

## ECOTOXICITY: INDICATORS, METHODOLOGY, RECENT AND FUTURE DEVELOPMENTS

### SYNTHESIS

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The SCORE LCA association is a study and research structure dedicated to work on Life Cycle Assessment (LCA) and environmental quantification. It aims to promote and organize collaboration between companies, institutions and scientists in order to encourage a shared and recognized evolution, at the European and international levels, of the Life Cycle Assessment method and its practical application.

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- The views and recommendations expressed in this document are those of the authors and do not necessarily reflect the views of the entire SCORE LCA membership, unless otherwise noted.
- The information and conclusions presented in this document have been established on the basis of scientific and technical data and a regulatory and normative framework in force at the date of publication of the documents.

## INTRODUCTION

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The topic of addressing the impacts of human activities on ecosystems is gaining momentum among the public and businesses. Considered as one of the five major pressures on biodiversity by the IPBES (*Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*) (IPBES, 2019) pollution includes impacts related to the ecotoxicity of substances released into the natural environment.

Historically, LCA has mainly considered freshwater ecotoxicity, but the ecotoxicity impact also affects terrestrial and marine species for which indicators and evaluation methods are still poorly developed. This partial consideration of issues related to ecotoxicity, associated with work and indicators still limited, leads to LCA results today considered not very robust and therefore not very communicated.

The study synthesized here had three objectives:

1. To carry out an inventory of existing ecotoxicity indicators in LCA and of current or future developments;
2. To analyze the foundations of these indicators, understand the methodological choices, the calculation methods and the possible uses, in particular through LCA software;
3. Establish recommendations for the practitioner: specify the framework for fair and credible use of existing indicators.

This study is based on a bibliographical work of synthesis aiming at analyzing the ecotoxicity indicators in LCA to evaluate the limits of the methods behind and to propose recommendations.

The benchmarking work was based on the study of the 5 main methods used in LCA and the publications used to develop these methods. These methods are the following:

- USEtox 2
- Impact World +
- LC-Impact
- EF 3.0 (Environmental Footprint)
- ReCiPe 2016, the toxicity portion of which was constructed using the USES-LCA method.

USEtox 2 is the method resulting from the UNEP-SETAC international consensus. This international consensus groups all LCA impact chains, not just toxicity, under the acronym GLAM (Global LCA Access to Methods). As a method derived from the international consensus and recognized by GLAM, USEtox is the starting point of our study. In the analysis, the other methods are compared to USEtox 2.

## 2. STATE OF THE ART: DESCRIPTION OF THE METHODS

### 2.1. General operation of ecotoxicity methods in LCA

Life Cycle Impact Assessment (LCIA) methods in ecotoxicity model the fate of thousands of substances from the life cycle inventory of a product or a process. Based on the quantities emitted by compartment (air, freshwater, seawater, and soil), they model the fate of these substances in the different compartments (including transfers between compartments), as well as the impacts of these substances on ecosystems. All methods model the impacts of substances on freshwater organisms. Some also model the impacts on marine and terrestrial organisms.

When the methods stop at calculating potential effects on ecosystems, the result is a "midpoint" indicator. When they go as far as calculating the damage done to ecosystems, we obtain an "endpoint" indicator.

Contrary to the methods used in risk assessment, LCA methods do not evaluate a real impact (which depends on the exposure dose, is site-specific, and takes into account threshold effects), but an "averaged" impact, over the whole life cycle, assuming a linear effect, and without site-specificity.

