator: disregarding a few microgrammes of emissions of the most highly-polluting molecules may end up underestimating the global life cycle impact by a factor of 10. Indeed, for this indicator, there are considerable differences between molecules with a high degree of impact, varying between 1 and one million, which means that even very small-quantity flows must not be disregarded, because certain molecules are highly polluting.

3.5.1 IN THE BIBLIOGRAPHY

Even though it is difficult to fully apprehend all the flows actually integrated due to the lack of information supplied, the studies analysed generally present a fairly uniform level of inputs and emissions taken into account when they focus on the two principal impact indicators (non-renewable energy and greenhouse gas emissions). However, for the other impact indicators, it is difficult to assess the exhaustive nature and quality of the flows taken into account, since these are more complex to assess and quantify.

3.5.2 KEY ISSUES

The result obtained during a Life Cycle Analysis is nothing more than a picture of the flows taken into consideration during modelling, in addition to generic secondary information (unit impact inventories, unit toxicity factors for molecules emitted, etc). The choice and quantification of flows included within the scope of the study are therefore crucial in terms of the end result.

However, the issue is less sensitive for the two principal indicators, energy consumption and greenhouse gas emissions, for which the flows having an impact are generally known and monitored on a daily basis because of their direct energy costs. With respect to these indicators, the main questions relate to equipment depreciation and maintenance, as well as the model and sources given for N_2O emissions and/or agricultural methane.

The question is more delicate for impacts such as toxicity, for which the potential number of impact molecules is relatively high, the level of emissions to be quantified is sometimes very weak given the high degree of toxicity of certain emissions, and the issues at stake are less easy to apprehend. In other words, ensuring that a major pollutant emission has not been disregarded is fundamental, but may prove difficult to achieve.

It may quickly become necessary to involve companies' environment experts. They are in possession of data relating to the ICPE (Specific Installation Classified for the Protection of the Environment) standards to perform this quantification. These standards set maximum discharge levels for a large number of pollutants and pollutant families, and also call for a highly detailed impact study to be performed when submitting the authorisation request, which examines the potentially hazardous molecules relating to the site.

On the basis of this data, quantification of quite adequate quality may be performed and enable comparisons between different types of product, with the application of the same principles (monitored molecules are the hazardous molecules emitted in the greatest quantities; the quantification rules are uniform) offering a sound basis for comparison.

Care should however be taken in the event of such data being taken from sources passed on indirectly by the State (DRIRE reports or Pollutant register): since these are applied regionally;

some DRIRE (French Regional Department of the Environment) may be more stringent than others in terms of monitoring an industrial site's polluting emissions, which may partially skew comparison if information is requested from a site in at one location which it would not have needed to pass on in another region.

3.5.3 TEST RESULT

This question was not the subject of a specific test.

3.5.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

PAS 2050: All greenhouse effect flows must be taken into account.

ADEME-AFNOR: All flows must be taken into account, except those concerned by the cut-off rule.

3.5.5 RECOMMENDATION

- **For all indicators:**

Care must be taken in flow measurement to specify sources; data which is representative of the zone being studied should be used. All flows should be taken into account except for any subject to the cut-off rule (see below).

- **For indicators other than non-renewable energy and greenhouse gas emissions,**

IPCE environmental protection classification reports should be used as a minimum. This means using data measured on site wherever possible, or even calculating emissions on the basis of standard, official emission factors, incorporating all the molecules monitored for IPCE installations, excluding exceptional years and/or accidents. It should be checked whether the mean and annual data in question is representative with respect to the production levels of the years in question.

- **Depending on the purpose of the LCA:**

The other implication is that once these models have been taken into account, it may be decided that any other polluting flows have not been held to be potentially significant in terms of environmental hazards at the public enquiry stage, thereby providing support for the decision **not to incorporate other emissions in quantities deemed negligible** according to common principles - an important element **in the case of comparative LCAs**.

However, it may be appropriate to **take these additional polluting flows into account** in the case of **eco-design LCAs**, for which the objective may be to acquire as much knowledge as possible about all flows.

3.6. INVENTORIES

Life Cycle Inventories (or LCIs) are complete assessments of input and output flows, i.e. energy resources, raw materials and the transport required to manufacture a product.

These inventories, based on ISO standards in force (ISO 14 000 standard series) are established for a given quantity of product (e.g. 1 mJ of electricity, 1 kg of soda, 1 tonne-kilometre travelled by a vehicle) and published in private and public databases. They form the basis of all life-cycle analysis.

3.6.1 IN THE BIBLIOGRAPHY

Details of the inventories used by the studies have not been supplied systematically. Where details are supplied, the inventories are generally derived from the ECOINVENT database.

3.6.2 KEY ISSUES

This data is of paramount importance in the final result. It is the source of a non-negligible degree of variability between studies, due to the use of different sources and/or databases when estimating input impacts. Each database incorporates different modelling options (the degree to which depreciation is taken into account, allocation options, scope of the study) and datasets with differing degrees of representativeness (systems which are representative for a given country or procedure; data dating from 2003, etc,).

One example relating to two studies concerning biofuels is of particular interest here. The following table illustrates the discrepancy which may arise solely on the basis of natural gas and electricity inventories for the industrial processing stage which makes ester from oilseed rape. The discrepancy between the inventories used completely cancels out the more favourable input data.

Table 6 – Example of the importance of choosing the right inventory: two studies relating to biofuels

	ADEME DIREM 2002	BIO 2009	% BIO/DIREM	Explanations
Input energy data, industrial stage (gross mJ consumed / tonne of biofuel)	3745	3473	93%	Higher input data for ADEME-DIREM,
Primary Energy consumed once the "mean use" inventories have been applied (final mJ / tonne of biofuel)	4484	5212	116%	Inversion: the BIO study data is now higher due to the higher values derived from the inventories based on ECOINVENT

Commentaire : OK

It is clear that in these circumstances, direct comparison between studies is highly influenced by this element.

3.6.3 TEST RESULTS

A test was performed to illustrate the impact of the choice of inventory on the assessment. To achieve this, two calculations were performed:

- use of ECOINVENT inventories which do not take into account infrastructure depreciation;
- simulation using 2 indicators (non-renewable energy consumption and greenhouse gas emission) and changing the inventory source (inventories for gas, electricity, trucks, methanol and fertilisers) using figures from JRC and the ADEME-DIREM study.

The results are presented in the table below.

Table 7 – Inventory test result for the 3 bioproducts

for 1 kg of bioproduct	Non renewable primary energy (MJ/kg)	Greenhouse gas emissions (kg CO2 eq/kg)	Photochemical oxidation (kg C2H4 eq/kg)	Human toxicity (kg 1,4-DB eq/kg)	Eutrophication (kg PO4-/kg)
Isosorbide					
ECOINVENT inventories	100%	100%	100%	100%	100%
ECOINVENT inventories, without infrastructure depreciation	98,4%	97,8%	93,6%	83,2%	99,2%
using 5 inventories from other sources	95,1%	88,1%	72,1%	78,2%	95,3%
Materbi					
ECOINVENT inventories	100%	100%	100%	100%	100%
ECOINVENT inventories, without infrastructure depreciation	96,1%	95,8%	94,5%	61,7%	96,6%
using 5 inventories from other sources	93,8%	95,5%	92,6%	86,5%	93,4%
Biolubrifiant					
ECOINVENT inventories	100%	100%	100%	100%	100%
ECOINVENT inventories, without infrastructure depreciation	97,4%	97,8%	94,5%	95,6%	99,8%
using 5 inventories from other sources	89,1%	82,7%	66,4%	92,4%	98,0%

3.6.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

ADEME-AFNOR: A database will be set up.

PAS 2050: Databases which comply with PAS 2050 to be preferred, followed by the most relevant sources validated by critical review or issued by public stakeholders (State, UN, etc.).

3.6.5 RECOMMENDATIONS

Irrespective of the inventory chosen, maximum transparency as to the inventories used is vital.

Even where it is not possible to recommend which inventories should be used, it should be emphasised that the use of large, uniform and recognized databases (e.g. ECOINVENT, GaBi, ELCD, LCAfood DK, etc.) helps to protect users against any criticisms in this area. In addition, these databases offer the advantage of often including references relating to fossil product processes, facilitating comparative LCAs.

Recommendation for simplified methodology:

It is possible to disregard input transport, all the more so because inventories already include a standard transport component.

3.6.6 RESPONSES AND DISCUSSION

The possibility of assigning a degree of uncertainty to inventories was raised by members of the technical committee. However, this data is as yet rarely calculated or supplied with each inventory. Nevertheless, this comment may serve as a recommendation for the future establishment of inventories by ADEME.

3.7. THE CUT-OFF RULE

This rule defines the criteria for inclusion or exclusion of product life cycle inputs and outputs. It allows simplifications to be made to the life cycle inventory by offering the following input and output exclusion criteria: mass, energy and environmental relevance. The mass cut-off criterion is often used due to its ease of implementation.

3.7.1 KEY ISSUES

The cut-off rule makes it possible to simplify calculations, by excluding a certain number of inputs and outputs from the system when they are deemed to be negligible and do not have a Life Cycle Inventory, for example. However, the mass cut-off criterion may lead to non-negligible discrepancies if specific precautions are not taken. In particular, substances which are classified as highly toxic or hazardous for the environment should be the subject of special attention and be incorporated in the inventory irrespective of their mass.

3.7.2 TEST RESULTS

By way of illustration, a cut-off rule was tested on the transport of inputs constituting a tiny part of the assessment of the product being studied (less than 1 per 100 in terms of quantity). This approximation also appears to be justified given the basis on which ECOINVENT inventories are established. Indeed, for most inputs, these incorporate a *transport* component for transport to a mean distribution location over a standard route. This cut-off makes it possible to simplify the collection of data by disregarding the transport of small minority inputs to the bioproduct manufacturing site, since this transport data has been taken into account using the ECOINVENT inventory generic mean. This is the subject of the test presented below: calculation of the environmental impact of Materbi was performed, disregarding the transport phase for minor inputs.

Commentaire : OK

Table 8- Cut-off test for the transport of minority inputs

	Non-renewable primary energy	Greenhouse Gas Emissions	Photochemical oxidation	Human toxicity	Eutrophication
Materbi					
Reference value	100%	100%	100%	100%	100%
Test without input transport	99.7%	99.6%	99.7%	99.7%	99.7%

The result discrepancy is very slight for all indicators: less than 0.5%. The simplification therefore appears to have little impact on the overall product assessment.

3.7.3 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

ADEME-AFNOR: The methodological outline is similar to the general principle of the ISO standard. Permanent exclusions have also been suggested (transport of staff, inputs producing human energy or the transport of users).

PAS 2050: At least 95% of GG emissions must be taken into account (excluding the usage phase). If any single flow accounts for 50% of emissions, the 95% figure applies to the other flows.

3.7.4 RECOMMENDATIONS

Pursuant to what is permitted by standard ISO 14 044, and depending on the level of accuracy sought, a maximum cut-off threshold of 5% should be established for all impacts.

This impact threshold should then be converted into a mass threshold in order to decide whether or not a flow may be disregarded on the basis of the available data for this flow (for instance, a particularly polluting input may represent 1% of total mass but 10% of the impact). This conversion is delicate and is only possible if two conditions are fulfilled:

- Ensuring that the product in question does not present unit impacts which are too great: this may often be the case for indicators such as human health, eco-toxicity or photo-oxidation (one microgramme of a highly toxic molecule may sometimes have a considerable effect).
- Taking into account of the variable nature of unit impacts by choosing mass thresholds with sufficient uncertainty margins (e.g. 5% impact = 2% mass). Although some flows are deliberately disregarded on the grounds of their marginal nature, it is important for these simplifications to be explicitly stated in the study report along with any supporting documentation showing these calculations, specifying the names of any flows which have not been taken into consideration.

In line with the ADEME-AFNOR platform proposal, we suggest that some items (employee transport, user transport, etc.) should be excluded. Similarly, following the PAS 2050 considerations, we suggest that the 50% rule be applied: if any single flow accounts for 50% of emissions, at least 95% of the other emissions should be taken into account.

3.8. ALLOCATIONS

Co-products are frequent in bioproduct life cycles. These may include proteins, glucose syrup, vegetable oil, etc. Similarly, the agricultural production phase often involves the production of agricultural residues.

When such co-products are generated, the question of assigning the environmental load generated by the production of these various products arises. Known as "allocation", this assignment has considerable influence on the LCA results; a number of approaches are possible.

3.8.1 IN THE BIBLIOGRAPHY

The studies analysed offer a broad diversity of choices as to the methods of assigning impacts to the various products and co-products:

- Substitution with allocation of credit for avoided impacts;
- Economic-based allocation;
- Mass-based allocation.

