PRACTICAL RECOMMENDATIONS FOR THE ENVIRONMENTAL ASSESSMENT OF BIO-BASED CHEMICAL PRODUCTS

Executive summary

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INTRODUCTION

Plant-based chemistry is an innovative sector that represents a **real opportunity for the development of new solutions based on biomass**. It is an important pillar of the more general concept of "Sustainable Chemistry" or "Green Chemistry".
The Association Chimie Du Végétal is **the first and only European association gathering all sectors implicated in the plant-based chemistry** (agro-resource producers, chemical manufacturers, formulators, …).

In 2020, the National Low-Carbon Strategy defines a trajectory for reducing greenhouse gas emissions up to 2050. Representing 25% of the industry's total emissions, the French chemical industry is committed to reducing its greenhouse gas (GHG) emissions by 26% by 2030 compared to 2015 (i.e. 5.7 MtCO2eq, at constant production).

Life Cycle Assessment (LCA) is the **reference method** for assessing the **environmental impact** of products (goods or services). **The Association encourages the use of LCA**, which positions itself as the reference method for the evaluation of environmental impacts of products. LCA, however, and especially that of bio-based raw materials, raises a number of **specific issues** that are currently not resolved in a consensual manner.

The purpose of this guide is to provide a consolidated and harmonized methodology for the environmental assessment of bio-based chemicals according to LCA methodology, in order to promote the environmental performance of these products.

The present document consists of **23 summary notes** that present the main points addressed in the complete guide, ***"Practical recommendations for the environmental assessment of bio-based chemical products"*** commissioned by the Association.
The guide covers in particular :

- Methodological choices when evaluating biobased products
- Impact categories to be covered in order to suggest a relevant environmental assessment
- Key information to be provided when communicating LCA results

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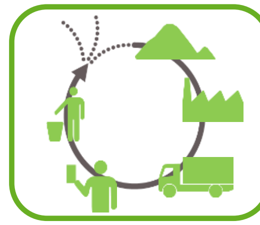
SUMMARY NOTE N° 1

LIFE CYCLE



BACKGROUND

- The ISO 14044 standard defines the life cycle as **consecutive and interlinked stages of a product system**, from raw material acquisition or generation of natural resources to final disposal.
- However, sometimes studies are not considered throughout the entire life cycle but from cradle to factory gate, especially in the case of **intermediate products** whose **use and end of life can greatly vary**.

- **Some stages of the life cycle are difficult to assess**, and not directly accountable to one product, for example, consumer displacement, impacts related to R&D services or an enterprise's marketing.

Issue:

➢ **Which phases of the life cycle must be considered in an LCA?**

STATE OF THE ART

- All documents specify that **a maximum of life cycle stages** must be taken into account, including the end of life.
- Data created in the project AGRIBALYSE3.0® are « Cradle to Farm Gate » data. The draft standard (Pr EN 16760, 2014) provides a framework for the use of « Cradle to Gate » LCA results : they **can be used for comparison only after a full assessment of the comparability of the product's downstream environmental impacts.**
- In the PEF (2013/179/EU:, n. d.; European Commission 2021) and in The report 'Product Carbon Footprint Guideline for the Chemical Industry' of Tfs, 2022 : it is stated that any exclusion of supply chain stages must be **explicitly justified and reviewed**, and **its impact on the final results examined**.
- There is no clear consensus on the life cycle stages to exclude. However, the commonly used practices are the exclusion of commuting and other phases on which allocation is difficult (e.g. administration, R&D, marketing, …).

PRACTICAL RECOMMENDATIONS FROM ACDV

It is recommended wherever possible to **make a comprehensive analysis of the entire life cycle of the product**, but also to **offer, by communicating the LCA results, the impact results per unit of outgoing product from the factory. The end-of-life stage can have a major impact** on certain indicators, End-of-life modeling can therefore be crucial in certain cases.

The **chosen scope** must be **justified according to the study's objectives:**

- The cradle to grave perimeter makes it possible to compare products that are different but fulfil the same function.
- The cradle-to-gate perimeter is of interest from a business-to-business (B2B) communication point of view throughout the value chain, by providing impact results to customers and users of the intermediate product. In this case, communication shall fulfill good practices detailed in SUMMARY NOTE N°22. This scope of analysis also makes it possible to compare identical products from different origins; as the downstream phases of transport, use and end-of-life are identical, a cradle-to-gate analysis is sufficient in this case.

In any case, it is interesting to assume a given application in an eco-design rationale, by realizing a cradle to grave analysis.

SUMMARY NOTE N°2

FUNCTIONAL UNIT

BACKGROUND

- The functional unit is a **common unit** serving as reference to express the environmental performance of a product. It quantifies the results of an LCA study compared **to the service.**
- To compare bio-products to their fossil equivalent, it is necessary to draw upon **equal provided service**, taking into account the eventual differences in properties.

Issue :

➢ **What functional unit is to be used for the biobased product evaluation?**

STATE OF THE ART

The studied references are relatively consensual on the functional unit to be used. The functional unit (FU) deals with the provided service of a finished product: km traveled, mL of coffee, food portion, … For intermediate products, the simplest and most coherent FU is the **product's mass or volume** (e.g. kg, m^3).

The references provide several specifications and recommendations for the FU:

- Use kg of dry material (Pr EN 16760, 2014)
- Specify the choices made (kg of dry material, kg of raw material, …) (ADEME, 2009) (NF EN ISO 16760 2015)
- The finished product is generally considered bare (without packaging)
- For a comparative LCA, it is usually necessary to refine the FU (ADEME, 2009)

Whatever the chosen FU, it is crucial to clarify whether it is dry weight, gross weight, …

PRACTICAL RECOMMENDATIONS FROM ACDV

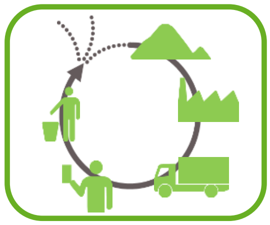
It is recommended wherever possible to analyze the impacts results according to two types of functional unit:

➢ **Functional unit oriented to the service provided** by the product, in the case of cradle to grave analysis

➢ **Functional unit simplified by unit mass of dry material outgoing from the factory** (specifying the moisture content in the product, as well as the inclusion or not of conditioning).

SUMMARY NOTE N°3

QUALITY OF GENERIC DATA



BACKGROUND

- Life Cycle Inventories (or LCIs) **compile the inputs and outputs required for a given product system** throughout its life cycle. Based on ISO standards, they are the basis for all life cycle analyses.
- These inventories can then be published in public or private **databases**, which each integrate **different modeling choices** and **datasets of different representativity**.
- **The choice of the inventory database influences the final result** and is the source of a significant part of the possible variability between different studies.

Issue :

➢ **Which database is the best for generic secondary data?**

STATE OF THE ART

There are several data standards:

1) ISO 14040 and 14044 standard data
2) ILCD and ISO 14040/14044 standard data
3) EF, ILCD and ISO 14040/14044 standard data

The PEF guideline recommends first using databases compatible with the EF standard, then databases compatible with the ILCD data standard. However, the EF 3.0 database is currently under-supplied compared with other generic databases such as ecoinvent, is only available in aggregate format ("black box" data) for the time being, and is not supported by SimaPro. The EF 3.1 database is currently being developed. It should be supported by SimaPro and available in 2023 ("Environmental Footprint Database" n.d.).

The other references consulted do not offer **quantitative requirements** for the quality of generic data to use. They propose to use **LCA reference databases:** ecoinvent, AGRIBALYSE3.1®, WFLDB 3.5, Agri-footprint 5, LCDN node platform, USLCI,…
Nevertheless, the question of the **quality of these inventories** remains regarding data **on the upstream farming**, and an eventual prioritization of available databases.

PRACTICAL RECOMMENDATIONS FROM ACDV

➢ The generic data quality depends on the chosen database and its relevance on the studied system.

➢ Wherever possible, the practitioner must analyze and compare the different LCIs from the databases he/she has available. This **comparison allows an evaluation of the differences between data, and helps in choosing the most relevant LCI.**

➢ The use of **large, homogenous and recognized databases** by all LCA practitioners (such as ecoinvent or AGRIBALYSE3.1®) helps avoiding any criticism on the subject.

➢ Concerning the databases provided in terms of agricultural production LCI, it is important to note that the **ecoinvent, AGRIBALYSE3.1® and World Food LCA databases** are the most comprehensive on the **inclusion of agricultural emissions and infrastructure.**

➢ The scope of the inventory and its age (over 10 years) indicate that Dk Food LCA database should be used with caution.

QUALITY OF SPECIFIC DATA

BACKGROUND

- Similarly to generic data, specific data are **of paramount importance in the final result**. They are source of a **significant part of the variability** that can exist between studies.

- Two points are essential to guarantee when using specific data: **transparency** and **quality** of these data.

Issue :

➢ **How to ensure the quality of specific data?**

STATE OF THE ART

Regardless of the geographic scale used, the data should always be provided from **recognized sources** and a **sufficiently large geographical area** to allow **sufficient averaging effect**. The data and scales chosen must be **clearly outlined** for **maximum transparency**.

To assess data quality, it is possible to score each LCI using a pedigree matrix (relevance/quality/representativeness score). These matrices differ from one methodology to another. Two interesting matrices to explore are those of the PEF, and the Ecoinvent matrix (which is applied to each generic LCI contained in the database, but which can be used for other applications and was notably used to develop the PEF matrix).