### 2.2. Summary of existing methods and their evolution

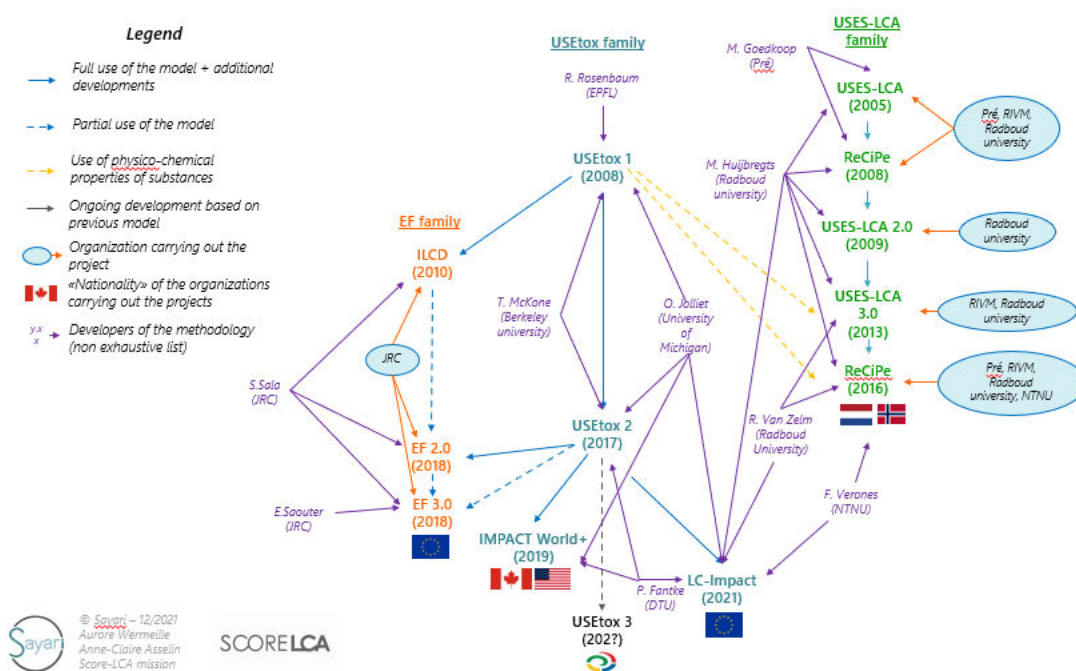


Figure 1 Mapping of the different methods studied, their developers and the methods on which they are based for the ecotoxicity indicator(s).

Figure 1 presents the existing methods, as well as the main developers. These can be grouped into 3 main families:

- The USEtox family, which includes versions of USEtox but also IMPACT World+ and LC-Impact, which are mostly based on USEtox for the ecotoxicity indicator;

- The EF family which consists of ILCD and the 3 versions of EF which are based on USEtox with however significant modifications of some assumptions and data used.
- The USES-LCA family which includes the different versions of USES-LCA and ReCiPe.

## 2.3. Description of methods by family

### 2.3.1. USEtox family

#### 2.3.1.1. GLAM and the USEtox 2 method

In 2018, the UNEP-SETAC consensus experts met to formalize a state of the art and recommendations for ecotoxicity assessment in LCA. The results of this meeting were summarized and recommendations were made. This is what we later refer to as the "GLAM recommendations".

Below are presented (Table 1) the GLAM recommendations, as developed in 2018 and published in 2019. (UNEP-SETAC Life Cycle Initiative, 2019).

**Table 1 List of GLAM recommendations from (UNEP-SETAC Life Cycle Initiative, 2019)**

Criteria GLAM
<b>SR 'Strongly recommended'</b>
General assessment framework: building upon the current framework in LCIA for assessing ecosystem damages from emissions to toxic chemicals
Based damage on potentially disappeared fraction of species. However, the link between fraction affected and fraction lost must be established.
Use data that has a traceable origin
Use free ion activity models to calculate effect factors for metals
Consider solid phase speciation (accessibility) in the calculation of exposure factor for metals in soil
Consider liquid phase speciation on metals in the calculation of exposure factor in freshwater, coastal seawater, soil and freshwater sediment
Disregard bioaccumulation as removal mechanisms in all compartments when calculating exposure factors
Consider specific characteristics of chemicals, organism, and compartments during the calculation of effect factors
Develop methods to address pollinator exposure and related impacts in LCIA due to the importance of this impact pathway
<b>R 'Recommended'</b>
Include ecotoxicological effects of chemical substances on organisms living in freshwater sediment, soil, and coastal seawaters in LCIA
Calculate effect factor from HC20 derived using SSD model constructed using chronic EC10-equivalents
Use comparative toxic units for ecotoxicity (CTUe) as unit of impact score

**USEtox** is the international scientific consensus method endorsed by the UNEP/SETAC Life Cycle Initiative. Its latest version is 2.12, developed in 2008 by (Rosenbaum et al., 2008).

USEtox is a *single-issue* method, which is specific to ecotoxicity and human toxicity. It does not consider other impacts.