This breadth of choice is present in both the agricultural and industrial phases.

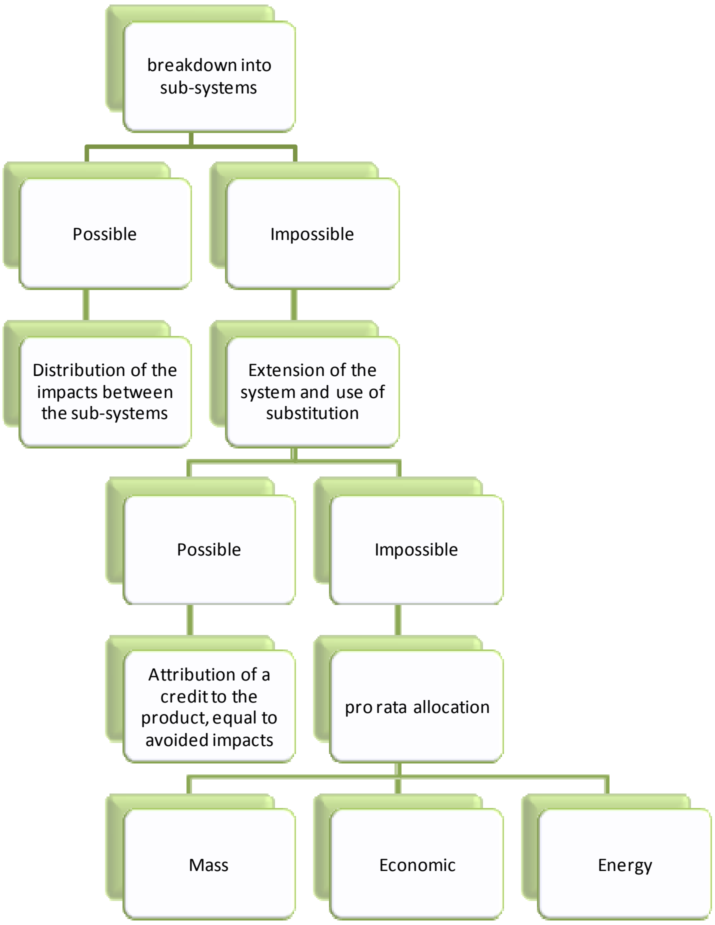
The only consensus across the majority of studies is the allocation of a credit in the event of the production of energy (heat/electricity).

3.8.2 KEY ISSUES

The choice of allocation method represents a crucial issue in the performance of an environmental assessment for a product.

When choosing an impact allocation method, the ISO 14 040 Standard recommends the following reasoning, set out in the decision tree below. This reasoning should be applied to each stage of the life cycle which generates co-products.

Figure 12 – Decision tree for choosing the method to assign impacts



The first solution envisaged, **breakdown into sub-systems**, is performed when possible; this makes it possible to circumvent this question by taking into account only the loads and emissions of the product being studied itself. However, in many cases, when co-products are derived from a single process, this breakdown cannot be achieved.

Extension of the system and **the use of substitution** may often be considered, but presents a number of major difficulties:

- Which product should be substituted?
- Is the service performed really equivalent?
- Is there an equivalent methodology for the substitute product?
- Is the value for this product reliable and robust?
- Is it representative?
- The issue of the stability of the result over time if the LCA for the substitute products changes.

As can be seen, it is difficult to apply this solution. It should be reserved for highly specific co-products, such as those used for energy. In other cases, substitution incurs an additional margin of error, by using results derived from other studies, which are often not fully evaluated in terms of their validity and robustness.

The preferred solution which may be envisaged is that of **pro rata allocation**. Environmental impacts for a given stage are allocated to the products and co-products on a pre-defined pro rata basis. This pro rata basis may relate to mass, energy or be economic in nature.

Figure 13 – Advantages and weaknesses of various allocation methods

Pro rata basis	Economic	Mass	Energy
Advantages	Takes product value into account Applies to virtually any co-product Appropriate for co-products of differing natures	Remains "stable" over time Simple	"Stable" result Highly appropriate for certain products (oil, ethanol, etc) Consistent with biofuel reference document
Weaknesses	Fluctuations in prices Possible fluctuations in use	Difficult to justify if the products are of highly different nature and/or value	Not appropriate for all products
Appropriate for bioproducts	Yes, except products whose market price is not established	depends on the case	Not all bioproducts have an energy dimension.

3.8.3 TEST RESULTS

These tests were guided by two objectives:

- obtaining results with a number of pro rata bases: mass, upstream energy (i.e. energy allocation for the agricultural stage, consistent with the biofuels reference document, plus mass allocation) and economic;
- ensuring that these tests cover a sufficiently broad range of variation to provide some idea of the impact of this parameter in the final result.

Test 1 – The table below provides details of the pro rata elements used for each calculation and the range of variation tested. It be seen that in one instance, allocation on the basis of the respective masses of various starch co-products (gluten, corn or wheat gluten feed, germs) results in an allocation of 63% of the upstream stages to the starch separation stage (impacts generated by the production of agricultural raw material, transport and separation of co-products). If an economic-based allocation is used (on the basis of BIO price estimates), this percentage rises to 68%.

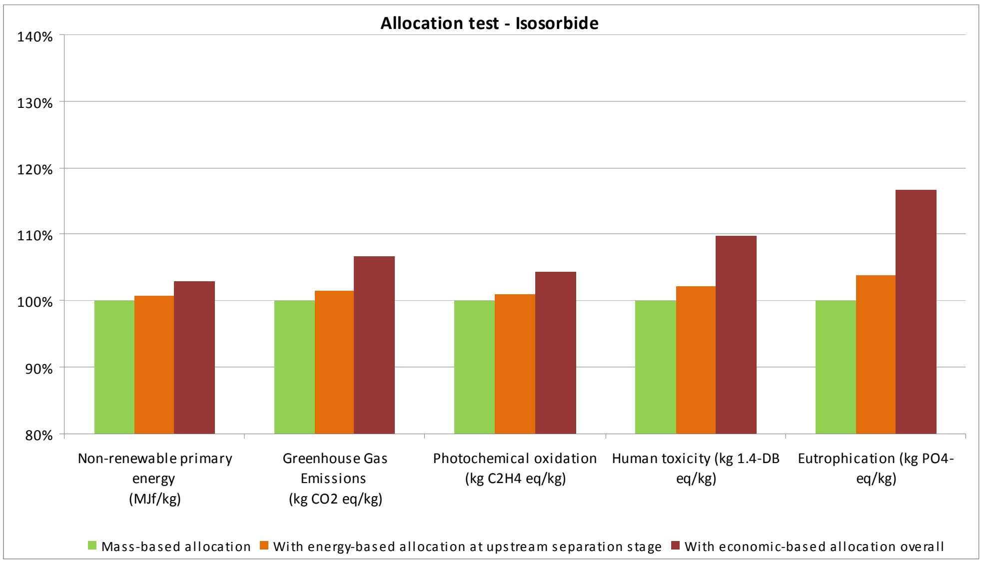
Table 9 – Values used for allocation tests

Allocation	Mass-based	Upstream energy-based	Economic-based
Isosorbide			
Starch production stage	59%	63%	68%
Materbi			
Starch production stage	70%	73%	79%
Soya oil production stage	20%	34%	40%
Glycerin production stage	10%	5%	14%
3rd intermediary product production stage	40%	-	51%
Biolubricant			
Sunflower oil production stage	45%	63%	68%
Refined oil production stage	99%	99%	99%
Bio diesel production stage	89%	94%	85%

This range of values was obtained on the basis of the LHV (lower heating value) of the molecules, the masses generated and the prices to which BIO had access for this study (data from agricultural reviews and customs data, averaged over 4 years (2005-2008)).

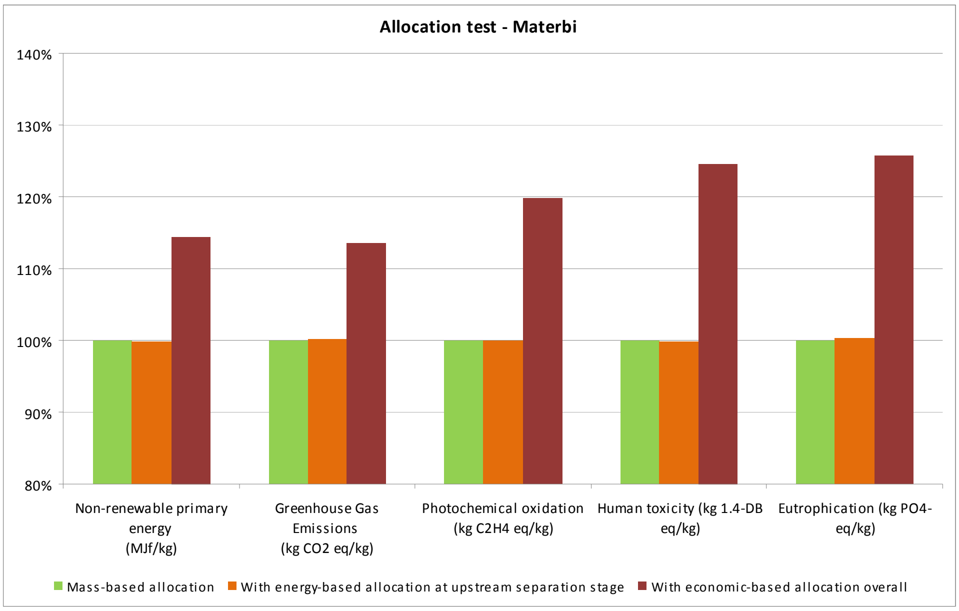
The other stages of the product life cycle did not result in allocations and therefore do not feature in this table.

Figure 14 – Test results for isosorbide



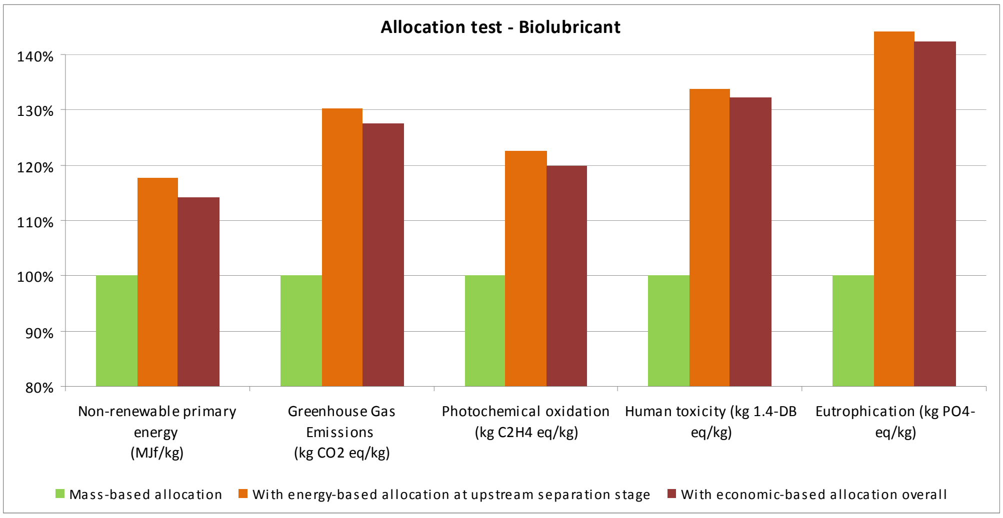
The results for isosorbide show little variation between the mass and upstream energy-based allocations. The economic-based allocation results in a greater difference, but this does not exceed 2-15% depending on the indicator.

Figure 15 – Test result for Materbi



The Materbi results are rather more distinct: they demonstrate a high degree of similarity between mass and upstream energy allocation, but the economic-based allocation leads to differences of between 13 and 25%.

Figure 16 – Test result for biolubricant



For the biolubricant, the range of pro rata bases varies considerably (from 45% to 68% for the sunflower oil production stage), which leads to significant variations in the total assessment. The energy and economic-based allocations appear to reflect the significance of oil compared to its co-products in a similar manner. In this instance, mass-based allocation does not appear to be relevant.

For products with an intrinsic energy value, such as sunflower oil, we therefore recommend using an allocation on an energy pro rata basis instead of a mass pro rata basis, solely for the upstream fibre separation stage.

Test 2 – A second test was performed, using the economic values of the products and co-products over 4 years, in order to assess the variation of the economic pro rata basis from year to year, and to illustrate the potential variability arising from the use of an economic pro rata basis.