PRACTICAL RECOMMENDATIONS FROM ACDV

The LCA practitioner must keep in mind the data's evaluation criteria dictated by the **Pedigree Weidema et Wesnaes matrix (1998):** Geographical relevance, temporal relevance, technological relevance, completeness and representativeness.

In order to obtain at least minimum quality and to allow transparency on the collected data, it is essential to establish rules for compiling life cycle inventories using specific data. This guide addresses a number of inventory issues, including the cut-off rule, infrastructure, co-product management and upstream agricultural inventories.

In the case of biobased products, the variability of environmental impacts is mainly due to the variability of agricultural practices (technical itineraries, mechanisation, intensive vs extensive, etc.) and not to the energy mix as in conventional chemistry. This is why the quality of the specific data collected in the field is crucial. The choice of data for upstream agricultural modelling is detailed in note 9. It is important to remember that cohesion between the objectives, the resources deployed, particularly in terms of data quality, and the conclusions is crucial. **The quality of the data should be discussed when interpreting the impact results**.

SUMMARY NOTE N°5

CUT-OFF RULE

BACKGROUND

- According to ISO 14044, the **cut-off criterion** is the specification of the total flow of matter, energy, level of environmental contribution associated with elementary processes or product systems **being excluded from study**.
- This rule defines the criteria for **inclusion or exclusion** of the life cycle's inputs and outputs. It allows small **simplifications in the life cycle inventory**.
- It proposes as input and output exclusion criteria: **mass, energy and environmental relevance.**

Issue :

➢ **Which cut-off rules can be applied to the inventory?**

STATE OF THE ART

- **The PEF guide recommends avoiding any cuts (2013/179/EU:, n.d.).** However, it allows elementary **processes and flows contributing less than 3%** cumulatively to environmental significance (single score) and material/energy flows to be excluded from the study (European Commission 2021).
- The AGRIBALYSE3.0® report (Koch & Salou, 2013) does not provide precise recommendations on the cut-off criterion to be used.
- Other documents, including the BP X30-323 (ADEME / AFNOR, 2011) and the PAS 2050 (BSI, 2008), agree upon: 1) **Proposed cut-off rule of 5%. 2) Ideally while using a criterion of environmental influence.**
- The Tfs guide "Product Carbon Footprint Guideline for the Chemical Industry" (TfS 2022) recommends :

1) Include all material inputs that collectively represent at least 95% of the total mass inputs of the unit process. It is recommended to aim for 98% or more to increase completeness and reduce uncertainties.
2) Idem for energy
3) If the contribution and influence of certain factors on the product's carbon footprint are unclear, use generic data for a comprehensive calculation to decide whether a threshold can be applied or not (iterative approach).
4) certain incoming material flows, such as catalysts containing precious metals like platinum group metals, which have a significant environmental impact upstream, must be included in the calculation of the product's carbon footprint, regardless of their relatively small contribution to the total material mass (even if their mass is <= 1% of the total).

- Although some flows are deliberately neglected (because marginal) it is important to explicitly **write down these simplifications in the study report.**

PRACTICAL RECOMMENDATIONS FROM ACDV

➢ It is recommended to conduct the inventory with **at least 97% of the mass inputs/outputs and at least 97% of the energy inputs/outputs (3% cut-off rule).**

➢ For each identified input, the practitioner must try to find inventory data. If a gap is identified (no generic or specific data), the input **can be excluded from the system**, and will be taken into account when calculating the cut-off rule and the results interpretation.

➢ This rule must be adapted when the incoming material flows have a significant upstream environmental footprint (for example, catalysts containing precious metals, or substances carcinogenic, mutagenic or reprotoxic substances (CMR)) even if their incoming mass is < = 1% of the total mass. It is important to be as ambitious as possible when collecting data, even if this means lowering the targets if the data is not available.

SUMMARY NOTE N°6

MANAGEMENT OF CO-PRODUCTS AND ALLOCATION (1/2)

BACKGROUND

The production of bio-based products often involves the production of co-products and agricultural residues, inseparable from the main production, particularly related to upstream cultivation.

The issue of extending the system boundaries or the distribution of environmental burdens generated from the production of these products arises. Called "allocation", this distribution strongly influences the results of the LCA. Different approaches can lead to wide variations in results.

Issue :

➢ **How to manage environmental burdens of the different products and co-products generated?**

STATE OF THE ART

Rationales retained by different existing references are relatively close.

Can the process under study be separated into several sub-processes?	Yes	Break down into separate processes	**Subdivision**
No ↓ Can a product that would replace the by-product if it did not exist be identified?	Yes	Distribute by applying system expansion (also called substitution)	**Expansion**
No ↓ Do the product and by-product have a <u>similar and constant</u> purpose?	Yes	Identify the physical criterion representative of this use and divide it up according to this criterion	**Physical allocation:** product and by-product supply energy, for example
No ↓ Distribute according to the economic value of the product and co-product		**Economic allocation**: products and co-products supplied: food, energy, clothing, etc.	

The different alternatives for product and co-product management are:

Subdivision: subdivision of the process studied into two separate sub-processes, to avoid the presence of a process that generates co-products within the life cycle of the product studied.

Expansion (or Substitution): subtracting the avoided impacts (by the co-products valorization) from the total process impacts.

Physical mass allocation: applicable to all material products but does not take into account the difference in value between products and co-products.

Physical energy allocation: applicable for products for which the energy content relevantly reflects differences in content, and therefore value of the material (oil and cake, ethanol and stillage, oil and glycerin, ...)

Economic benefit: applicable where market values are known and stable for all products. Relevant if two products from the same stage have widely divergent market values.

SUMMARY NOTE N°6

MANAGEMENT OF CO-PRODUCTS AND ALLOCATION (2/2)

STATE OF THE ART

The following table shows the order of priority in the choice of allocation in the benchmark (in order: 1,2,3,4)

	ISO 14044	ADEME Guide 2009	PrN16760	AGRIBALYSE	BPX30-323	PAS 2050	Référentiel biocarburant	PEF 2013	TfS, 2022
Subdivision	1	1	1	1	1	1		1	1
System boundary expansion – substitution	2	2	2	2	2	2	1	2	2
Allocation :sensitivity analysis of methods		3	3						
Physical mass allocation	3			3	3			3	2-3
Physical energy allocation	3			3	3		2	3	2-3
Economical allocation (economic benefit)	4			4	4	3		4	2-3

PRACTICAL RECOMMENDATIONS FROM ACDV

1. **When possible, subdivide the process into two sub-processes.**

2. **If not possible, select the expansion of the system boundaries (=substitution) when it is possible and relevant. The aim is to calculate the impacts avoided by the co-product's valorization.**

3. **Failing that, conduct an allocation** (in practice, this scenario is quite common), **or maximize the impacts of the studied product.**

1

- **Choose physical allocations** (mass, energy or other)
- Mass allocation: base the quantities on the **co-product's content in dry material**.

2

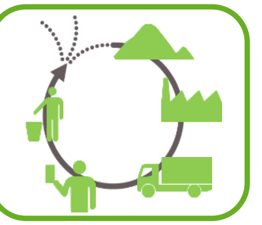
- As a last resort, allocations on **economic criteria** can be applied.

NB The choice of allocation must be derived from the system in question and the LCA study objectives.

➢ **Biogenic carbon storage**: for all cases perform **a specific allocation** based on the carbon content of products and co-products, in order to avoid skewing the **carbon storage** and the impact results of the **climate change indicator.**

➢ Whatever the chosen allocation is, **perform a sensitivity analysis.**

INFRASTRUCTURE



BACKGROUND

- Infrastructure can represent a significant environmental challenge (particularly for small-scale production), as well as "falling" into the cut-off criterion in cases where, in relation to the volumes produced, it is highly depreciated.
- If the practitioner wants to exclude infrastructure, he can do it in 2 ways: at the inventory step (by not collecting the corresponding data), or during the impact calculation (by choosing to exclude *a posteriori*) .
- **The exclusion of infrastructure can be a methodological choice, or due to a lack of available data.**

Issue :

➢ **Is it necessary to take into account the infrastructure?**

STATE OF THE ART

The guide (ADEME, 2009) recommends **taking into account the depreciation** to whatever possible extent. However, by not being identified as a major issue, **infrastructure can be similar for a given step** (e.g. same infrastructure for different processes). **PlasticsEurope indicates that infrastructure is not always included in their data**, and that it depends on the sector. **According to the PEF,** capital goods (including infrastructure) and their end-of-life must be included, unless they can be excluded **on the basis of the 1.0% cut-off rule.**

Recommendations of standards:

For a non-comparative LCA: take into account the infrastructure for a comprehensive assessment in preparation for eco-design.

For a comparative LCA fossil vs bio-based: due to a lack of data on certain oil sectors in terms of infrastructure, the depreciation of equipment and infrastructure of the agricultural sector must not be taken into account, so as not to penalize the bio-based products (difference in scope of analysis).

ILLUSTRATION WITH A CASE STUDY

- A sensitivity analysis was conducted on including infrastructure. This inclusion or exclusion **strongly influenced the results of 5 indicators :** human toxicity (carcinogenic and non-carcinogenic), freshwater eutrophication, ecotoxicity and **above all the depletion of mineral and metal resources** (impacts multiplied by more than 2 on this indicator).

PRACTICAL RECOMMENDATIONS FROM ACDV

➢ By default, it is recommended to include infrastructure, especially for environmental labelling and eco-design.