In USEtox, the chain of cause and effect (detailed in Figure 2) for the characterization of the impact related to the emission of a substance is composed of the chain of 4 factors:

- The **fate factor** of the substance from the emission environment to the target environment is used to convert the quantity of substance emitted (kg<sub>emitted</sub>) into the quantity of substance per environmental compartment (kg)
- The **exposure factor** of the species to the substance in the target environment allows to model the exposure of the organisms to the substance

- The **effect factor** of the substance on the fraction of the different species (effect factor), allows to obtain the **characterization factor (CF) "midpoint"**, expressed in [CTUe] or [PAF m<sup>3</sup> day] per kg emitted (*Potentially Affected Fraction of species*)
- And finally, the severity factor, which converts the potential fraction of affected species into the potential fraction of disappeared species, i.e., the **"endpoint" characterization factor (CF)** expressed as [CDUe] or [PDF m<sup>3</sup> day] per kg emitted (*Potentially Disappeared Fraction of species*).

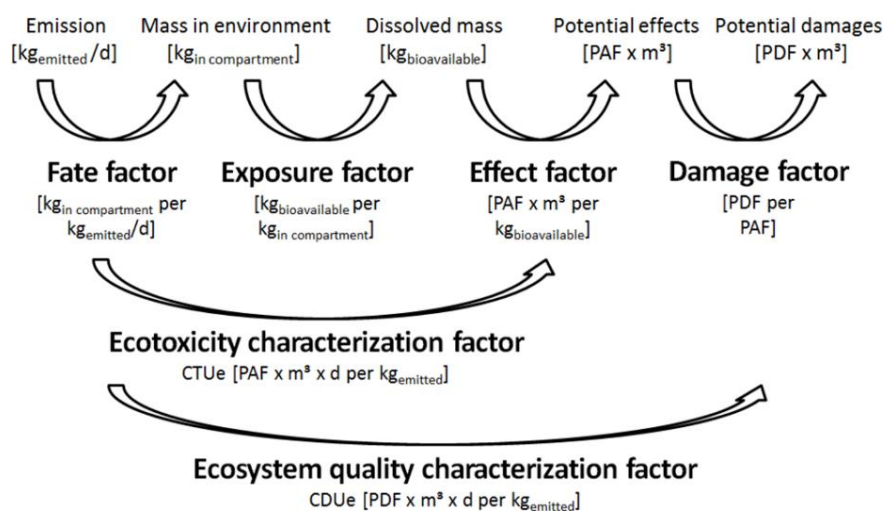


Figure 2 Description of the calculation method for characterizing ecotoxicity impacts in USEtox, from emissions to damage (Fantke et al., 2017).

The majority of LCIA methods on ecotoxicity today fall under this chain of cause and effect, which has been taken up in the latest GLAM publication (UNEP-SETAC Life Cycle Initiative, 2019). Some of them, however, stop at the effect factor (included), which is the intermediate level retained as the "midpoint" and do not consider the severity factor, which allows to go to the "endpoint".

USEtox is declined in 2 versions: USEtox (R) and USEtox (R+I), reflecting the level of reliability of the calculations (in modeling and/or availability of data on the substances) in a qualitative way by indicating whether the characterization factor is "provisional" (I: indicative) or "recommended" (R: recommended). All metals and organometallic substances are classified as "provisional".

The emission compartments for characterizing the ecotoxic impact of a substance are the same for all methods of the USEtox family.

### 2.3.1.2. LC-Impact

**LC-Impact** (Verones et al., 2020) is an exclusively "endpoint" method. As far as ecotoxicity is concerned, LC-Impact is mainly based on the USEtox 2.1 method, with a few corrections. In particular, it proposes 2 scenarios, the "core" version which determines the impacts at 100 years and the "extended" version which determines the impacts at infinity (only the impact of metals differs from the "core" version), i.e. at the steady state as proposed in USEtox.

### 2.3.1.3. IMPACT World +

**IMPACT World+** is an update of the IMPACT 2002+, LUCAS and EDIP (Environmental Development of Industrial Products) methods, covering all impact categories in midpoint and endpoint characterization. It is a so-called global regionalized method, offering the same regionalization as USEtox. The ecotoxicity impact is based on the parameterized version of USEtox 2.0 (R+I).