Table 10 – Example of annual variation of an economic-based allocation for starch

Principal product	2005	2006	2007	2008
Starch for isosorbide	73.4%	78.2%	77.6%	76.5%
Starch for Materbi	76.6%	80.8%	80.4%	79.5%

This table shows the potential variation for a product over 4 consecutive years. It provides further support for the recommendation **to use mean values smoothed over a number of years if the economic pro rata basis is to be used**.

Test 3 - A **third test** was performed with regard to the following simplification:

Not performing allocations for co-products generated in very small quantities (a ratio of 1 to 100 between the principal product and its co-product) and with an economic value which does not significantly exceed that of the principal product.

Table 11 – Simplification test: not performing an allocation on marginal co-products (here: acid oil)

	Non-renewable primary energy	Greenhouse Gas Emissions	Photo-chemical oxidation	Human toxicity	Eutrophication
Biolubricant					
Reference value	100%	100%	100%	100%	100%
Test without allocation for acid oil	100.5%	100.7%	100.5%	100.8%	100.9%

Not taking into account acid oil in biolubricant co-products makes only a small difference in the overall assessment (a discrepancy of less than 1%).

In order to simplify calculations and data gathering, it is possible not to perform an allocation for co-products generated in very small quantities with no economic value.

3.8.4 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

ADEME-AFNOR: the methodological appendix reviews the principles of the ISO standard (see "overview of key issues"), without taking a more specific position.

PAS 2050: Economic-based allocation is ranked in third place, behind extension/substitution. Physical allocation is not even referred to. It follows that PAS 2050 expresses a clear preference for economic-based allocations.

3.8.5 RECOMMENDATIONS

As discussed above, **substitution** appears to be applicable only for highly specific co-products whose use raises no problems in terms of modelling. This is deemed to be feasible **for energy production**, for which substitution may easily be made depending on use and the energy mix in the country in question, or for **co-products used as fertiliser or soil amendments** which replace the manufacture of mineral-based fertilisers.

For other co-products, in the light of the complexity of the types of products and services provided, and for the purposes of consistency, we propose adopting **load allocation on a pro rata basis.**

The **energy-based pro rata** should be preferred when the co-products from the agricultural stage are separated, for products for which this is deemed appropriate: **oil, oilcake, ethanol, vinash and glycerin, etc.** Energy-based allocation is appropriate for these products, for which the energy content is a good representation of differences in content and thus of value of the material. This approach also has the advantage of being completely consistent with one of the major applications, energy (see the reference document for the performance of biofuel LCAs).

A mass-based pro rata would not be appropriate due to oil being excessively under-weighted. An economic-based pro rata would give similar magnitudes to the energy-based pro rata, but would use data which is more variable and more complex to obtain (market value of products).

The **mass-based pro rata** is recommended **for other situations**, for the separation stage for fibres without any energy issues (hemp, for example, or the production of starch) and for other product life cycle stages.

However, in order not to distribute impact without taking into account the added value of the various co-products, the question of **economic-based** and **energy-based allocations** should also be examined if the differences in value are too great. With regard to the economic-based allocation, if two products from the same stage have highly disparate market values, it appears appropriate to assign a greater share of the impacts to the most profitable product and a lesser share to the others, which would then be considered as ancillary products. For products for which an energy-based allocation is meaningful, the energy allocation test is also necessary in order to support the investigation and determine whether the mass-based allocation has a tendency to underestimate products' intrinsic values. **When the difference between the recommended allocation and the economic or energy-based allocation is in excess of 10 points[7], we recommend using the economic-based allocation.** Above this order of magnitude, we recommend raising the issue of the most appropriate allocation and performing a more detailed analysis.

Precautions to be taken with the economic-based allocation

It should be emphasised that even when it is based on market prices smoothed over a number of years, the use of an economic-based allocation has an impact on the long-term validity of results, which may become obsolete in the event of significant price variations. Before embarking on an economic-based allocation, we highly recommend **verifying the historic price stability** of the products in question.

Where the price of products is directly or indirectly related to the cost of oil-based products, this may lead to considerable variations in a very short period of time.

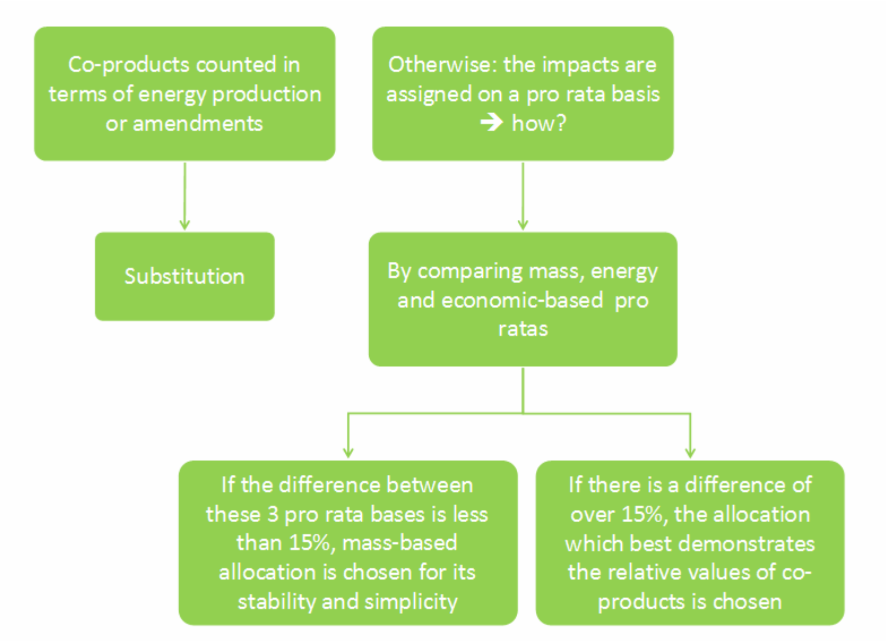
Similarly, for certain emerging products and/or products subject to little-known market rates, it is not possible to obtain values and thereby use the economic-based allocation.

While the economic-based allocation makes it possible to show actual values for various co-products, the resulting environmental assessments will be subject to considerable variations. The lack of long-term validity of these results may disrupt their distribution, in terms of both image and logistics.

With regard to energy-based allocation, co-products' mass-based pro rata values should also be **compared to pro rata allocations based on their energy content, in order to choose the allocation which best reflects the share of different co-products** in the production of environmental impacts.

Figure 17 - Summary of recommendations for the choice of allocation (to be applied for each stage which generates several co-products)

[7] Example: the mass-based pro rata should be applied for the product being studied, and would result in an allocation of 51% of upstream loads. If calculation of the economic-based pro rata indicates that this allocation would increase to over 61% (51% + 10%), then using the economic-based pro rata as a solution should be considered, for these types of co-products with highly differing values.



In the event of specific inventories for agricultural products being established by ADEME, the issue of allocations to agricultural co-products will be decided upstream, when the "corn starch" or "sunflower oil" inventories are established. This allocation to agricultural co-products is not intended to differ according to product use: food, biofuels, bioproducts, etc.

It is therefore crucial for the establishment of this database to be uniform and transparent in order for it to be incorporated intelligently and appropriately in LCAs.

Furthermore, it has been shown that allocation values for starch can vary significantly depending on the products into which it is integrated (59%-60% according to allocation type for isosorbide, 70%-79% for Materbi). Specific investigation relating to starch may provide clearer responses as to how allocations for this product should be handled.

Recommendation for simplified methodology:

Allocations for co-products which are marginal in terms of mass and value may be disregarded.

3.8.6 RESPONSES AND DISCUSSION

Following discussions with members of the technical committee, it has again been specified that the economic-based allocation was not the priority recommendation. Prior to proceeding with mass or energy-based allocation, the issue is that of verifying whether or not there is a significant imbalance in terms of economic value between the products to which impacts are to be assigned.

One of the difficulties in this verification is the scarcity (or indeed complete absence) of information about market prices. The issue is therefore one of ensuring whether or not the various products derived from a process have similar values, in terms of an order of magnitude. If significant discrepancies exist, mean values smoothed over a number of years should be used to allocate impacts to products in accordance with these mean economic values. There is an additional problem with economic-based allocation: co-products derived from a given phase often have to be processed and prepared before being assigned a market price. Identifying the price of products at the closest possible stage following separation should therefore be preferred.

The discussion also revealed that allocations would probably be different in the agricultural and industrial phrases. In the agricultural phase, the two principal options are energy or mass-based allocation, with energy-based allocation having a specific advantage in terms of consistency with biofuels. In the industrial phrase, mass or economic-based allocations should be envisaged. Since the price of bioproducts is particularly subject to fluctuation, attention is drawn to the fact that mass represents a more stable basis, which is also easier to apprehend.

3.9. Depreciation

For LCAs, depreciation designates emissions relating to the manufacture of durable goods required for the manufacture of the product being studied (machines, factories, vehicles, etc.). When gathering data, the question of taking into account emissions relating to infrastructures, and thus the incorporation of depreciation of these emissions into the product's environmental assessment, must be raised.

3.9.1 In the bibliography

The issue of whether or not various depreciations are taken into account is very rarely dealt with in the studies which we were able to consult. When depreciation is mentioned, it is to specify that it has not been taken into account. Overall, it can therefore be deduced that it is extremely rare for this element to be taken into account in LCAs performed on bioproducts.

3.9.2 Key issues

Depending on the choice of method, infrastructure depreciation may be incorporated into the environmental assessment of the product being studied. This calculation requires additional data regarding the principal materials used to construct industrial buildings and production units. It should be noted that major databases offering unit inventories to perform LCAs (ECOINVENT, GaBi) offer values which incorporate these types of depreciation. Although this data is open to challenge, it does at least exist. The issue is thus one of having relevant information in terms of production sites and agricultural equipment.

It may be noted that this data is becoming available for recent sites but is not available for older sites. Furthermore, taking into account this plant and equipment raises methodological questions in terms of equipment lifespan, allocation to the various co-products produced on a single site, renewal, and the scope and sophistication of measurements for comparative LCAs (how detailed should these be? What boundaries should be set as to which equipment to take into account?).

3.9.3 Test results

Simulations were performed on the 3 bioproducts studied in order to assess the potential impact of depreciating plant and equipment in the overall assessment. Plant and equipment data for the industrial site has been adapted from a previous study performed by BIO Intelligence Service on biofuels. The same levels of plant and equipment per kilogram of bioproduct (see table below) were introduced into the assessments of each bioproduct under consideration. The values for the agricultural stage have been taken from data in the literature.

Table 12 – Values used for simulating depreciation

	Depreciation reference period	Depreciation - reference value	Short period	Depreciation - upper value
	Years	kg material / kg product	years	kg material / kg product
Industrial depreciation				
Concrete	50	$1.5.10^{-6}$	33	$2.2.10^{-6}$
Steel	50	$6.4.10^{-4}$	33	$9.5.10^{-4}$
Bitumen asphalt	50	$9.0.10^{-4}$	33	$1.3.10^{-3}$
If stainless steel	20	$2.0.10^{-4}$	33	$3.6.10^{-4}$
Agricultural depreciation				
Soya	15	13	10	20
Sunflower, wheat	15	25	10	37
Corn	15	36.6	10	55

Source: BIO, adapted from PROLEA data

The following charts present the results of the simulation performed for the three bioproducts tested. These are simulations due to the lack of actual data for each of the three products. The interest of the test lies solely in the comparison between the different depreciation values. In no way should the charts be understood to represent actual depreciations for isosorbide, Materbi or the biolubricant. The following may be distinguished:

- calculations using mean values and mass-based allocation to products;
- calculations offering a greater degree of precision (adding stainless steel equipment);
- calculations using higher values, simulating faster depreciation (10 years instead of 15 years for agricultural equipment; 30% less for the bio-refinery site depreciation, depreciating bitumen and concrete over 40 rather than 50 years and stainless steel over 15 rather than 20 years).