➢ However, **in the case of a comparison with other fossil-based data** (generic or specific) that do not take into account the infrastructure (such as PlasticsEurope), **it is recommended to exclude them to avoid bias in the results and findings.**

➢ **The choice** whether to include infrastructure or not should be **notified in the metadata of the study.**

➢ When **reporting the results**, it may be appropriate **for clarity to separately represent the impact of infrastructure** (difference between the results with and without infrastructures)

SUMMARY NOTE N°8

LONG TERM EMISSIONS

BACKGROUND

Long-term emissions correspond to the emissions released in **a time horizon of more than 100 years**. Although they enter fully into the methodological framework of LCA, these emissions pose a number of issues related to uncertainty about the quantities emitted (integration to infinity in the long-term emission models) and to the emissions compartment (many emissions are regarded as emitted in the ocean in the very long term).

Issue:

➢ **Should long-term emissions be excluded from the calcultation of potential impact?**

STATE OF THE ART

- Among the studied references, **none provide recommendations** on the inclusion or not of long-term emissions.
- ecoinvent recommends excluding long-term emissions, in order to avoid **"artificially" increasing results for indicators of toxicity and eco-toxicity** (landfill leachate emitted at very long-term and on which there are significant uncertainties).

ILLUSTRATION WITH A CASE STUDY

- A sensitivity analysis was conducted on including long-term emissions. The inclusion or exclusion of long-term emissions **strongly influenced the results of 2 indicators :** ionizing radiation and freshwater eutrophication. For example, for freshwater eutrophication, the results are multiplied by an average of 4.8 if we include the long-term issues.

PRACTICAL RECOMMENDATIONS FROM ACDV

➢ **The LCA community generally excludes long-term emissions from the impact calculation** due to the significant uncertainties in inventories (model of integration to infinity emissions).

➢ A short-term approach is contrary to the very foundation of the LCA, and it is thus **very difficult to omit these long-term potential emissions**, that can significantly **affect toxicity, eco-toxicity, eutrophication and ionization radiation issues**.

➢ It is therefore recommended to **include these long-term emissions**, in order to have the most comprehensive view possible of the product studied.

➢ Nevertheless, it is recommended to test this choice by **sensitivity analysis** in order to identify the influence on the study's findings. It is also possible to present the values of these long-term emissions separately to the overall impact results.

➢ **Uncertainties** concerning long-term emissions **are strong** because they increase with the time horizon (100 years to infinity) and do not present the same problems when "diluted" over time.

SUMMARY NOTE N° 9

DATA REPRESENTING UPSTREAM AGRICULTURE: GENERAL, SEMI-SPECIFIC, SPECIFIC

BACKGROUND

The practitioner has the choice of using secondary or primary data. These choices must always be made in the light of the objectives of the study. The use of data for the agricultural stage meets the same requirements, with the specificity that the impacts of agro-sourced products are very often closely linked to the impacts of the manufacture of raw materials, particularly the agricultural stage. It is therefore very important to establish whether or not it is necessary to model data specific to the system under study, or to use generic data from databases.

Issues:

➢**When should specific data be modelized for agricultural upstream stage? When appropriate, what are the guideline to create good quality dataset?**

STATE OF THE ART

- Through the DNM (Data Needs Matrix), the PEF defines 3 different situations for a company:

1) the company is responsible for carrying out the process --> the company must use (and therefore create) specific data (except for the least impacting processes in the life cycle according to the PEF).
2) the company is not responsible for carrying out the process but has access to information --> several options are available: either the company creates specific data or uses EF-compliant data by adapting key parameters such as transport distances or electricity mix.
3) the company is not responsible for carrying out the process and does not have access to information --> the company can use generic data.

- Thus, in the PEFCRs representing agro-sourced products available until 2023 (Tee-shirt, Feed, Pasta, etc.), it is emphasized that the company manufacturing the finished product studied is generally not responsible for manufacturing the raw material (agricultural production of cotton, cereals, etc.). The use of generic data (EF-compliant data or, failing that, ILCD-compliant data) is therefore recommended.

  If the company manufacturing the finished product under study is indeed in charge of this agricultural production stage, then it is recommended that specific information concerning this stage be used, following the PEF's agricultural modelling recommendations.

PRACTICAL RECOMMENDATIONS FROM ACDV

The recommendation is to select the approach best suited to the case under study from the point of view of data availability :

➢Initially, the practitioner can use generic data available in sectoral databases such as AGRIBALYSE or the WFLDB. The ecoinvent multi-sector database sometimes contains data that does not exist in any other database and should be consulted as such. The origin of the agricultural material is important to consider, but in the absence of country-specific data, a nearby production area can be chosen.

➢Three main situations require the creation of specific or semi-specific data:

- The desire to take into account the specific features of certified production (e.g. AB, Rainforest Alliance, etc.), in which case the creation of semi-specific data, by adapting existing data on the parameters influenced by certification, is a good option.
- The case of a niche or underdeveloped crop not present in the databases
- The case of a strong focus of the study on upstream agriculture, often motivated by the existence of a dedicated supply chain over which the user of the raw material has control.

SPECIFIC AND SEMI-SPECIFIC MODELING : SCOPE AND REPRESENTATIVENESS (1/2)

BACKGROUND

When collecting data on upstream agriculture, a crucial point is to know whether these data are representative or not of a **"normal" crop cycle** (without climatic or other variations, or exceptional conditions). Three themes are addressed here:

- **Temporal scope to consider**: several crop itineraries follow one another on the same plot, therefore the impacts of some stages (e.g. tillage, cross-fertilization) could be assigned to several crops.
- **Rules to perform data collection**: the aim is to obtain an inventory as representative as possible.
- **Geographical and technical** representativeness

Issues:

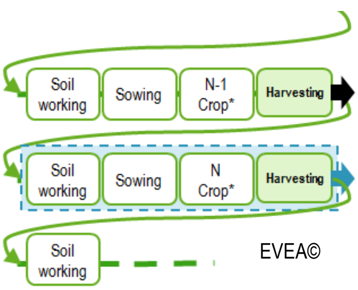
➢ **What are the main rules to ensure a good representativeness?**

➢ **Which steps should be linked to the studied agricultural product?**

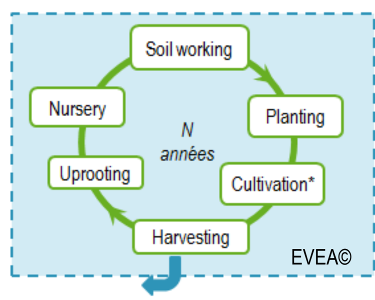
STATE OF THE ART

Temporal scope

The documents AGRIBALYSE (Koch & Salou, 2013), ecoinvent (Agroscope / ecoinvent, 2012), the GES'TIM+ guide (Aurélie Tailleur, Le Gall, and Lorinquer 2020) and the PEF provide clear explanations of the temporal scope to be considered in crop LCA.



For **annual crops**, the time limit is **from harvest to harvest.**



For **perennial crops**, the time limit is equal to the duration of the culture, **from the establishment until its destruction.**

- In order to increase the representativeness of the inventory, the PEF recommends taking an average of 3 years of data collection.
- AGRIBALYSE used an average of 5 years for the assessment of production systems.

Rules to perform data collection

The minimum data collection issues common to all agricultural data impact assessment projects are as follows:

- Crop yield (t/ha)
- Fuel consumption for mechanical operations (L/ha)
- Electricity consumption for irrigation and any other operations carried out with electrical equipment (kWh/ha)
- Types of fertilizer and quantities applied (kg Neq, kg P2O5 eq. and kg K2O eq./ha)
- Types of plant protection products and quantities applied (kg active substance/ha)
- Irrigation water volumes (mm/ha)

Geographical and technical representativeness

The technical and geographical representativeness of an agricultural life cycle inventory must be clearly stated. Data collection is specific to a geographical area (emissions model) and to farmer practices. The wide range of practices associated with different outlets (e.g. sweet corn vs. grain corn vs. silage corn) and production methods (organic farming, agroforestry, etc.) requires an effort to characterize inventories in relation to outlet and production method.

SPECIFIC AND SEMI-SPECIFIC MODELING : SCOPE AND REPRESENTATIVENESS (2/2)

PRACTICAL RECOMMENDATIONS FROM ACDV

➢To obtain representative data, the inventory must be conducted on **of at least 1 year for annual crops,** bearing in mind **that a period of 3 reference years is recommended.** As crops are subject to the vagaries of the soil and climate, it is important to collect data over **a representative period, avoiding extreme years.**

➢**Geographical and technical representativeness** are extremely closely linked for agricultural production, given **the variability of practices.**

➢To overcome non-representative collected data, here are some recommendations:

- Consult an expert that can validate the representativeness of a year or the **smoothing of data over several years,**
- Resort to **statistical databases** (FAOSTAT, EUROSTAT, AGRESTE, INSEE) for collection of baseline data for agricultural systems (yield, etc.),
- For the French cases, consult the **AGRIBALYSE® base** that includes the main French agricultural products. The AGRIBALYSE® data are smoothed over five years.

➢ **Special case of in-depth studies of upstream agricultural operations**:

The above recommendations exclude situations where the focus of the study is on the upstream agricultural sector, in which case the use of a specific inventory tool such as Means In-Out will enable fine modelling of agricultural operations. In this case, it is necessary to refer to the user guide for the chosen tool to identify the additional data to be collected.