Figure 18 – Result of the test of the impact of the level of depreciation on primary energy assessment

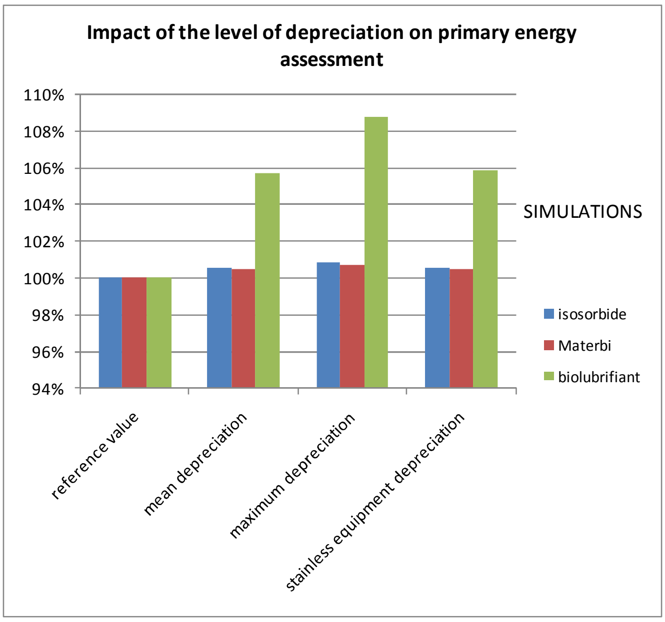
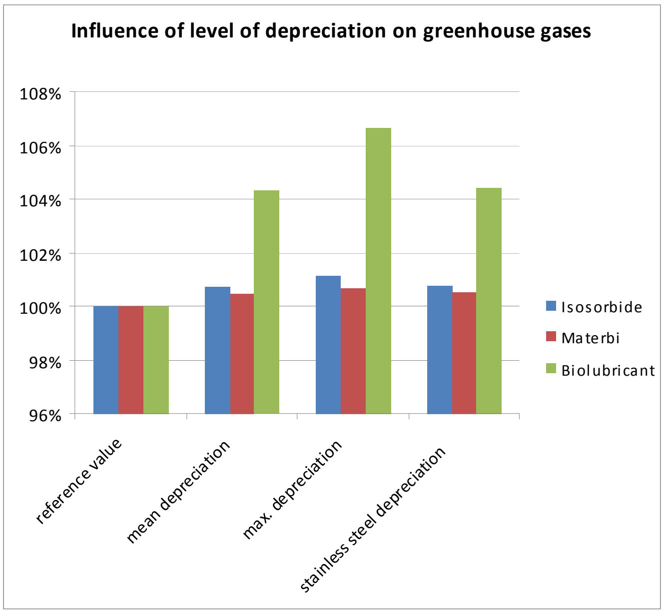


Figure 19 – Result of the test on greenhouse gases



Only primary energy consumption and greenhouse gas emissions are presented, because they are the indicators for which the test presents the greatest differences.

indicator). Since its global assessment is less than that of the other two products, an equal variation in absolute values has a greater proportional impact.

For the two other products, incorporating depreciations increases their assessment by less than 1% for the two indicators which are the most affected by this flow (energy and greenhouse gases).

The results differ depending on the choice of methods. Standardisation would be required in order for depreciation to be taken into account in a uniform manner.

3.9.4 Comparison with other methodological frameworks

ADEME-AFNOR: Depreciation of energy inputs and transport will be incorporated into the database. Depreciation of industrial sites, agricultural equipment, etc have not been discussed at present.

PAS 2050: Not incorporated in PAS 2050 to date; this point may be dealt with in future versions.

3.9.5 Recommendations

We recommend taking depreciation into consideration wherever possible. Specific discussion of how to take depreciation into account should be conducted and detailed in the summary report (what data is available? What depreciation should be assigned to which product? Where applicable, how should allocation to various products be carried out? Is the use of allocations defined across co-products meaningful? What depreciation period should be used?).

Recommendation for simplified methodology:

For simplified methodology, depreciations which it is difficult for users to assess, such as those relating to the production site may be disregarded (values suggested in unit inventories may be kept, since they are easily accessible). This simplification may be envisaged particularly in the case of comparative LCAs, in which refinery depreciation will not be taken into account either, because its various aspects are difficult to model. Conversely, if depreciation relating to refineries is taken into account, naturally it must also be incorporated into the bioproduct processes under study.

This is not a case of applying a cut-off rule for an impact which has been deemed to be too marginal, but very much a simplification relating to difficulties rendering modelling difficult and therefore as yet over-approximate (for instance, agricultural phase depreciation may not be fully neutral in terms of total energy).

3.9.6 Responses and discussion

During technical committee meetings, it was emphasised that for low-tonnage products (and often, higher added value products), infrastructure depreciation could represent a non-negligible share in the overall product life cycle. However, in many cases, this situation relates to the fact that these types of product are currently in a start-up phase: in the place of today's pilot sites, larger sites producing greater quantities are likely to emerge.

Depreciation relating to the manufacture of products in the development phase is therefore different in terms of coverage and application to that of an established, optimised site. These elements supply further grounds for simplification proposals at this stage, particularly for comparative LCAs.

3.10. Taking into account timescales and carbon sequestration

This section deals with both these issues since they are closely linked. The following two paragraphs supply some explanatory details with regard to these two issues.

Taking into account timescales

The greenhouse effect may be calculated over 20, 100 or 500 years. The Kyoto protocol defined its objectives by taking into consideration the mean consequences of greenhouse gas emissions over a period of 100 years. Data aggregated over 100 years provides a mean impact value for the whole of the period, without providing details of differences between the short, medium and long-term effects.

Given a time t_0 (the point at which the product being studied is produced), greenhouse gas emissions caused by the product under study will be looked at over the period of time between t_0 and t_0 + 100 years. Consequently, any difference between the times at which capture and emission take place may then have consequences on a greenhouse effect calculated on a mean basis over this set 100-year period.

This choice of method has a particular impact on two mechanisms relating to CO_2:

- The sequestration and breakdown of biogenic carbon in products with long lifespans;
- Modelling end of life for products with long lifespans.

Taking timescales into account also affects other processes. For instance, in construction, recycling may take place 40 years after production. The benefits of recycling will only become apparent 40 years on. For CO_2, emissions savings concern only a 60-year period. For emissions other than CO_2, with a very short lifespan in the atmosphere (or surface water), the issue is not that of their duration in the atmosphere but:

- the difference in impact of future processes: if steel is recycled in 40 years' time, what will be the impact of recycling processes (electric arc furnaces) and "new" steel processes (blast furnace) at that time? Technical progress over 40 years is likely to be considerable.
- the potential difference in the effect of a deferred emission. In 40 years' time, certain elementary flows will have highly different impacts, for instance in terms of water consumption (will our resources have stabilised, or will there be a more widespread lack of water?) or emissions contributing to eutrophication (what condition will rivers be in and how sensitive will they be?) etc.

Taking into account biogenic CO_2

Biogenic CO_2 (or biomass CO_2) is CO_2 captured by biomass or emitted during the natural decomposition or combustion of this biomass.

CO_2 has the same effect on our climate irrespective of whether it is biogenic or fossil in origin. However, carbon from biomass comes from carbon sequestered by the plant during growth. Three approaches are used in the literature in order for biogenic CO2 to be taken specifically into account:

- biogenic CO2 is not taken into account in the greenhouse assessment. The assumption is made that biomass is constant over time and that all gas sequestered will be emitted. On this basis, the flows cancel each other out.

- Measurement: all flows are taken into account, as for other pollutants. In theory, this means having data about what happens to carbon throughout the plant's life cycle, from the stage of photosynthesis and carbon sequestration through to the quantity of carbon contained in the part which is used. This clearly requires a very high level of precision.

- Sequestration: rather than measuring the flow, the difference between capture and emission is measured by measuring the amount of biomass carbon sequestered long-term in the technosphere and the increase in biomass. The result obtained is the same as that using the previous method; only the values for each stage change.

However, all methods measure flows of biogenic methane, since this gas has a high warming capacity, greater than that of the CO_2 from which it derives (originally captured from the atmosphere by the plant).

3.10.1 IN THE BIBLIOGRAPHY

Generally speaking, at present there is little discussion of these issues in LCAs. This observation is borne out by the bibliographical analysis of the bioproduct LCAs carried out for this study.

In terms of timescale, the LCAs examined do not differentiate the way they take impacts into account depending on the moment of emission.

The effect of sequestering carbon in the product is not generally taken into account; only the existence of biogenic carbon in the product is estimated and taken into account in the assessment as a differentiating element for end of life.

3.10.2 KEY ISSUES

Taking into account timescale

Many studies have opted not to take this issue into account for the purposes of simplicity. Nevertheless, the implicit limits of such studies should be borne in mind.

It is effectively assumed that the moment of emission is not important and that an emission (of CO_2, for instance) today will have the same impact as an equivalent emission in 10 or 20 years' time.

- For biogenic CO_2, this means that the sequestration phenomenon is not considered and that irrespective of the moment of emission, the emitted CO_2 is taken into account as though it was emitted at time t_0 (no time factor distinguishing the moment of emission from the 100-year reference period).

- For other greenhouse gases, the impact of gases emitted at a time t_0+x is underestimated in that their GWP should be adjusted upwards to take into account the period of time during which they remain in the atmosphere (100 years - x).

Taking into account biogenic CO2

Taking into account the biogenic carbon contained in a product at end of life should be carried out bearing in mind the following elements:

- assuming that biomass management is sustainable, i.e. that the carbon emitted will be fully offset by the sequestration of an equivalent quantity of biogenic carbon when biomass grows.
- not taking into account the phenomenon of the sequestration of biogenic carbon in biomass-derived materials with long lifespans (> 1 year), e.g. furniture - or when the product is taken to a disposal site. Similarly, the net growth of forest biomass carbon content (fallen leaves and branches which become humus accumulating on the ground) is not taken into account.
- in certain anaerobic and damp conditions, in the event of biomass decomposition, biomass carbon is partially turned into methane, the global warming potential of which is 25 times higher than that of CO_2. Not taking biogenic carbon into account increases the risk of not taking this methane emission into account.

3.10.3 COMPARISON WITH OTHER METHODOLOGICAL FRAMEWORKS

Taking into account timescale

Only **PAS 2050 deals with this issue**, using two calculation methods, depending on the time between production and emission.

For emissions which take place at a single point in time, after a period of 25 years maximum, **PAS 2050** suggests the following formula to calculate the emission multiplying factor:

Commentaire : OK, cohérent

$$Factor = [1 - (T * 0.76 / 100)]$$

where T: number of years between the production of the product and actual emissions

If the emissions take place over a number of years or before a period of 25 years minimum, the factor is calculated as follows:

Commentaire : OK

$$Factor = \Sigma\, Xi * (1 - i/100)$$

Where i is the number of years of emissions and Xi is the proportion of emissions in the year i

The **ADEME-AFNOR platform** does not take into account the date on which greenhouse gases are emitted.

Sequestering biogenic carbon

In its methodological work, the **ADEME-AFNOR platform** has adopted a position with regard to carbon sequestration. It suggests taking into account biomass storage if the forest or farm is managed on a sustainable basis. A factor making it possible to characterize output flows compared to input flows has been introduced, calculated using the following formula:

$$Factor = [1 - (T / 26)]$$

where T: number of years of storage

The factor 26 derives from a financial discounting calculation for one tonne of CO_2 avoided. The platform also considers that if a product sequestering biogenic carbon is placed in a landfill site, the carbon has been stored permanently (T = 26).

The platform mentions the fact that this biomass carbon sequestration accounting rule will require updating depending on international rules adopted in the course of application of the United Nations Framework Agreement on Climate Change.

PAS 2050 takes into account carbon sequestration only for durations in excess of one year. The carbon stored in the product is multiplied by a factor depending on the duration of sequestration; this value is then subtracted from the total greenhouse gas emissions assessment. This calculation is equivalent to applying the calculation relating to the emission date, another way of approaching the issue of deferred emissions of biogenic CO2.

The sequestered carbon multiplication factor is calculated as follows:

If 2<T<25 years, Factor = 0.76*T/100 where T is the number of years' storage

If T>25 years, Factor = Σ_i (Xi/100) where Xi is the proportion stored in the year i.

3.10.4 TEST RESULTS

Test 1 – A **test** was performed **to take into account the greenhouse gas emission date**, taking a hypothetical lifespan of 10 or 20 years for Materbi type plastic, using the **PAS 2050 formula.**

This formula provides the following results, presented in terms of the differences between the reference value and the hypothetical value if the emission date is taken into account. The carbon sequestered in the product has been estimated on the basis of unit inventories.

In order to illustrate the same approach for fossil products, the calculation was also performed for a plastic similar to Materbi but with solely fossil content.

Table 13 – Test for taking into account carbon emission and sequestration dates for a bioplastic

Test using the PAS 2050 method	Duration (sequestration or emission)	Multiplying factor for greenhouse gas emissions at end of life	Impact on the overall greenhouse gas emission assessment
MATERBI reference value		100%	100%
Incineration	5	95%	97.7%
Incineration	10	90%	95.5%
Incineration	20	80%	91.0%
Landfill	10	85.5%	95.4%

Depending on the product lifespan, taking into account the emission date may have varying degrees of effect on the assessment of greenhouse gas emissions generated throughout the life cycle. However, it should be emphasised that this simulation was performed with fictional lifespans, far in excess of the current lifespan of Materbi type plastic.

The same calculation applied to a hypothetical 100%-fossil-origin plastic would lead to identical results, because all the carbon sequestered in the products (both biogenic and fossil) is accounted for in this formula.

Test 2 – A **second test** was performed concerning the effect of taking into account carbon sequestration on the product life cycle.

Tests using the PAS 2050 method	Sequestration duration before end of life (years)	Multiplying factor for greenhouse gas emissions	Impact on the overall greenhouse gas emission assessment
MATERBI reference value		100%	100%
Incineration	5	3.8%	99%
Incineration	10	7.6%	980.1%
Landfill	10	14.5%	99.2%
Test using the ADEME-AFNOR method	**Sequestration duration before end of life (years)**	**Multiplying factor for greenhouse gas emissions**	**Impact on the overall greenhouse gas emission assessment**
Incineration	5	80.8%	95.1%
Incineration	10	61.5%	90.0%

This test returns more moderate results than the previous test: using the PAS 2050 method, taking into account biogenic carbon sequestered in products has little effect on the overall product assessment. The ADEME-AFNOR platform formula has a greater effect on the assessment.

Nevertheless, taking into account biogenic carbon sequestration makes it possible to identify a difference in results between fossil-origin and bioproducts, unlike the method which takes into account the emission date.

3.10.5 RECOMMENDATIONS

Taking into account the dates on which biogenic carbon is emitted and sequestered may partially alter the assessment if the product lifespan exceeds 10 years.

Tests were performed using lifespan scenarios of 10 and 20 years. In actual fact, bioproducts generally have shorter lifespans than those used for the calculation hypotheses. Consequently, this methodological point is unlikely to have a genuine impact on the vast majority of bioproduct assessments.

Furthermore, there is not as yet one single consolidated formula.

In this context, we recommend **not using these formulas** and not taking into account the emission date when calculating bioproduct environmental assessments.

3.11. THE AGRICULTURAL PHASE

The agricultural phase constitutes a key element in the performance of Life Cycle Assessments for bioproducts. Indeed, specific methodological questions arise during this stage, often with a potentially non-negligible impact on the results.

However, the issue of assessing the environmental impacts of agricultural products used as raw materials in bioproduct lifecycles should be resolved by establishing a specific database. Questions relating to the gathering and processing of agricultural data should be the subject of broad-based work as part of an ADEME project aimed at establishing an agricultural database under the aegis of the INRA and ART.

Several methodological recommendations may already be made for this project, notably so that these agricultural inventories can subsequently be incorporated into bioproduct lifecycle assessments.

3.11.1 THE LEVEL OF GEOGRAPHICAL DETAIL

In the bibliography

Irrespective of the type of agricultural product concerned, there are several sets of inventory data which may be used, including inventories at the national and regional levels, etc. Depending on the specific crop farming practices and climate and soil considerations in each region under consideration, inventory data will differ and result in distinct environmental impacts. Data liable to create the greatest amount of difference between regions includes **agricultural yields, contributions of mineral fertilisers and the quantity of nitrous oxide** (N_2O) emitted in the field (this will depend particularly on contributions of nitrogen and mineral fertilisers, crops, rotation, etc.). However, these parameters are very rarely detailed.

What is more, some studies take only one reference crop for the agricultural phase, without specifying the data or regions used for the calculation, and do not detail processes prior to the industrial stage (use of starch or sugars).

Key issues

The level of geographical detail selected at the agricultural phase may entail non-negligible discrepancies in the overall product results.

Indeed, selecting one region rather than another may make the final results for greenhouse gas emissions vary by an order of magnitude of +/- 10%. Care must therefore be taken in the choice of geographical area to be modelled. In addition, recognized mean values and data sources which are as representative as possible of the zone under study should be used.

Recommendations

The choice of level of geographical detail should depend in large part on availability of data and the purpose of the LCA.

LCA for environmental display / comparative LCA

The use of inventories averaged for the whole of France appears to be appropriate and adequate to establish display building blocks and make comparisons between two products. This approach should be conservative (i.e. it should not simply use the best French region) and should be based on reasoned weighting of the various regions. This is in line with the spirit of LCAs for comparison (with fossil products and for labelling) in which the question generally relates to a product averaged across France as a whole.

If there are specific elements which support using a given supply region (for instance, the operation of a cooperative), the approach may be at the regional level, or even the département scale if the region is too disparate. However, this choice should be properly argued, and the supply base should remain stable over time. Using data with a greater level of detail than the region appears to be more delicate, since the supply basin may vary even at the scale of a cooperative and the robustness of data becomes a limiting factor.

LCAs for the purposes of eco-design

In very specific situations (for instance choosing an assessment for products derived from precision agriculture) or for eco-design LCAs, these limits do not apply and the choice of the level of data will depend on the user and the degree of precision required. The characteristics of a given agricultural region or specific farming mode (intensive, organic, precision) may then be incorporated.

General recommendation

Irrespective of the chosen geographical scale, data should always be from recognized sources and assessed across a sufficiently large geographical area for there to be a mean effect. The data and scales used should be clearly specified in the study in order to ensure optimal transparency. Lastly, mean values by region can be used only for part of agricultural data (contributions from fertilisers, yields, etc), since other variables cannot yet be regionalised due to the lack of a recognized model (e.g. N_2O emissions).

3.11.2 LEVELS OF DETAIL FOR INPUT DATA

In the bibliography

In general, input data is very rarely specified in the studies, making it impossible to identify the items with the highest emissions or assess the impact of the level of detail of data on the overall assessment.

Key issues

In order to illustrate the relevance of the various input data, the following table has been devised; it should be read as follows:

The first column (fossil energy) contains the data required to calculate the consumption of fossil energy due to the agricultural phase. The first cell contains the data required to cover 80% of the impacts (nitrogen/mineral fertiliser and mechanisation), the second cell contains the data to be added to achieve 95% impact coverage (plant protection products, drying and phosphate fertilisers). The third cell contains the data to be added to cover all fossil energy consumption. It should be noted that the energy-based depreciation of equipment and buildings has not been incorporated into this calculation; these items would probably come in the 80-95% range for energy.

Figure 20 – Input data required to calculate various indicators

Share in agricultural total (kg/grain)	Fossil energy	+ Greenhouse Gas	+ toxicity	+ photochemical oxidation	+ acidification	+ eutrophication	+ water consumption
80%	mineral N fertiliser Mechanisation	N2O emissions	Pesticide emissions to soil Trace element emissions to field	P2O5 fertilisers	NH3 emissions	Nitrate emissions to field	Irrigation
95%	Plant protection products Drying P2O5 fertilisers Depredation of agricultural equipment				NOx emissions		
100%	K2O fertilisers Seeds		Air pesticide emissions			Phosphate emissions	

Next, to calculate the other indicators, additional data must be taken into account.

Toxicity can be taken as an example. To cover 80% of impacts, all the data present in the line "80%" from the first column across to the "toxicity" column must be used: mineral/nitrogen fertiliser, mechanisation plus N_2O emissions + pesticide emissions into the soil and trace element emissions.

For the example of acidification and 95% of impacts, data from the first two lines (80% and 95%) must be used, taking all the columns from the first across to "acidification": i.e. the same columns as in the previous example, plus plant protection products, drying, phosphate fertilisers + P_2O_5 fertiliser, NH_3 emissions and NOx emissions.

The data is shown in different colours depending on its origin and reliability. Data shown in black is directly accessible, data in blue is calculated on the basis of the previous level of data and relatively well-recognized emission models, while red indicates data which is difficult to assess and which has been obtained with a high degree of uncertainty.

A number of conclusions can be drawn from this table:

- It can again be seen that the "fossil energy" and, to a lesser extent, "greenhouse gas emissions" indicators are calculated on the basis of known, relatively reliable data (black). The other indicators take into account additional data which is deemed less reliable (red).
- A small quantity of the data to be gathered is sufficient to take into account between 95% and 100% of "fossil energy" and "greenhouse gas emissions" impacts.

Recommendations

The possible level of simplification will play a determining role. As a minimum, we recommend not going beneath the 95% threshold.

For comparative LCAs, modelling should seek to be as complete as possible ("100%"). However, for the purposes of simplification, it is possible to take mean values from the bibliography for some data, rather than the exact details for all products used, for which the available inventories will probably become a limiting factor (active materials, plant protection, nitrates, trace elements).

Recommendation for simplified methodology:

Depreciations are included in ECOINVENT databases for inputs and are therefore taken into account systematically. However, as discussed above, data relating to the depreciation of agricultural equipment is more difficult to calculate. As for the "Biofuels" reference document, it is possible not to take this into account for comparative and labelling LCAs, for the purposes of simplification. However, this data must be incorporated wherever possible and systematically when the LCA is for the purpose of eco-design.

3.11.3 TAKING INTO ACCOUNT FERTILISERS

In the bibliography

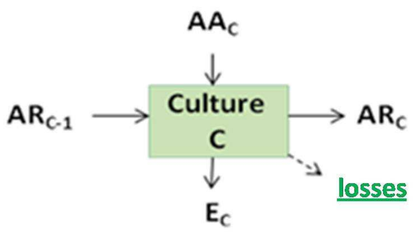
Very little detail regarding the methods for taking fertilisers into account is provided in the studies analysed in the bibliographical phase.

Key issues

Nitrogen/mineral fertilisers account for a large proportion of fossil energy consumption during the agricultural phase. They also have an impact on the potential for eutrophication, acidifcation, toxicity, etc. These contributions to crops occur during rotation, and may therefore have effects on subsequent crops. Consequently, impacts due to fertilisers applied to the plot (leaching, evaporation) may be calculated in different ways with differing results.

Recommendations

We recommend using the same method as that applied in the "Biofuels" reference document set forth below:



Quantity of nitrogen attributable to collected biomass:

E_C + losses = $AA_C + AR_{C-1} - AR_C$

AR represents the nitrogen contained in residues from the previous crop. The AAc flow represents the contributions of mineral and organic nitrogen, Ec represents nitrogen exported by the crop. This simplified assessment uses these magnitudes because they play a determining role in the assessment, but it should be noted that this assessment simplifies reality, because not all transfers of nitrogen between the crop, residues, the soil and the atmosphere have been incorporated. It follows that this assessment is not necessarily balanced for each crop, particularly because atmospheric contributions are not taken into account, and even more so because contributions from the soil have been estimated solely using the previous crop residue parameter.

This calculation method makes it possible to take into account the fact that some crops transfer more nitrogen than others to the following crops. However, the calculation relies on the approximation which assumes that all nitrogen contained in the residues is recovered by the following crops.

3.11.4 N_2O EMISSIONS

In the bibliography

There are a number of models for calculating nitrous oxide emissions during the agricultural phase. Different models are used depending on the study. Sometimes, N_2O emissions have not been incorporated in the absence of a satisfactory calculation model.

Key issues

All of these models contain non-negligible uncertainties as to their results, since N_2O emissions are still the subject of study. The principal methods used are presented in the following table.

Figure 21 – Presentation of various methods of calculating nitrous oxide emissions

Methods	Direct emissions	Indirect emissions
IPCC tier 1	1% of (N supply + N inside the crop residues)	0,8% of leached N (NO3) 1% of volatilized N (NH3)
IPCC tier 2	Adaptation of several factors to the country. *Biofuel study : adaptation of leaching and N from crop residues*	
IPCC tier 3	Use of sophisticated models, with climate, soil properties, cultural itineraries, etc. *Not used at present, lack of robust model*	
Stehfest	0,91% of N supply	Not counted
Skiba	From 0,5% to 1,6% of N supply according to crops	Not counted
DNDC	From 0,8% to 2,9% of N supply according to crops, model	

One example of the degree of variation entailed by the choice of method is presented below, for three different crops:

Figure 22 – N_2O emissions (kg of N_2O / kg of nitrogen contributed) using 4 methods

Crop	IPCC tier 1 (direct + indirect)	IPCC tier 2 (direct + indirect)	DNDC (direct + indirect)	Direct emissions, measures, France
Wheat	3,3	2,7	1,9	2 kg
Corn	4,1	3,3	3,5	?
Rape seed	3,7	2,9	2,7	1 to 2 kg

When this raw data in terms of kg of N2O emitted per kg of nitrogen contributed is incorporated into the total life cycle assessment, it leads to the following discrepancies:

Figure 23 – Discrepancies arising from the use of different methods: examples of rapeseed and

wheat

In total life cycle	Rape seed	Rape seed	Wheat	Wheat
	Non renewable energy	GHG	Non renewable energy	GHG
IPCC tier 1	101%	108%	99%	105%
IPCC tier 1, including N inside the crop residues	103%	110%	99%	104%
IPCC tier 2, including N inside the crop residues	100%	100%	100%	100%
EF for N_2O using DNDC, including N inside the crop residues	100%	98%	100%	92%

These results were obtained assuming that the agricultural share represented 35% of the fossil energy total (FE) and 75% of greenhouse gas emissions (GGE) for rapeseed, and 20% of total fossil energy consumption and 60% of total greenhouse gas emissions for wheat.