SUMMARY NOTE N°11

EMISSIONS OF THE UPSTREAM AGRICULTURE(1/2)

BACKGROUND

- The use of agricultural inputs (fertilizers and phytosanitary products) generates direct and indirect emissions in the environment (atmosphere, water, ground): nitrates, pesticides, …
- Substances emitted during this « upstream agriculture » step can have **significant environmental consequences on several potential impact indicators: climate change, acidification, particle emissions, photochemical ozone formation, eutrophication, toxicity and eco-toxicity.**

It is therefore important to quantify the main emissions to the field, in order to determine the environmental profile of the bio-based product.

Issues:

- **Which are the emissions to quantify?**
- **Which data and emission models to use to calculate the emissions?**

STATE OF THE ART

Emission estimation models based on emissions and databases with agricultural raw materials

Emission	Agri footprint (Durlinger et al. 2017)	ecoinvent v3 (Thomas Nemecek et Kägi 2007a)	AGRIBALYSE ® (Koch et Salou 2015)	WFLDB (T Nemecek et al. 2014)
Ammonia (NH_3)	(IPCC 2006)	Agrammon (Kupper, Häni, et Bühler, s. d.) (Tier 3Switzerland methodology)	EMEP Tier 2 (European Environment Agency. 2016)	EMEP Tier 2 (European Environment Agency. 2013)
Nitrous oxide (N_2O)	(IPCC 2006)	(IPCC 2006): crops: Tier 1 livestock: Tier 2	(IPCC 2019): crops: Tier 1 livestock: Tier 2	(IPCC 2006): crops: Tier 1 livestock: Tier 2
Nitrate (NO_3^-)	(IPCC 2006)	Europe: SALCA-Nitrate (Richner et al. 2014), Other countries : SQCB (Faist et al, 2009)	Annual crops in France: COMIFER 2001 adapted (A. Tailleur et al. 2012) Perennial crops: SQCB (Faist, Zah, et Reinhard 2009)	Europe: SALCA-Nitrate (Richner et al. 2014), Other countries: SQCB (Faist, Zah, et Reinhard 2009)
Phosphorus (P, PO_4^{3-})	(Struijs et al. 2011)	SALCA-P (Prasuhn 2006)		
Heavy metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn)	(Mels, Bisschops, et Swart 2008; Romkens et Rietra 2008; T. Nemecek et Schnetzer 2011)	SALCA method (Freiermuth 2006)		
Pesticides	100% emitted to soil	PestLCI Consensus model (PestLCI 2023)		100% emitted to soil (agricultural)

- Today, all databases quantify nitrogen (NH_3, N_2O, NO_3, NOx), pesticide, phosphorus and heavy metal emissions, using **approaches that vary in complexity**.
- N2O emissions are systematically estimated using the IPCC method, which was last updated in 2019.
- Several simple models can be described for calculating pesticide emissions:
  - the approach proposed by (Thomas Nemecek and Kägi 2007a), which consists of emitting 100% of active substances into the soil, was standard practice for several years
  - the PEF recommends, as a temporary approach, that pesticides applied to a plot of land should be modelled as being emitted 90% into the agricultural soil compartment, 9% into the air and 1% into water.
  - Pest-LCI 2.0 is the finest emission allocation model currently available in LCA models and represents a major advance in the robustness of impact quantification on toxicity and ecotoxicity indicators (PestLCI 2023). Pest-LCI 2.0 was added to MEANS InOut during 2022 in a default version.

SUMMARY NOTE N°11

EMISSIONS OF THE UPSTREAM AGRICULTURE(1BIS/2)

BACKGROUND

- The use of agricultural inputs (fertilizers and phytosanitary products) generates direct and indirect emissions in the environment (atmosphere, water, ground): nitrates, pesticides, …
- Substances emitted during this « upstream agriculture » step can have **significant environmental consequences on several potential impact indicators: climate change, acidification, particle emissions, photochemical ozone formation, eutrophication, toxicity and eco-toxicity.**

It is therefore important to quantify the main emissions to the field, in order to determine the environmental profile of the bio-based product.

Issues:

- **Which are the emissions to quantify?**
- **Which data and emission models to use to calculate the emissions?**

STATE OF THE ART

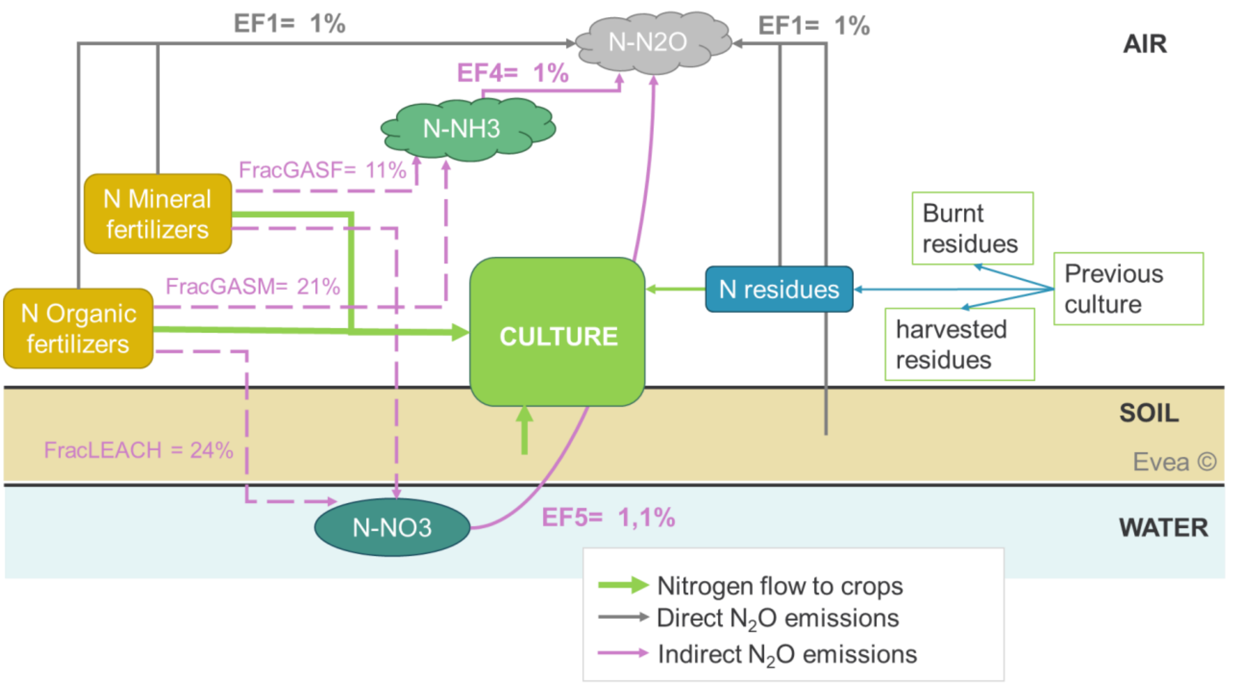


Diagram showing the model for estimating N_2O (and NH_3 & NO_3) emissions according to the IPCC (2019)

- Today, all databases quantify nitrogen (NH_3, N_2O, NO_3, NOx), pesticide, phosphorus and heavy metal emissions, using **approaches that vary in complexity**.
- N2O emissions are systematically estimated using the IPCC method, which was last updated in 2019.
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EMISSIONS OF THE UPSTREAM AGRICULTURE(2/2)

PRACTICAL RECOMMENDATIONS FROM ACDV

Emissions to quantify according to the analysed impact indicators:

Impacts Emissions	Climate change	Acidification	Particles emissions	Photochemical ozone formation	Freshwater eutrophication	Marine eutrophication	Toxicity and eco-toxicity
N_2O	X						
NO_3^-	X *					X	
NH_3	X *	X	X **			X	
NO_x	X *	X	X **	X		X	
CO_2	X						
Phosphates					X		
Pesticides							X
MTE							X

*: Emission to quantify to calculate the indirect emission of N2O

** Indirect effect through the formation of secondary particles

NITROGEN EMISSION

Several models exist for calculating these emissions, from the simplest to the most complex, from the most generic to the most specific. Given the complexity of the biological and physico-chemical phenomena behind these emissions, it is important to stress the significant uncertainty in the results of these estimates.

The recommendation concerning the choice of emission model is to select the model best suited to the case under study in terms of data availability.

- For an initial approach **to nitrogen emissions, the practitioner may opt for the simplified approach proposed by the most recent IPCC model.**
- To go further, depending on data availability, quantification efforts should **focus mainly on refining emission factors for nitrate leaching and nitrogen volatilization.**
  - For ammonia emissions, the practitioner may opt for the simplified approach proposed by the most recent **EMEP model**.
  - For nitrate emissions, calculating a **simplified nitrogen balance as recommended by the PEF** is a good alternative for estimating the quantities of nitrogen lost through leaching.

PESTICIDES EMISSION

- **In a conservative approach, it is recommended that 100% of pesticides applied should be emitted to the ground**.

PHOSPHORUS AND TRACE METAL EMISSIONS

Phosphorus and TME emissions are mainly linked to soil erosion, runoff and leaching, and to a lesser extent to inputs. The limited scope and complexity of existing approaches limit their relevance.

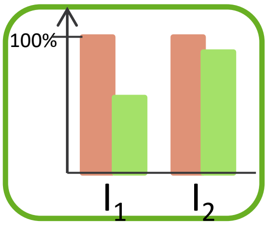
- **The recommendation would be to disregard these emissions**.

SPECIAL CASE OF IN-DEPTH STUDIES OF UPSTREAM AGRICULTURE:

The above recommendations exclude situations where the focus of the study is on upstream agriculture.