Recommendations

By default, we recommend using IPCC tier 1 factors: they are recognized internationally and take into account indirect emissions. As in the "Biofuels" reference document, we suggest that the two adaptations for France be incorporated, relating to leaching and crop residues (which we have designated tier 2 due to the marginal adaptation of certain parameters).

However, it should be emphasised that this method has been selected by default, pending the development of regional emissions factors and/or the development of agronomic and biophysical models.

Furthermore, since N_2O emissions may have a considerable degree of influence on the environmental assessment, the parameters (emissions factors and nitrogen contributions) should be subject to a sensitivity analysis.

3.11.5 CHANGE IN LAND USE (CLU)

Commentaire : Le terme approprié est « Land Use Change (LUC)

In the bibliography

No new elements relating to this topic have appeared since the methodological reference document on "Biofuels" was drafted.

Key issues

Change in land use may have major repercussions on the quality of the environment, depending on the country, region and ecosystem in which it takes place. For instance, the replacement of primary forest by palm plantations causes damage in terms of soil erosion, loss of biodiversity and carbon sequestration.

Recommendations

In the absence of new elements, we recommend following the recommendations published for the "Biofuels" methodological reference document, presented below.

Direct case:

Geographical area	Direct Land Use Change	Accounted in the LCA ?
Europe	Presumed: zero	
North America	High uncertainties	Sensibility analysis, waiting for robust studies. If, in a specific LCA, it is possible to define a Land Use Change scenario, the study must take it into account.
South America		
Asia		

Indirect case:

Geographical area	Indirect Land Use Change	Accounted in the LCA ?
Europe	High uncertainties	Sensibility analysis If, in a specific LCA, it is possible to define a Land Use Change scenario, the study must take it into account.
North America		
South America		
Asia		

3.11.6 SHOULD THERE BE SPECIFIC PRODUCTION INVENTORIES FOR DEDICATED BIOPRODUCT CROPS?

At present, it is not possible to envisage **specific agricultural inventories for the production of bioproducts** (for instance, distinguishing "food corn" and "bioplastic corn" inventories) since such inventories do not exist. Furthermore, few elements are available addressing the issue of specific varieties developed for bioproducts.

However, the following elements of analysis may be supplied. This reasoning applies to a set geographical area and therefore to specific climate and soil conditions.

- **The two determining parameters in crop environmental assessments are yield per hectare and the fertiliser required to obtain this yield.** These two elements are connected (the more nitrogen, the higher the yield) by relatively well-known response functions which are virtually linear between two close production objectives. This agronomic link means that these effects partially offset each other. However, this offsetting is not precise and the varietal effect may have an influence on the response curve.

- **Consequently, the same amount of fertiliser may lead to different yields**

depending on the crop variety. Wheat, because of its breadth of uses, is a crop which presents non-negligible differences in yield per unit of contributed nitrogen depending on crop varieties and purposes (design for a specific yield or level of protein). As a result, for various highly different varieties of wheat, the same amount of nitrogen can generate highly variable yields in terms of grains per hectare, with variable protein contents[8].

- However, in the case of bioproducts, **it is possible that the most suitable varieties are close to varieties already grown for other uses**, since the variety selection criteria are the same (yield in grains/starch for corn, yield in oil for rapeseed, etc). Wheat crops could potentially differ slightly, with varieties selected for their yield in starch rather than the yield/protein ratio.

- This question will require **further study** during the **environmental display database project.** The participating agricultural technical institutes will be able to provide relevant information regarding the existence of properties of crop varieties grown for bioproducts.

Since there is at present no dedicated inventory for specific crops for bioproduct production, **we recommend that for a simplified approach, generic inventories which do not take account of these potential differences** be used. However, if dedicated inventories are developed, they should be used preferentially if the agricultural resources come from these dedicated crops.

[8] See "Environmental analysis of intensity level in wheat crop production using life cycle assessment", R. Charles et al., 2004.

3.12. SUMMARY: THE IMPACT OF THE PROPOSED SIMPLIFICATIONS

3.12.1 KEY ISSUES

Depending on the objectives of the LCA, it is possible to simplify calculations, data or hypotheses. Options for simplifying calculations have been discussed in the recommendations of each methodological point raised.

In order to estimate the impact of these simplifications, the calculation below offers an estimation relating to the simplification proposals for the 3 products studied. In addition to quantifying the global impact of the proposed simplifications, it makes it possible to identify the discrepancy that would be entailed (some complete LCA data corresponds in fact to BIO hypotheses) by applying these simplifications to the three products under study.

However, it is important to note that since BIO did not perform these LCAs itself, it does not have complete visibility as to other simplifications or cut-offs which may have been made previously when the LCAs supplied were performed. Similarly, part of this test is approximate, since real plant and equipment data and real site supply basin data was not gathered.

3.12.2 TESTS

A calculation was performed by applying all the simplifications proposed above, in order to compare them to the same calculation performed with no simplification. The proposed simplifications were as follows:

- Choosing an averaged inventory for France rather than a regional inventory
- Not taking into account the transport of minority inputs (less than 1% of the final product mass)
- Not assigning allocations for minor co-products (minor in terms of mass and value)
- Not taking into account depreciation for bioproduct production sites
- Not taking into account greenhouse gas emission and carbon sequestration dates.

The simplifications tested for **isosorbide** were as follows:

Table 14 – Geographical scales tested for isosorbide

Crop	Large-scale	Smaller scale
Wheat	Mean, France	Weighting across 3 agricultural regions (Picardie, Champagne Ardennes and Haute Normandie)
Corn	Aquitaine region	Smaller supply basin in Aquitaine

Table 15 – Other simplifications tested for isosorbide

Simplification	Possible	Application
Input transport	yes	Transport disregarded
Allocation for minor co-products	yes	No minor co-products
Depreciation	yes	Calculation with and without depreciation of structures
Greenhouse gas emission date	yes	Calculated (10 years in landfill with no emissions, then emissions distributed over 10 years)

NB: Depreciation for structures was calculated using a simulation due to a lack of actual data. Theoretical calculations may be performed with and without these depreciations, but it should be borne in mind that these are values which are not specific to actual isosorbide production sites.

The simplifications tested for **Materbi** were as follows:

Table 16 – Geographical scales tested

Crop	Large-scale	Smaller scale
Corn	Aquitaine region	Smaller supply basin in Aquitaine
Soya	Mean, Brazil/USA	Average, USA

The same simplifications as for isosorbide were performed.

The simplifications tested for the **biolubricant** were as follows:

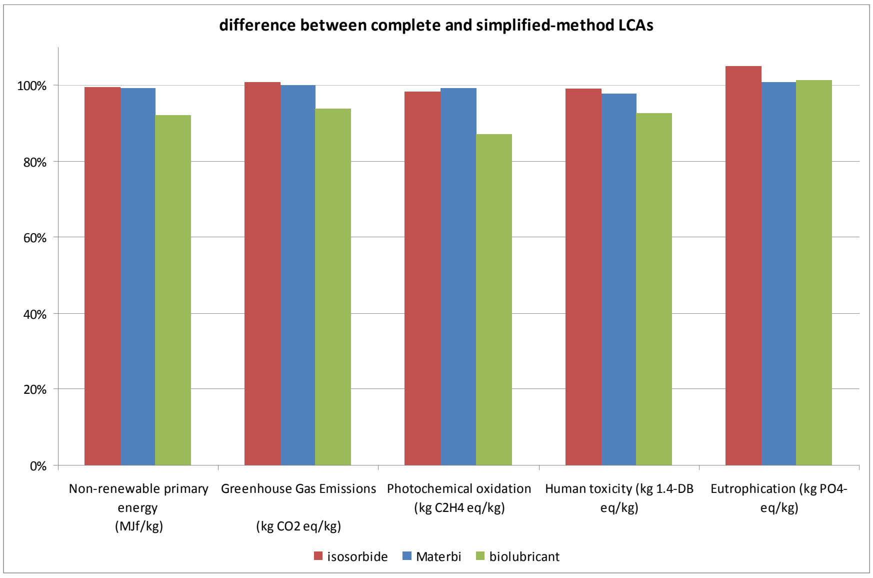
Table 17 Geographical scales tested

Crop	Large-scale	Smaller scale
Sunflower	Mean, France	Weighting across 3 French agricultural regions (Aquitaine, Centre and Midi-Pyrénées)

Table 18 – Other simplifications tested for biolubricant

Simplification	Possible	Application
Input transport	yes	Transport disregarded
Allocation for minor co-products	yes	No minor co-products
Depreciation	yes	Calculation with and without depreciation of structures
Greenhouse gas emission date	yes	End of life is incineration only, therefore no calculation.

Figure 24 – Simplification test results



The main differences between the total result and the results using simplifications arise with respect to the agricultural stage. The change of scale between averaged inventories and inventories relating more closely to a limited supply basin (averages for agricultural routes for three regions) has the greatest impact on bioproduct assessments. This proposed simplification involved selecting a single national inventory without seeking to trace the origin of the agricultural raw materials, making it possible to disregard any fluctuations in supply. It has the advantage of being more stable over time, while a choice of regional inventories based on actual supplies is bound to vary depending on the supply basin and render data gathering more complex.

Commentaire : A remplacer par « Itineraries »

It should also be noted that the discrepancy arising for the biolubricant needs to be seen in context:

- Sunflower oil often comes from a large number of regions, whereas this simulation is based solely on three regions chosen at random (which is not the case in actual fact for this product);
- Comparative and labelling LCAs (for supplying an averaged inventory to be used by downstream companies only) are often designed with general use in mind, justifying the use of a mean value for France: they are seeking to identify the mean value for this generic product

process compared to the corresponding mean value for another product process.

- Gaps in knowledge as to the N_2O emission factor means that at present, it is impossible to regionalise these emissions, despite them being a major item in terms of CO_2 emissions for agricultural inventories. The same applies to nitrate leaching and what happens to the pesticides used. Given the existence of data which is valid in terms of aggregation, it appears reasonable not to claim any greater degree of regionalisation.

Depreciation of plant and equipment also accounts for a few percent in the biolubricant assessment, for which this item had the greatest impact. It has been deemed that these depreciations may be disregarded in the case of comparative LCAs, inasmuch as this simplification, if applied to all the product processes being compared, does not create a significant difference between them.

For the sake of completeness, it should be noted that with regard to the actual use of the three bioproducts tested here, whether or not biogenic carbon sequestration or the emission date is taken into account does not affect these assessments. Indeed, this effect can only be discerned after 10 years or more of sequestration. In this respect, and as has been seen for the question of depreciation, it should be borne in mind that this simplification would be applied to all the products, thus all equivalent products will undergo similar changes, thereby reducing the discrepancies between products which could have been introduced by this simplification.

3.12.3 RECOMMENDATIONS

One of the purposes of this study was to identify possible simplifications designed to facilitate calculations and data collection wherever these could be envisaged.

The above tests show that an estimation of the cumulative effect of the simulations suggests a discrepancy between "complete" and "simplified" LCAs which can be described as minor (less than 2-3%) for 2 out of the 3 products studied. The discrepancy appears to be greater for the biolubricant because it is more sensitive to depreciation and agricultural supplies. However, as has been seen, this discrepancy has probably been overestimated because of a simulation of the actual product process supply basin which is not very realistic, and can be seen as less important as regards comparative LCAs, for which depreciation can justifiably be disregarded

This test brings together all the suggested simplifications. Even if it is hypothetical with regard to certain elements, it indicates discrepancies between "complete" and "simplified" LCAs which remain acceptable. The cumulative impact of these effects most probably remains within the bracket of accuracy which can be claimed by an environmental assessment of this nature. Consequently, it confirms the possibility of envisaging a number of simplifications when performing LCAs, provided these are properly overseen and verified.