- **In this case, the use of a specific inventory tool such as Means In-out enables fine modelling of operations and all emissions.**

ENVIRONMENTAL IMPACT INDICATORS IN LCA



BACKGROUND

▪Agriculture generates impacts on the environment, mainly because of:

- loss of nutrients not assimilated by plants,
- transformation of these elements into other substances,
- emissions of pesticides and heavy metals

▪The substances emitted during this agricultural phase can have **important environmental consequences**, on several potential impact indicators:

- climate change,
- acidification,
- particle emissions,
- photochemical ozone formation,
- eutrophication,
- toxicity and eco-toxicity.

▪Furthermore, irrigation of crops used as raw material for bio-based chemicals may lead to water scarcity issues.

Issue :

➢ **Which indicators should be considered during the LCA of bio-based chemicals?**

STATE OF THE ART

WBCSD recommendations for chemicals:

- **7 fundamental indicators:** climate change, photochemical ozone formation, acidification, fossil resource consumption, consumption of abiotic resources, eutrophication and toxicity / eco-toxicity.
- **3 recommended indicators:** particle formation, land use, species diversity.
- **2 optional indicators:** reduction of the ozone layer, water scarcity.

Recommendations of the sectoral reference for food products (ADEME / AFNOR):

5 priority indicators: climate change, biodiversity, water consumption, aquatic eco-toxicity, eutrophication.

PRACTICAL RECOMMENDATIONS FROM ACDV

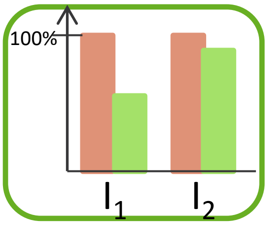
▪**Maintain a water indicator** because it is a sensitive resource for bio-based products (at least one flow indicator and possibly water footprint).

The ACDV conducted a methodological note for each of the seven indicators that present methodological issues:

- **Climate change**
- **Water depletion**
- **Non renewable resource depletion**
- **Land use and soil quality**
- **Toxicity and eco-toxicity**
- **Biodiversity**

SUMMARY NOTE N°13

WATER DEPLETION



BACKGROUND

The consideration of the impact of water use is a major issue for the environmental assessment of bio-based products. Since 2014, major improvements have been made in measuring the impact of water consumption.
Different approaches exist to assess water use impacts. The practitioner can evaluated:

- water withdrawals
- net water consumption (*net water consumption* = *water withdrawals* – *water discharge*)
- water availability (water stress)
- the water footprint (water availability and water quality)

There are different types of water: freshwater, marine water, groundwater, freshwater used for cooling, freshwater used for irrigation, wastewater, etc.

Issues:

- ➢ **Which type of water to consider and which water utilization to take into account ?**
- ➢ **Which method should be used to measure impacts of water use ?**

STATE OF THE ART

- The **WULCA** group recommends the **AWARE** method (**A**vailable **Wa**ter **Re**maining), that evaluated water availability once the demands of humans and ecosystems have been met.
- The PEF method and the international EPD system (Environment Product Declaration) recommends the AWARE method.
- The **ISO 14046:2014** standard specifies the principles, requirements and guidelines of assessing and reporting **water footprints**. Water footprint is the assessment of impacts by LCA on the quantity and quality of the water resource (i.e water availability, freshwater eutrophication, eco-toxicity, acidification, etc.). To assess water quantity, it is recommended to use the AWARE method.
- The NF EF 16760 doesn't recommend any method.

PRACTICAL RECOMMANDATIONS FROM ACDV

- ACDV recommends to assess water availability with the **AWARE method**. The AWARE method is a regionalised method: it's important to regionalise water flows of major contributors to water availability.
- It is recommended to use the latest AWARE version: AWARE 1.2c (downloadable on WULCA website)

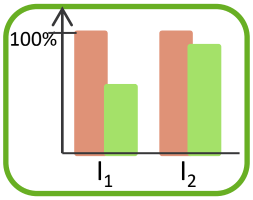
NB: the PEF method uses AWARE 1.2

- If water availability has an important issue for your project, you can refine characterisation factors (to adapt to an agricultural use, to the month of withdrawal and to watershed). See the WULCA website for more information (https://wulca-waterlca.org/aware/download-aware-factors/).

NB: in the PEF method, the water of irrigation is considered as consumed, the water consumption of agriculture is therefore maximised.

- It is not recommended to use "water, GLO" flow: if you can't regionalise your data (because you have no information about it), it is preferable to use the ReCiPe method than the AWARE method. The ReCiPe method evaluates the net water consumption (water flow).

RESOURCE DEPLETION



BACKGROUND

- Characterization of the **impact of resource depletion** is an important issue for the evaluation of environmental performances of bio-based products, especially when they are in competition with products originating from non renewable resources.
- At the present time, and in a majority of cases, only the depletion of **non renewable resources** (mineral and energetic) is characterized in LCA.
- Several approaches have been developed to create **characterization factors specific to every resource.**

Issue:

➢Which method to use to take into account the resource depletion?

STATE OF THE ART

- Several models have been developed to characterise the impact on abiotic resources. These models can be grouped into 4 categories:

1) Modelling based on thermodynamics. These methods aim to assess extraction according to a quantity intrinsic to the resource. The CExD (Cumulative Exergy Demand) and CEENE (Cumulative Exergy Extracted from the Natural Environment) methods are based on this approach.
2) Modelling based on the rate of resource depletion and calculation of a ratio between the rate of extraction of the resource and the reserves available for that resource. This type of modelling is used in the CML-IA and Anthropogenic stock extended, Abiotic Depletion Potential (AADP) methods.
3) Modelling based on the economic and energy effort required to extract a resource in the futures. This type of modelling is used by ReCiPe (endpoint category) (based on additional economic cost), the Ecoindicator99 (EI99) method and Impact2002+ (FC EI99 resource i / FC EI99 Fe) (based on additional energy costs).
4) "supply risk methods" category that considers both the probability of supply disruption (for example, due to trade barriers, armed conflict,…) and vulnerability to supply disruption (for example, assessed by the potential socio-economic impacts that supply disruption would cause).

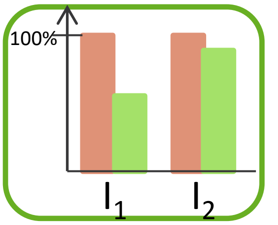
The JRC and the UNEP (GLAM project) all recommend the ADP model (Abiotic Depletion Potential, ultimate reserve; Guinée et al., 2002; van Oers et al, 2002).
This is the indicator currently included in the EF3.0 method.

PRACTICAL RECOMMANDATIONS FROM ACDV

It is recommended to evaluate the resource issue with two complementary indicators:

- An indicator of mineral resources (information on the scarcity of some raw materials): The ADP model (Abiotic Depletion Potential, ultimate reserve; Guinée et al., 2002; van Oers et al, 2002) is currently recommended.
- An indicator of energetic resources (energy monitoring, especially of processes): The indicator "ADP fossil" is recommended for assessing the depletion of energy carriers. It is important to note that this indicator is based on the energy content of each resource. Resource scarcity is therefore not taken into account in the indicator and the relative contributions for the different resources are identical to those obtained with the CED indicator.
- At Endpoint level, all the models evaluated are considered too immature to be recommended. However, the Surplus Cost Potential can be used as an interim solution (available in Recipe Endpoint 2016 calculated by Vieira and Huijbregts)

IMPACTS OF LAND USE ON SOIL QUALITY



BACKGROUND

Land use and soil quality are closely linked. Cultivation practices and industrial activities affect soil quality to a certain extent.
The issue of land use refers to two flows: land occupation and land transformation (change in the land occupation). These two flows are characterised with a soil quality indicator.
However, there is no consensus to characterise soil quality. Indeed, the spatial and temporal complexity of soil functions and properties makes it difficult to assess soil quality. Current LCA models do not provide a complete assessment of soil quality. They focus on different parameters covering various physical, chemical and biological properties (i.e. soil organic matter, soil erosion, biotic production, biodiversity etc.).
LANCA® model is a multi-criteria model which considers soil erosion resistance, mechanical filtration, physicochemical filtration, formation of new groundwater, and biotic production potential.
NB: for impacts of land use on biodiversity, see summary note 17. For soil carbon storage, see summary note 22.

Issue :
➢How to take into account the impacts associated with land use ?

STATE OF THE ART

- In 2010, the ILCD recommended the model of Milà i Canal *et al (2007),* based on the change in organic matter of soils.
- In 2013, the PEF recommend an adapted LANCA model (based on 4 parameters: soil erosion resistance, mechanical filtration, physicochemical filtration, formation of new groundwater)
- In 2015, the EN16760 standard doesn't recommend any method.
- In 2019, the UNEP life cycle initiative (United Nation Environment Program) recommends to use the soil organic carbon deficit potential (Milà Canals et al (2007)) and the LANCA® model to characterize erosion.
- In 2019, the JRC reaffirms the recommendation of the PEF method: the LANCA® model is currently the model with the best attempt at modelling the impact on the various soil properties. It is considered applicable in an EF context.

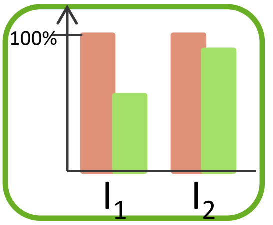
RECOMMANDATIONS FROM ACDV

➢ For the moment, there is no consensus on the characterization of soil quality.