4. THE PRODUCT ASSESSMENT ('BILAN PRODUIT')

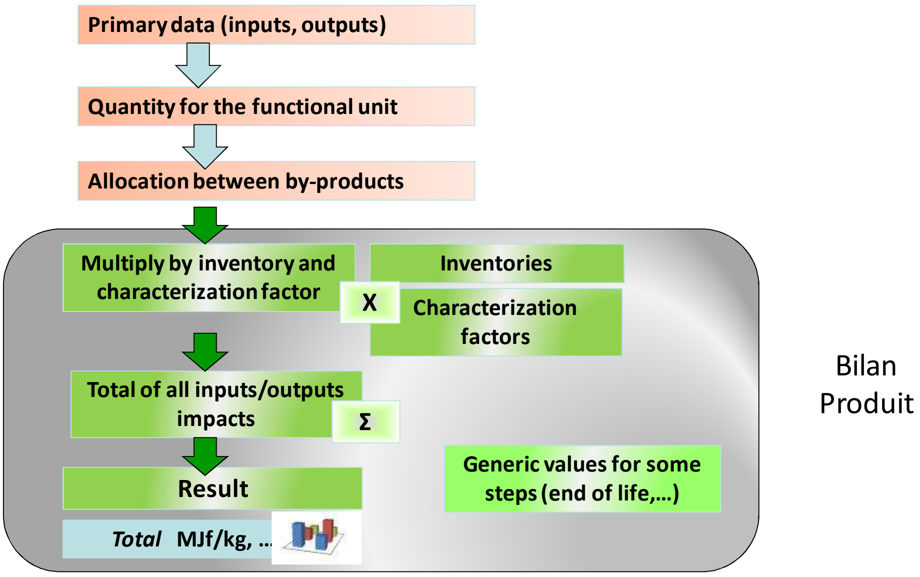
The Product Assessment ("bilan produit") is a resource created by ADEME in partnership with the University of Cergy-Pontoise and Ecoinvent centre (data version 2.0).

During the steering committee meeting of June 19, 2009, it was stated that the work to be done on this question consisted in identifying the missing data and elements with regard to future integration of bioproducts into this worktool.

4.1. PRESENTATION OF THE PRODUCT ASSESSMENT

The Product Assessment worktool is a calculation resource which allows the product to be studied to be modelled simply, taking into account the principal stages of its life cycle: the materials of which it is made up, manufacturing procedures, means of transport and sources of energy.

The worktool provides users with life cycle inventories for a broad range of products, for the purposes of performing an LCA intended for eco-design.



4.2. ADJUSTING THE PRODUCT ASSESSMENT TO BIOPRODUCTS

Discussion of incorporation of bioproducts into the Product Assessment worktool must make use of work by ADEME concerning improvement of this resource.

The following paragraphs outline a number of points for improving the Product Assessment in order to incorporate bioproducts.

Addition of missing inventories

The existing Product Assessment lacks many of the essential inventories required to perform bioproduct LCAs: **agricultural products**, **chemical intermediaries**, **pollutant flows** specific to the industrial and agricultural stages (VOCs, pesticides, etc.), production procedures, etc.

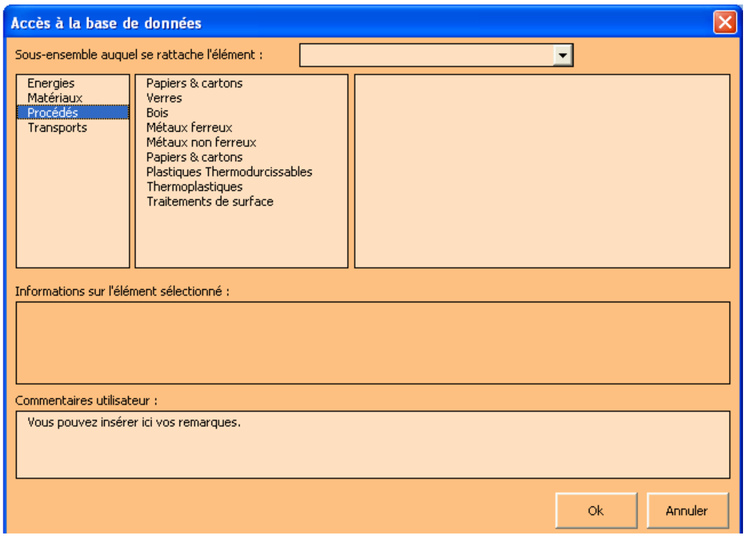
To complete the list of inventories available in the Product Assessment, a uniform, robust and relevant construction method must be implemented in order to ensure consistency with existing inventories made available from large-scale databases (particularly ECOINVENT).

For instance, **unit inventories for the principal agricultural products within France and in other countries** (solely the principal import countries, in order to simplify this approach) need to be estimated. Different levels of detail could be suggested to users, initially by suggesting a mean value for France, followed by mean values for each region ("1 kg wheat, France", "1 kg wheat, Haute Normandie", "1 kg wheat, Centre", etc), and mean values for each exporting country ("1 kg soya, Brazil", "1 kg soya, United States", etc) or by crop type where appropriate (energy crops, for instance).

In terms of **chemical reagents and inputs**, it will be important to incorporate as many existing products (already present in major inventory databases) as possible. Verification using the bibliography followed by discussion with the principal industrial players should enable adequate coverage of products used to be ensured.

Similarly, **pro forma procedures** exist in the current version of the Product Assessment but are limited in number and focused on only some categories of materials.

Figure 25 – Input screen for materials and procedures, Bilan Produit 2008



▸ Integrating metadata with these inventories

When an LCA is performed, it is important to have specific information about the unit inventories used. This information, which may appear to be ancillary, is in fact of prime importance to inform calculation hypotheses and any approximations which use of this inventory may entail as compared with the actual product in question. Practically speaking, this transparency means providing information to the user on three different levels:

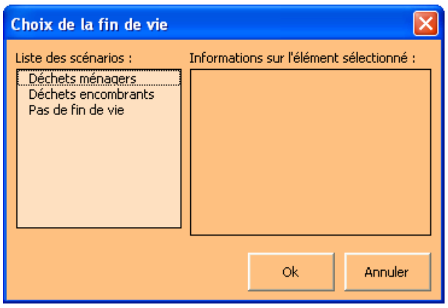
- Supplying the exact name of the product modelled by the inventory (specifically including its concentration in the case of chemical products);
- The precise source of this inventory (this already exists in the worktool) and a link to further information;
- Some explanatory details concerning this inventory: the date it was drafted, the assumed valid geographical coverage, the type of procedure taken into account where more than one exists, the humidity level of the final product if it is available with different levels, explanations on the possibility of extrapolating this inventory, for instance to similar, more diluted products, incorporation or otherwise of depreciation, etc.:

This work is time and energy-consuming, but is important in terms of providing the transparency and confidence required for such complex calculations.

Verification of end-of-life parameters

The Product Assessment offers three possible end-of-life scenarios: household waste, bulky waste and no end of life. It follows that these calculations cannot incorporate the particularities of bioproducts such as the proportion of biogenic carbon in end-of-life emissions.

Figure 26 – Waste type selection menu, Bilan Produit 2008



This is an important property of bioproducts which should be reflected in environmental impact studies of these products. A module could be envisaged making it possible to enter products' biogenic carbon content. Offering other, more specific end-of-life types (incineration, landfill, etc) is also necessary in order to enable users to provide closer modelling of this stage. Still another solution would be to establish specific end-of-life scenarios for bioproducts. However, given the breadth of diversity which exists among bioproducts, this solution appears more complex to implement.

Lastly, investigation of a simplified, generic recycling module would be one way of approaching the possible impacts in such approaches.

Updating the characterization methods used (USETOX and other methods)

Indicators are calculated using the CML method. The following impact indicators are obtained:

Indicators calculated in the Product Assessment
Non-renewable energy consumption (mJ equivalent)
Resource consumption (kg Antimony Sb equivalent)
Greenhouse effect, 100 years (kg CO_2 equivalent)
Air acidification (kg SO_2 equivalent)
Water eutrophication (kg PO_4^{---} equivalent)
Photochemical pollution (kg C_2H_4)
Aquatic ecotoxicity (1.4-DB equivalent)
Human toxicity (kg 1.4-DB equivalent)

As we have seen previously, some of these indicators are less robust than others, and flows may be aggregated according to different methods (particularly as regards airborne and waterborne emissions). It may be appropriate to call some of these indicators into question and perhaps choose more robust and recent calculation methods. The **USEtox method** in particular appears to be more robust than CML for calculating the impact of airborne and waterborne flow emissions. Pending better stabilisation of USETOX as a method to be used, the proposal of multiple methods which users can easily compare would be one way of setting the results of an approach in perspective. For instance, a sensitivity analysis could be devised to compare the results of USETOX to other toxicity assessment methods, such as the critical volume method, RECIPE or Impact 2002+.

4.3. Complete overhaul of the Product Assessment

The direct improvements required for the incorporation of bioproducts into the Product Assessment have been set out above.

ADEME's planned overhaul of the Product Assessment will however provide an opportunity for broader changes in the construction and operation of the worktool to be made. These more in-depth changes to the worktool may provide more sophisticated improvements for performance of such assessments.

Three major areas of work are emerging:

- Facilitating the work of the user
- Securing this work
- An increased degree of precision with a view to comparative and labelling type assessments

Fulfilling these objectives requires more than simply adjusting some parts of the existing worktool: it involves carrying out a reorganisation of the way the tool works. However, it is already clear that these three points are an attempt to bring the tool into the world of LCA performance tools. One of the key ideas of the Product Assessment is to remain accessible to non-specialists. Keeping in mind this **need for balance** between clarity, simplicity and any increased complexity of the worktool caused by these improvements is therefore important.

4.3.1 FACILITATING THE WORK FOR USERS

The worktool does not make it possible for users to perform a relatively complicated LCA. It makes inventories available in a user-friendly environment, but does not facilitate dealing with questions such as allocations, functional units, or the links between varied and numerous stages.

Some methodological questions could be the subject of dedicated modules, featuring advice and a clearly-defined, uniform method. In particular, it would be extremely useful to guide users step by step through allocation calculations. To achieve this, a specific tab for co-products and allocations could be added to the worktool.

In a further review of the worktool, **module-based operation** structured by users could be devised. Each module would correspond to a process stage with its inputs, their transport, output co-products, pollutant emissions and the co-product allocation rules to be implemented. Users would then create the subsequent module which would draw on one or more previously created modules, and so on. This would make it much simpler for users to perform assessments drawing on more than one reagent to be modelled upstream and several processing stages downstream from the material. A visual, ergonomic presentation would help users apprehend each module. These modules can also incorporate specific lines for products which have not been taken into account, or pre-recorded type values suggested to users (typical chemical product supply transport, etc.).

Similarly, certain methodological options may also have a significant impact on the total assessment. **Sensitivity analysis** makes it possible to assess this impact and validate or qualify the methodological options adopted. A sensitivity analysis assistance module could be added to the worktool to encourage and facilitate this approach. For instance, this would be useful for selecting allocations and/or characterization methods.

Lastly, the recommendations from this study could be presented in the form of a "Bioproduct Methods Guide", setting out details of the method and possible simplifications (functional unit, biogenic carbon sequestration, etc). Some could even be incorporated in pre-programmed form in specific "bioproduct" modules (if the quantity of imports is lower than a given threshold, transport data is not a factor of exclusion).

4.3.2 SECURING THIS WORK

The existing Product Assessment does not provide information about the methodological choices made by users when calculations are performed. For reasons of transparency, it should be possible to specify these choices when the worktool is used.

As explained above, it would be appropriate to set up operation based on specific modules in order to maintain a clear, guided record of assessment performance. This would involve users specifying the flows they have chosen to disregard (and perhaps even the approximate quantity of these flows), the types of co-product allocation, and what kinds of depreciation have been disregarded and/or taken into account.

Printing a summary sheet for the model, with details of each module, its inputs, methodological choices and how they are linked would constitute a communications resource which would then facilitate verifications and discussions with a greater number of individuals (colleagues, technical experts, management, etc.).

4.3.3 AN INCREASED DEGREE OF PRECISION WITH A VIEW TO COMPARATIVE AND LABELLING TYPE ASSESSMENTS

If the Product Assessment's purpose relates to comparison between products or environmental display on the basis of the worktool results, other more technical points need to be discussed.

What degree of freedom should be left to users?

In order to better reflect product particularities, whether in terms of their production stage, end of life or some other issue, allowing users to employ their own data for a certain number of items could be envisaged.

For instance, for agricultural inventories, it has been shown that certain types of data have a predominant effect on the principal impacts of the entire production cycle: yield, fertilisers and the nitrous oxide emissions calculation model. Data could be suggested by default, using values from the selected inventory (mean for France, regional mean), leaving users the possibility of changing some data according to their products' specific values. However, such a degree of freedom would raise the issue of transparency with regard to calculations and the verification/validation of the data entered.