➢The most mature method for LCA practitioners is the LANCA® method. We recommend the LANCA® method, keeping in mind that it only characterizes the loss of physical soil quality; it does not characterize biological soil quality or the impact of land use on biodiversity.

➢Given the regionalized nature of the indicator (the characterization factors depend on the country), particular attention must be paid to the regionalization (at country level) of the main flows or the flows that contribute most to this indicator.

TOXICITY AND ECOTOXICITY



BACKGROUND

After emission in the environment, chemical substances can have substantial consequences on the ecosystems (ecotoxicity) and human health (toxicity). Different models exist to characterize toxicity and ecotoxicity in LCA; however they have a large uncertainty, and the results are highly dependent on the model used.
In this context, a consensus model (USEtox) was developed through a collaboration between the different LCA research teams. This model is in continuous improvement, but has greatly reduced the uncertainty of results.

Issue :

- ➢ **How to characterize toxicity and ecotoxicity of a bio-based chemical as part of an LCA?**

STATE OF THE ART

The USEtox model contains around 3000 characterization factors for organic and inorganic chemical substances that represent their potential toxicity and ecotoxicity. The results are given in CTUe (Comparative Toxicity Unit) for freshwater ecotoxicology and CTUh for toxicology. The factors can be marked as "recommended" or "indicative" depending on the reliability of the data used.
To include an ecotoxicological assessment in their scope, most of the LCIA methods use the USEtox models after some edits:

- LC-IMPACT added USEtox in "endpoint" and extended it to terrestrial and marine ecotoxicity.
- IMPACT World +, except by adding a time horizon of 100 years of metals and persistent organic pollutants, did not distanced itself from USEtox's methodology.
- EF took the most liberties by sourcing their data on REACH, using HC20 of EC10 instead of HC50 of EC50 (Concentration hazardous for 20% of the ecosystem instead of 50%) and their own data quality scoring. For metals, EF introduced a robustness factor of 0.1 for inorganic substances, and 0.01 for essentials metals.
- Not all methods use USEtox, as ReCiPe chose USES-LCA model that includes as well terrestrial and marine ecotoxicity.

Limitations around USEtox concern mostly the lack of factors, the uncertainties (around 2 to 3 orders of magnitude) and the category of metals (because of their consequent resident time, their characterization factor can't be compared to the organic substances' factors).

RECOMMANDATIONS FROM ACDV

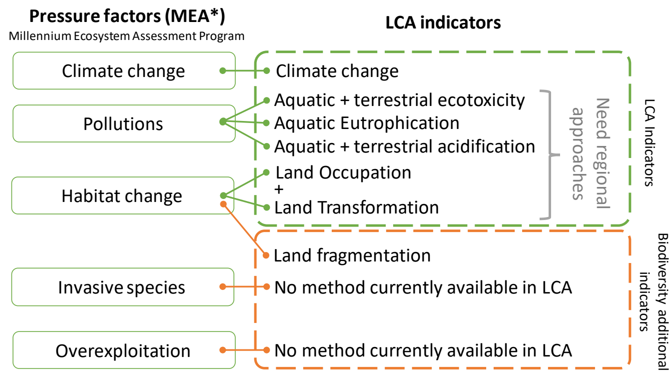
- ➢ It is recommended to include freshwater ecotoxicity and human toxicity in LCA despite the uncertainties, as putting it aside would hide some important issues in the bio-based chemicals value chain.
- ➢ The difference between two characterization factors must be superior to 10^4 to cover the uncertainties. It is therefore preferable to present the results in the logarithmic scale (log10).
- ➢ As metals and metalloids behave differently, it is recommended to present their results separately.
- ➢ All results should have only two significative digits.
- ➢ According to the ScoreLCA's. decision tree, to conduct a multi-indicator study including toxicity and ecotoxicity issues you have to choose LC-Impact or IMPACT World +.
- ➢ It must be noted that human toxicity evaluation in LCA deals with indirect exposure. In that sense, it is not a risk assessment and should not be taken as such. The two approaches are complementary, and both are very relevant in chemical substances life cycles.

BIODIVERSITY (1/2)

BACKGROUND

▪All products have the potential to impact upon biodiversity : pressure factors range from emitting polluting substances along the value chain to global warming, all the way through changes in habitat (land use change), exotic invasive species spreading risk and resources overexploitation. These issues are relevant in the chemicals value chain, and are even more important issues for bio-sourced products. The impacts of upstream agriculture can indeed greatly vary depending on the agricultural raw material and in particular the resource management and type of agriculture.

▪Although some LCA indicators available address some aspects of the potential impacts on biodiversity, scientists and LCA experts recognize that there are gaps, and that both characterization and weighting methods (to reach an overall "Biodiversity" indicator) still need to be developed.



Issue:

➢ **How to take into account the complexity of biodiversity loss for a system ?**

STATE OF THE ART : LCA

▪The European Commission (EC) EF method, as any midpoint method, does not include any "impact on biodiversity" category. The EC currently acknowledges the lack of international consensus on characterizing this impact in LCA. Nevertheless, the PEF recommendations guide of December 2021 indicates that the subject of a biodiversity indicator was one of the areas of work. No mention is made of the actual date of implementation.

▪The European Commission stresses the fact that biodiversity is an important issue on the political agenda, and recommends, when drawing up a PEFCR, to treat biodiversity separately (through certification systems, in addition to the PEF impact categories). However, this complementary approach has its limits (e.g. for sectors where no relevant certification system exists).

3 methodologies are detailed in the guide: LC-IMPACT, Impact World +, ReCiPE 2016

▪The three methodologies presented for quantifying damage to biodiversity have the advantage of being directly implementable in LCA. Main inventory flows are regionalized so that they can be characterized for the assessment of impacts on biodiversity. If the country level is adequate, no additional data need to be collected.

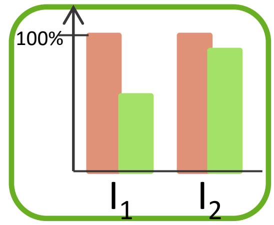
▪Nevertheless, all methodological issues are not solved (heterogeneity of impacts on the taxa covered by the indicators within and between methods, perimeters between indicators, and soil life (bacteria and fungi) essential to the maintenance of soil fertility mechanisms is not covered…).

▪There is currently no differentiated weighting of indicators in the methodologies presented for calculating damage to ecosystem quality. The impact of the category is obtained using a sum of the indicators. However, the land use indicator contributes more heavily in the erosion of biodiversity than climate change or pollution, which are usually represented by several indicators.

▪Finally, the intensiveness of practices, particularly in terms of land use indicators, is not currently included in the calculation methodologies (see summary note n°15).

SUMMARY NOTE N°17

BIODIVERSITY (2/2)



STATE OF THE ART : complementary approaches

▪Emerging alternative methods to LCA that are more specific to upstream agriculture for assessing biodiversity are appearing. Their aim is to quantify specific impacts on biodiversity, taking into account farming practices :

- **Lindner approach :** This methodology requires the collection of specific data in addition to the LCI, and it is currently only possible to quantify the impact of upstream agricultural activities.
- **“Agro-ecological infrastructure" method :** A study by the French Ministry for the Environment presents a proposed indicator for taking biodiversity into account in LCA, based on Agro-Ecological Infrastructures (AEI). This method focuses on the agricultural production stage and is only applicable in a European context.
- **“Ecosystem services" method :** The work of the Millennium Ecosystem Assessment (MEA) and The Economics of Ecosystem and Biodiversity (TEEB) has highlighted the links between human activities and biodiversity, and these links can be translated into ecosystem services. Ecosystem services can be approached in two ways: by **an indicator of ecological function** that can define them ("at the beginning of the chain") or by **their monetary value** ("at the end of the chain"). The first one is not currently available; the second one is currently available and operational, but there are inaccuracies due to the lack of information on how these economic values were obtained.

POTENTIAL APPROACHES

Three main LCA methodologies were investigated for the quantification of impacts on biodiversity on a life cycle scale.The bibliography on global methods enabled a macroscopic comparison of the level of analysis (number of substances analysed, number of indicators concerned). The application of these methodologies to the case study provided an initial insight into the characterisation of the factors and their robustness.

- ➢ On the basis of these analyses, we do not recommend to use any of these 3 methodologies for the assessment of impacts on biodiversity. The 3 methodologies tested revealed weaknesses, and the alternative methodologies are biased in terms of their direct applicability in LCA (failure to take account of certain pressure factors, heterogeneous contribution of the stages, etc.).
- ➢ Nevertheless, as shown by the sensitivity study on the regionalisation of flows, the adaptation of land use and land transformation flows can be a first step towards understanding the biodiversity issues, when using the **Chaudhary method**. These flows often drive most of the biodiversity impacts in the cases studied. relating to the pressure factor of loss of natural habitats
- ➢ In addition to the aggregated impacts associated with each flow giving an impact value in PDF.m².yr, it is possible to dissociate the impacts on the 5 taxonomic groups using the Chaudhary factor spreadsheet available online. In this way, by combining cultivation zone, cultivation practices, crops and taxa that are mainly impacted, a more concrete action plan can be devised.
- ➢ Complementary to the quantitative LCA studies, a qualitative assessment of the issues linked to biodiversity can lead, on a case-by-case basis, to the identification of an additional indicator among those presented above, which, if the data are available, can represent the impacts on living organisms.

CLIMATE CHANGE – choice of metrics

BACKGROUND

Agriculture is, in France, the third greatest emitting sector of greenhouse gas emissions and the greatest emitting sector for methane (CH_4) and nitrous oxide (N_2O), two greenhouse gases with significant and long-lasting global warming potential.

- The emitted methane can originate from livestock sectors or rice production.
- N_2O emissions are caused by the use of nitrogen fertilizers, mineral or organic. They also result from the combustion of organic materials.
- CO_2 emissions originate from fuel combustion by farm machinery, from processing of agricultural commodities (such as fertilizers), from fossil energy consumption, Land Use Change (*see summary note n°21*) as well as the application of urea or liming of agricultural land.

However, agriculture can also have a beneficial effect on pollution. Soils as well as some cultures enable biogenic carbon storage. Conferences of parties in Bonn and Marrakech have included the possibility of recording stocks related to forests and agriculture which are therefore recognized in the “Label Bas Carbone” in France..

Issue:

- **There are several metrics for measuring the impact of climate change, which can be grouped into two main categories: instantaneous metrics (Global Warming Potential GWP) and cumulative metrics (Global Temperature Potential GTP). Greenhouse effect can be calculated over 20, 100 or 500 years. Which calculation method should be used?**
- *For issues concerning inventory of biogenic carbon and GHG delayed emission : see dedicated summary notes.*

STATE OF THE ART

- The 2015 Paris agreements stipulates that the 100-year GWP values from the AR5 or the latest available IPCC report should be used to report global GHG emissions and removals, expressed in CO_2 equivalent. It is also mentioned that each party may also use other metrics (e.g. GTP) to report additional information on global GHG emissions and removals, expressed in CO_2 equivalent.
- In the LCA community, the recent UNEP recommendations (Frischknecht and Jolliet, 2016) advocates both indicators (GWP and GTP). It is important to note that going further down the causal chain, GTP has a greater uncertainty than GWP. However, this uncertainty is considered acceptable compared to the higher uncertainties around the characterization factors for certain impact categories.
- The time horizons proposed in the first 4 IPCC reports are 20, 100 and 500 years. The report states that these three values "are presented as subjects for discussion and should not be regarded as having any particular significance". The 100-year time horizon is currently the most widely used. In the 5th and 6th IPCC reports, the 500-year time horizon was dropped, due to the high long-term uncertainties in the values of radiative efficiencies and the roles of carbon sinks.

PRACTICAL RECOMMENDATIONS FROM ACDV

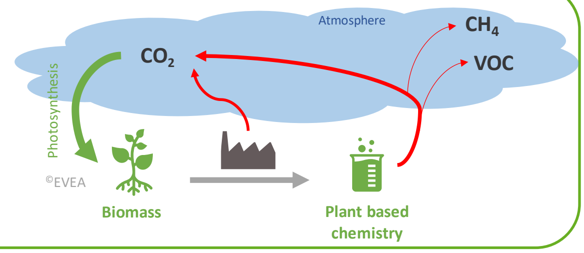
- Use the IPCC GWP 100 year horizon model, on which there is consensus and has been adopted under the Kyoto protocol.
- Sensitivity analysis can be carried out on
  - the GTP 100, particularly when a significant proportion of GHG emissions come from methane emissions.
  - The GWP 20 can be used to complete the analysis, as it takes better account of the impact of very short-lived GHGs (methane and others).

SUMMARY NOTE N°19

INCLUSION OF BIOGENIC CARBON STORAGE (1/2)

BACKGROUND

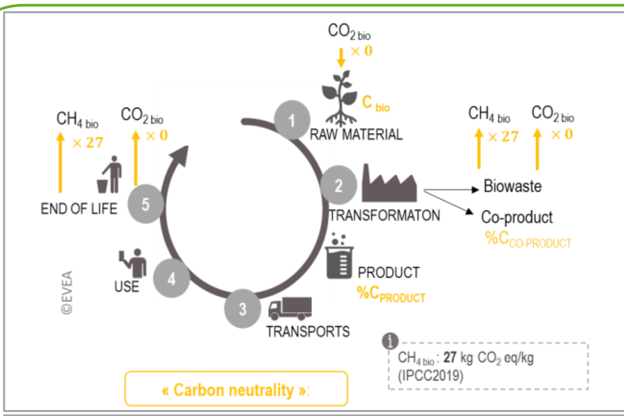
Greenhouse gases such as CO_2 or CH_4 have an effect on our climate, whether their carbon atom originates from biomass or a fossil source. However, carbon from biomass (or biogenic carbon) comes from CO_2 captured by the plant during its growth through photosynthesis. As such, **its impact is offset by the initial removal from the atmosphere.**

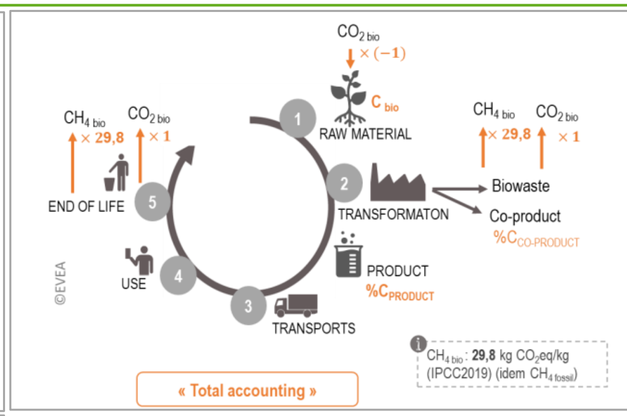


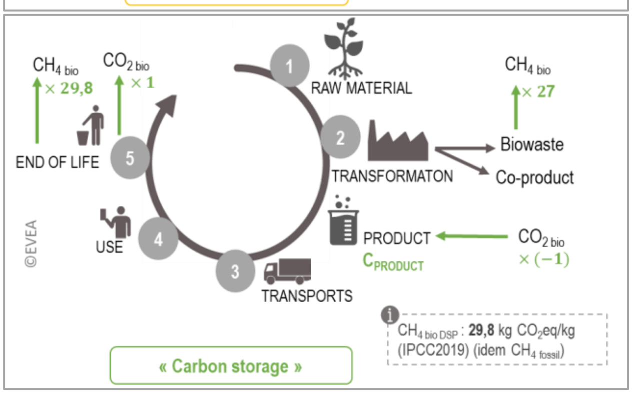
Issue :

➢**How to take into account the climate change benefit resulting from CO_2 uptake by the plant?**

STATE OF THE ART







When methane (CH_4) is released into the atmosphere, it eventually degrades into CO_2 through natural processes, with an average lifespan of approximately 12 years. The difference in characterization factors between biogenic methane in this three approaches arises from how the carbon dioxide (CO2) resulting from methane degradation is considered in greenhouse gas emission calculations.

The three main approaches are presented above.

Please note that **all three methods give the same result in a cradle to grave perspective** (except when some carbone is stored in the soil or in the product on a long term range (>100y): not shown in the diagrams above).

1-«Carbon neutrality»: CO_2 captured by the plant and biogenic CO_2 emissions **are not included in the inventory,** and are therefore neutral on climate change. This is the approach currently used in the EF method recommended by the European Commission. However, it does not allow a fair valuation of the bio-based product compared to a fossil-based product in a "cradle to gate" approach, nor does it take into account the fact that the biogenic CO_2 may not be re-emitted (leading to carbon storage). A biogenic CH_4 characterization factor is needed.

2-«Total accounting»: Detailed flows accounting (carbon storage through photosynthesis, carbon content of the recovered part of the plant, CO2 emitted at different product steps ...). It is a time consuming and complex process with a **high risk of errors** (for instance, most of current databases do not account for corresponding flows).

3-«Carbon storage»: Calculation of the CO_2 captured by the plant, corresponding to the biogenic carbon content, of the final product only. For instance, this calculation can be based on the chemical structure of the molecule. This calculation can be verified by a carbon 14 analysis if physical proofs are required. A biogenic CH_4 characterization factor is needed as well as a biogenic CO_2 characterization factor equalling 0 for upstream steps.

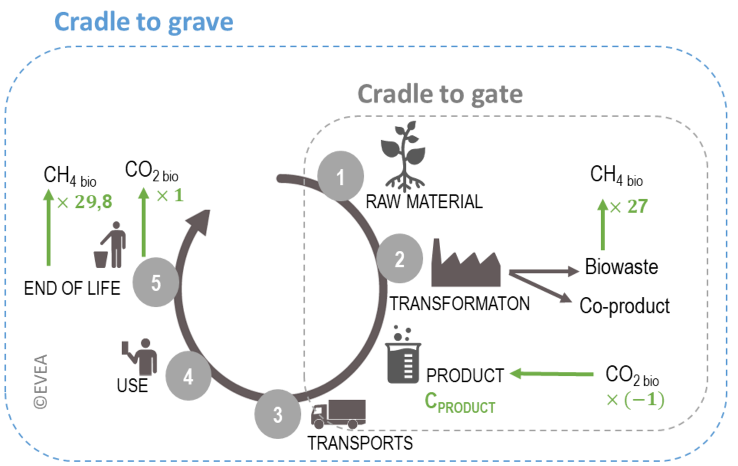
SUMMARY NOTE N°19

INCLUSION OF BIOGENIC CARBON STORAGE (2/2)

RECOMMENDATIONS FROM ACDV

➢ Use of the « Carbon storage » method:

It is **necessary to take into account the CO_2 storage in the plant**, because it allows a relevant comparison between bio-based and fossil-based products. Thus, this comparison can be performed in a "**cradle to gate**" as well as a "**cradle to grave**" scope, when carbon is not fully re-emitted (e.g. landfill) or is emitted in forms other than CO_2 (e.g. emission as VOCs).