Similarly, during the industrial stages, process and energy production inventories are calculated on the basis of performance values defined by the database (particularly for boiler performance). However, these values may vary depending on the installation and thereby have a direct effect on the relevant inventory. Users employing particularly efficient processes or machines may wish to adjust performance values and therefore the inventories being used.

Using the product assessment for comparisons

Comparison between several equivalent products (and, for the specific case of bioproducts, between fossil-origin products and their renewable-origin equivalents) also requires work to be done on fossil product processes. This specifically includes:

- Defining an official, coherent allocation rule for refinery co-products;
- Offering examples of corresponding fossil products and the relevant, completed calculations;
- Enabling users to model the corresponding fossil product using selected, up-to-date inventories.

More generally, users may wish to compare their values with other products or bioproducts. This need is legitimate and should even be promoted with a view to emulation and communication. While this objective may appear overambitious at this early stage, it appears achievable in the long term if the worktool provides the following elements:

- Securing calculations in terms of the methods and unit inventories used: this involves having assessments estimated using similar approaches which are therefore comparable.
- Validation of these calculations by a specific system of visualisation, control, etc;
- Anonymous, averaged communication of results for each product range, aggregating several assessments performed by other users wherever possible (see following point).

- **Suggesting available, ADEME-AFNOR-validated products in the Product Balance, in order to serve as building blocks in display construction**

Once the Product Assessment has been reviewed and circulated, it could be worthwhile collecting the results obtained by Product Assessment users and validating their methods and results in order to integrate these products in the Product Assessment.

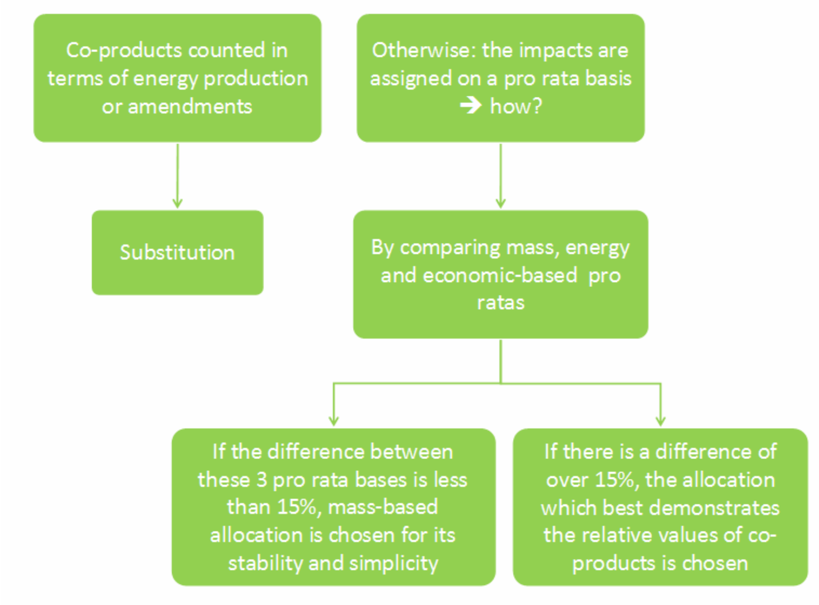
For instance, an industrial player performing a Product Assessment for glycerol could have their initiative validated by ADEME-AFNOR; the results would then be available in the Product Assessment inventory database, so that other players could then use them to construct the assessment of their own product, or compare their values.

These various points open up as many avenues of investigation to be explored for the integration of bioproducts and improvement of the Product Assessment worktool. They could also contribute to the work done by ADEME and the Eco-design and Sustainable Consumption Department on overhauling the Product Assessment.

5. CONCLUSION

The work undertaken in this study has led to the formulation of recommendations, which are either transverse or specific depending on the primary purpose of the LCA.

These recommendations are presented in summary form in the following table.

Question	Recommendations		
	Eco-design	Environmental display	Comparative LCA
Scope of study	Complete LCA	Depending on study requirements	
Functional unit	Simple unit: For instance, 1 kg of product		A more refined functional unit where relevant
Impact indicators	Greenhouse gas emissions, non-renewable energy consumption + toxicity indicators used with caution		
Quantified flows, sources of data	Systematically specify sources of data and how representative it is		
Inventories	Opt for recognized databases, and specify the inventories used systematically		
Allocations			
Timescale and carbon	Not to be taken into account given the existing state of knowledge.		

Question	Recommendations		
	Eco-design	Environmental display	Comparative LCA
sequestration			
Cut-off rule	Maximum cut-off threshold of 5% for all impacts.		
Depreciation	Take depreciation into account wherever possible.		
Agricultural phase			
Level of geographical detail	National or regional inventory depending on the user	National mean inventories, except if elements justify the use of the regional level	
Level of detail of input data	Do not go below a simplification threshold of 95% of impacts		Aim for exhaustive modelling
Take fertilisers into account	Same method as for biofuels reference document: take crop residues into account.		
N_2O emissions	Use IPCC tier 1 factors by default, with certain factors adjusted to the country in question		
Change of land use	Use the same method as for the biofuels reference document, clearly distinguishing direct and indirect change.		

It should also be emphasised that the choices made by authors of LCAs should be expressed with as great a degree of transparency as possible in order to facilitate comparison between the results of different studies.

Where no rule exists for the format in which results should be presented, transparency as regards hypotheses and methodological choices made is a crucial element. The environmental assessment should be presented in relation to life cycle stages, and clearly specify the flows or items which have not been taken into account in calculations. The ISO 14044 standard stipulates that "results, data, methods, hypotheses and limitations shall be transparent and presented in a manner which is sufficiently detailed to enable readers to understand the complexities and compromises inherent in LCAs".

Lastly, as has been mentioned a number of times in this report, certain methodological aspects await the results of national or international working groups: the ADEME-AFNOR platform on the choice of indicators and characterization methods, UNEP-SETAC for the water indicator, ADEME for the construction of databases, particularly agricultural databases, etc.

6. APPENDICES

6.1. DETAILS OF IMPACT CATEGORIES

► GLOBAL WARMING INDICATOR

- **Greenhouse effect**

This indicator characterizes the increase in mean atmospheric concentration of substances of anthropic origin such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These emissions disrupt the balance of the atmosphere and contribute to global warming. The unit used is the kg CO_2 equivalent.

►INDICATORS OF IMPACTS WHICH CONTRIBUTE TO THE EXHAUSTION OF NON-RENEWABLE RESOURCES

- **Non-renewable energy consumption**

This covers all sources of energy which are extracted from natural reserves (coal, natural gas, oil and uranium). The unit is the mJ.

- **Natural resource exhaustion**

This indicator quantifies the extraction of natural resources which are considered as non-renewable, i.e. consumed faster than they can be formed naturally. The unit used is the kg Sb equivalent (antimony).

- **Water consumption**

This indicator enables water consumption to be assessed. The unit used is the m^3.

►INDICATORS OF IMPACTS AFFECTING HUMAN HEALTH

- **Ozone layer depletion**

This potential impact is caused by complex reactions between stratospheric ozone and compounds such as CFCs. Thinning of the ozone layer has effects including less effective natural filtering of ultraviolet radiation. The unit used is the kg CFC-11 equivalent.

- **Photochemical oxidation**

This indicator characterizes impacts due to organic substances. It is expressed in kg C2H4 (ethylene) equivalent. It expresses a number of complex reactions between volatile organic compounds and nitrous oxides which contribute to the formation of low-atmosphere ozone. Tropospheric ozone has harmful effects on human health and plants.

This impact category takes into account the formation in the troposphere of certain reactive chemical compounds known as photo-oxidants, specifically including ozone O3, through the action of the sun on certain primary pollutants.

In particular, photo-oxidants may appear in the troposphere due to the influence of ultraviolet radiation, photochemical oxidation of volatile organic compounds (VOCs) and carbon monoxide CO, in the presence of nitrous oxides (NOx). Ozone O3 and, to a lesser degree, peroxyacyl nitrates or PANs, are considered to be the principal photo-oxidant compounds. The full range of effects that this type of pollutant may potentially have is relatively poorly understood. For instance, ozone O3 has effects on human health including irritation of the eyes, respiratory tracts and mucous membranes. These problems may become much more serious for individuals suffering from respiratory problems. This category of impact is also known as "smog formation" or "summer smog".

Volatile Organic Compounds (VOCs) are the principal causes of this effect. However, NOx acts as a catalyst.

This question is often apprehended by means of a synthetic indicator known as Photochemical Ozone Creation Potential (POCP). This value, measured experimentally for each molecule, is expressed as the effect that x kg of ethylene (C_2H_4) would have, which is why it is expressed in kg ethylene equivalent.

Table 19 – Indicative list of highly-reactive volatile organic compounds

Isoprene	1.3-Butadiene	All alkanes	Toluene
m-Xylene	Propene	Acetaldehyde	Methyl-Cyclopentane
Ethene	Formaldehyde	Xylene	Ethanol

- **Human toxicity**

This impact category relates to the effects of substances which are toxic for human health. These substances may be present both in the environment and in the workplace. The range of molecules, their modes of action and the damage caused depending on exposure, the effects of indirect exposure and cocktail effects represent such a degree of complexity that this impact category is one of the most difficult to model. Consequently, in general, the results supplied should be seen as orders of magnitude, and differences should be observed for a number of factors before a real difference in terms of impact may be inferred.

Table 20 – Principal families of toxic molecules

Family	Examples
Metals, metal ions and other metallic compounds	Arsenic, mercury, chromium, antimony, etc
VOCs	Aldehydes, benzene, dichlorobenzenes, 1.3-butadiene, etc.
Other atmospheric pollutants	NOx, SOx, etc.
PAHs	Pyrene, naphthalene, tephenyl, etc.
Particulate Matter (PM)	<2.5 microns, < 10 microns, etc.
Other toxic molecules (particularly carcinogens)	Pesticides, naphthalene, toluene, chlordane, etc.

► INDICATORS FOR IMPACTS WHICH AFFECT THE QUALITY OF ECOSYSTEMS

- **Aquatic and terrestrial ecotoxicity**

This indicator makes it possible to assess eco-toxicity. It characterizes the potential risks arising from the presence of chemical compounds within a specific ecological system. The unit used is the kg 1.4 DB (DichloroBenzene) equivalent.

- **Terrestrial acidification**

This indicator characterizes the increase in the quantity of acidic substances in the lower atmosphere. These emissions are responsible for acid rain, leading to the deterioration of certain forests. The compounds which contribute to this phenomenon include the following: SO_2, NOx, NH_3, HCl, HF. Acid precipitation affects materials, forest ecosystems and freshwater ecosystems. This indicator is expressed in kg SO_2 equivalent.

- **Aquatic eutrophication**

The introduction of nutrients in the form of phosphate or nitrogen compounds disrupts ecosystems by favouring the proliferation of certain species (microalgae, plankton, etc.). This effect may lead to a drop in the oxygen content of the aquatic medium, with significant repercussions on aquatic fauna and flora. The unit used is often kg PO_4^{3-} (phosphate) equivalent. The table below offers impact factors for a number of molecules using the approach adopted by the CML model.

Table 21 – Characterization factors for molecules with eutrophication potential.

Molecules	Emission medium		kg PO_4^{3-}eq
Phosphorus	air, soil, water	kg	3.06
Phosphate	water	kg	1
phosphoric acid	air	kg	0.97
Nitrogen	Soil, water	kg	0.42
Ammonia	air	kg	0.35
Ammonia ion	water	kg	0.33
Nitrous oxides	air, water	kg	0.13
Nitrate	water, air	kg	0.1
Nitrite	water	kg	0.1
COD (Chemical Oxygen Demand)	water	kg	0.022

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6.3. GLOSSARY

LCA Life Cycle Assessment

CLU Change of land use

CML Centrum voor Milieukunde Leiden: University of Leiden Centre which has developed a VOC characterization model featuring impact factors for various environmental indicators

NMVOC Non-Methane Volatile Organic Compounds

COD Chemical Oxygen Demand

FE Fossil Energy, sometimes used inaccurately to refer to "non-renewable energy"

GG Greenhouse Gas.

IPCC Intergovernmental Panel on Climate Change.

NG Natural Gas

PAH Polycyclic Aromatic Hydrocarbon

ICPE Specific Installation Classified for the Protection of the Environment (French classification

mJe Megajoule of electricity: electrical energy consumed

mJf Megajoule of non-renewable energy

N2O Nitrous oxide: a powerful greenhouse gas emitted mainly by farm land, animal faeces and the combustion of fossil fuels.

LHV Lower Heating Value

GWP Global Warming Potential: describes the impact of a gas in global warming.

tkm Tonne x kilometre: a widely-used unit in LCA which describes transporting a given mass over a set distance.