« Carbon storage »

- ➢ **Systematic accounting of biogenic methane flow**, which has a heating power stronger than the CO_2 originally captured by the plant from the atmosphere.

- ➢ It is also strongly recommended **not to use "including CO_2 uptake" methods** in plant chemistry but to use methods that do not include CO_2 uptake (indeed, the physical content of biogenic carbon in the ecoinvent data is very often false because of economic allocations). Forcing biogenic carbon stored at product level to be taken into account via a fossil CO_2 flow to which a negative flux value is associated (-1 kg of fossil CO_2 per kg of stored CO_2) use the "fossil" versions of the carbon flows for the entire inventory downstream of the product, particularly for end-of-life.

RECOMMENDATIONS REGARDING COMMUNICATION

- ➢ **Need to specify the biogenic carbon content of the product** in the communication of results for this product

- ➢ **TRANSPARENCY** on the biogenic carbon content of the product is key when communicating along the value chain to ensure
  - ➢ a consistent accounting of climate change along the value change from one LCA practitioner to another
  - ➢ No misunderstanding concerning benefits biobased products can have on climate change.

SUMMARY NOTE N°20

DYNAMIC APPROACH AND APPLICATION TO THE CONSIDERATION OF BIOGENIC CARBON

BACKGROUND

The lack of consideration of temporal dynamics in the assessment of the impact of greenhouse gases can raise issues in terms of consistency in the temporal profiles involved in the life cycle of a product/service. Comparing products with different temporal emission profiles therefore means assessing results over different time periods, which must be emphasized when interpreting the results.

The use of the principle of biogenic carbon neutrality in LCA is also criticized for failing to take into account the temporal aspects of carbon flows. Indeed, even if the biogenic carbon balance is zero (i.e. the quantity of carbon sequestered by the biomass is equal to the quantity of carbon emitted), the delay between emission and sequestration may mean that, depending on the time horizon considered, the impact on the climate is not zero.

Issue:

- **Should the delay of CO_2 emissions be taken into account in the case of bio-based products?**

STATE OF THE ART

- Several authors (Cherubini et al. 2011, Levasseur et al. 2010, Kendall 2012, Benoist 2009) have proposed **methods based on a temporal distribution of sequestration/emissions flows and the use of time specific characterization factors for each sequestration/emission flow**. This makes it possible to assess the impact of climate change in relation **to a fixed reference point in the future.**
- In order to incorporate this temporal dimension, **a dynamic inventory** is needed to obtain an impact as a function of time. Biogenic carbon flows must therefore be disaggregated in the inventory stage, and temporal emission profiles (storage and removal flows) must be taken into account at all stages of the life cycle.
- These temporal biogenic carbon emissions/storage profiles have been proposed in various ways in the literature, ranging from relatively simple biomass growth models (normal distribution (Cherubini et al. 2011) to more complex approaches (Rosa et al. 2018). All are very difficult to apply in terms of computation in LCA softwares.
- The RE2020 describes a simplified dynamic LCA methodology. It takes into account the emission year and considers the impact over a fixed horizon of 100 years. Greater weight is given to emissions at the beginning of the life cycle than at the end. A temporary emission increases the carbon impact, and a temporary storage decreases the carbon impact (French Government 2020). This simplified approach is relatively easy to implement in simple cases, provided that the timing of GHG emissions along the product's life cycle is known. On the other hand, it can be long and laborious in cases where GHG emissions occur in different years.
- **If a product's life-span is “long”** (which ranges from more than 1 year to more than 25 years, depending on the sources), multiple references recommend **taking into account the carbon sequestration.**

RECOMMENDATIONS FROM ACDV

Do not take into account the delay in GHG emissions:

Taking into account the delay in greenhouse gas emissions is scientifically questionable because it is closely linked to the fact that the Kyoto Protocol defines the time horizon as the integration of impacts over 100 years. In the case of an integration of impacts to infinity, this notion would be meaningless.

SUMMARY NOTE N°21

LAND USE CHANGE AND CLIMATE CHANGE

BACKGROUND

Agriculture and changes in land use account for around 30% of greenhouse gas (GHG) emissions on a global scale. Land use and changes in land use are intrinsically linked because they both affect the soil. More than 57% of carbon emissions from agriculture and land use change (LUC) come from the removal of carbon from the soil.

Although methodological or regulatory frameworks do exist (IPCC , ILCD , PAS2050 , CDM , RED II etc.), they are not all based on a single scientific consensus and are not straight forward ways in improving agricultural LCAs. **This lack of consensus and holistic consideration of land use in LCA contrasts with the major issues relating to the potential role of soil carbon in climate change.**

Issue:

➢ **Should the impact of land use change be taken into account?**

STATE OF THE ART

- There is a lack of consensus on how to take impacts of Land Use Change (LUC) on climate change into account.
- No calculation method distinguishes direct Land Use Change (dLUC) from indirect Land Use Change (iLUC).
- In the absence of a scientific consensus, the rule used by ecoinvent and the WFDB to trigger the calculation of emissions linked to land use change has the merit of being operational with FAO data and is implemented in the Blonk tool. This rule defines a change in land use if :

- the area under cultivation in the country has increased over the last 20 years
- the area occupied by natural spaces in the country has decreased over the last 20 years.

However, this rule excludes emissions from destocking and storage linked to a change in cultivation practices.

- The ILCD baseline (i.e. IPCC method) used by AGRIBALYSE is more inclusive in this respect.
- The IPCC emission factors are widely used for calculating emissions, although they are criticized for their limited ability to distinguish different land uses.
- With the exception of the Muller-Wenk & Brandão (2010) method, there seems to be a consensus that emissions should be amortized over a 20-year period.

RECOMMENDATIONS FROM ACDV

ACDV recommends taking into account the impact of land use change (and particularly deforestation), especially when comparing different bio-based products to guide manufacturers in their choice of alternatives to petroleum-based products.

In this context, the "land use change" inventories proposed by ecoinvent appear to be the easiest solution to implement. If necessary, for new crops and countries, it can be combined with the use of the Blonk consultant tool to calculate the areas transformed.

NB: Practitioners will need to be vigilant when interpreting the impact of land use change from one database to another calculation methodologies can vary.

COMMUNICATION OF RESULTS

BACKGROUND

- **Standards**

ISO14020:2022 provides the principles and general requirements for environmental declarations and associated programs for communicating the environmental aspects and impacts of products.
To go further, the ISO 14020 family of standards sets out principles and requirements for communicating the environmental aspects and impacts of products by means of environmental declarations.
In addition, European standard NF EN 16848:2016 sets out the requirements for companies to communicate the characteristics of bio-based products using a technical data sheet.
Finally, the ISO 14067 Standard on carbon footprints provides some recommendations on the report content requirements for publication.

- **Requirements**

To communicate LCA results, the commisionner must comply with requirements of standards 14040 and 14044.
A critical review may be necessary, particularly in case of comparison with a competing product. In this case, the critical review process described in ISO 14071 must be followed.
Regarding Product Carbon Footprint, ISO 14067 recommends that the effect of carbon storage in products shall be documented separately in the study report.

PRACTICAL RECOMMENDATIONS FROM ACDV

General requirements	Recommendations
Transparency: Detail the context of the study, the methology used, the life cycle inventory and the results and interpretations.	The Association Chimie Du Végétal recommends to write an LCA report. It is recommended to follow a plan based on the 4 main stages described in the ISO 14040 & 14044 standards. Moreover, the ACDV recommends to accompany any communication of the LCA study and its results with its metadata record (see the following summary note)
Quality of results: Justify interpretations, methodological choices, data and assumptions.	Sensitivity analyses guarantee the reliability of results: the Association Chimie Du Végétal recommends to carry out sensitivity analysis for all LCA to consolidate the conclusions of the LCA. For a comparative communication with a competitor, carrying out sensitivity and uncertainty analyses is mandatory.

EDITION OF METADATA

BACKGROUND

Any communication of the LCA study and its results must be accompanied by its metadata record. It allows the preservation of transparency and traceability of information (methodological choices and assumptions of the study).

This metadata are essential:

- to compare the results of the study to those of another product, identifying means and evaluating the reliability of the comparison
- to integrate the results of an intermediate product into a downstream environmental study : this information is crucial to avoid duplication or omission of stages in the life cycle by data user.

The following list, though non-exhaustive, presents the recommendations of the ACDV for writing metadata.

Data and precision on the product	
Biogenic carbon	Detail how the biogenic carbon is taken into account in the study. Indicate the biogenic carbon content per unit of finished product.
Functional Unit	If the unit is mass, specify whether it is expressed as weight of dry matter or raw material. Specify the percentage of moisture of the product. If the unit is volume, specify the product density. Specify whether the functional unit concerns bare (without packaging) or conditioned product.
Data and information on the modeling	
Study's scope	List exhaustively the included and excluded flows: particularly transport, non-production activities, packaging ... Specify whether or not the foreground and background infrastructures are taken into account.
Allocation	Specify the allocations selected for each multi-output process Whatever the choice is, specify the values used to calculate allocation factors and their sources.
Cut-off rule	Specify and justify the cut-off rule applied in the study (between 5% and 0% according to the ACDV recommendations).
Generic databases	List generic databases used in modeling
Specific agricultural data	List quantified emissions and the associated emission models
Details of the used impact indicators	
Calculation method	Specify the calculation methods (including the version of the indicator) from which the results of impacts originate. Specify whether the long-term issues are taken into account or not in the calculation.