### 2.3.2. EF Family

The EF method is supported by the European Union's scientific and technical research laboratory (JRC). This method only allows the calculation of midpoint indicators. However, it also proposes the aggregation of the different impact categories into a single score. Regarding the consideration of ecotoxicity, this method is based on USEtox, but makes several major changes. The latest version, EF 3.0, is based on USEtox version 2.1 while adding important contributions on the data used, in the calculation of effect factors (HC20 for non-metallic organic and inorganic substances) and adding robustness factors (which are under debate). A significant number of substances and physico-chemical data (necessary for the characterization of CFs) have also been added (based on different calculation methods than USEtox).

### 2.3.3. USES-LCA family

ReCiPe 2016 was developed by van Zelm et al (2016) and is based on the different versions of USES-LCA. This family of methods is developed by Dutch and Norwegian researchers. The ReCiPe 2016 method is **global**. Its particularity is that it proposes 3 "cultural" scenarios:

- "Individualist: short-term vision (20 years)
- "Hierarchist": consensus model, it is considered the default model (100 years time horizon);
- "Egalitarian: long-term version (infinite horizon): this is the one that is closest to the other methods.

In terms of ecotoxicity, the method proposes 3 midpoint indicators (freshwater, terrestrial and marine ecotoxicity) allowing this impact to be taken into consideration in the various environments.

### 3. COMPARISON AND LIMITATIONS OF METHODS

#### 3.1. Comparison of methods

The methods were compared in their native versions, corresponding to the methodology published by the method developers, Table 2 summarizes the main characteristics of these ecotoxicity methods in their native version.

**Table 2 Comparison of the methodological approach of the different methods selected.**

Méthodes	USEtox 2.12	IMPACT World +	LC-Impact	EF 3.0	ReCiPe 2016
Ecotoxicity impact category	Freshwater	x	x	x	x
	Terrestrial	No	no*	x	No
	Marine	No	no*	x	No
Type of substance	Organics	x	x	x	x
	Metallic inorganics	x	x	x	x
	Non-metallic inorganics	No	No	No	x
Number of substances in the native versions	Organics	2499	2499	2499	5632**
	Metallic inorganics	27	31	27	62**
	Non-metallic inorganics	0	0	0	397**
Time horizon	20 years	No	No	No	No
	100 years	No	No	x	No
	Infinity	x	x	x	x
Calculation level	Mid-point	x	x	No	x
	End-point	x	x	x	No
Indicator units	Unit - mid-point	CTUe, PAF m <sup>3</sup> day	CTUe, PAF m <sup>3</sup> day	-	CTUe, PAF m <sup>3</sup> day
	Unit - end-point	CDUe, PDF m <sup>3</sup> day	PDF m <sup>2</sup> year	PDF m <sup>3</sup> day	-
Selection of ecotoxicological effect data	Organics	EC50-level	EC50-level	EC50-level	EC10-level
	Metallic inorganics	EC50-level	EC50-level	EC50-level	EC50-level
	Non-metallic inorganics	-	-	-	EC10-level

\*IMPACT World+ does not characterise terrestrial and marine ecotoxicity per se. However, according to the IMPACT World+ methodology publication (Bulle and al. 2019), freshwater ecotoxicity impacts can be used as a proxy for measuring terrestrial and marine ecotoxicity. However, the reliability of these proxies is highly questionable.

\*\* The number of substances indicated is valid for the native version of EF 3.0. In contrast to the other methods, the number of substances available in the SimaPro version (9.3.0.3) for the EF3.0 method is different. Indeed, the methodological developments of 2021 proposing the addition of numerous substances are not yet implemented in the software. Thus, only 2806 organics, 42 metallic and 92 non-metallic inorganics are available in SimaPro (9.3.0.3) for EF3.0.

The first notable difference in the impacts on ecotoxicity is the consideration of **terrestrial and marine ecotoxicity**. These are only taken into account in LC-Impact and ReCiPe.

The **nature of the available substances** also differs between methods. Thus ReCiPe characterizes only a small number of metals, some of which are widely used in industrial processes. In particular, ReCiPe does not characterize Aluminum, Iron, Cesium, Manganese etc.

In contrast, EF 3.0 remains the only method that offers the characterization of non-metallic inorganic substances. It also characterizes the most substances, due to the addition of data from the REACH database, originally designed for risk assessment.

The **number of substances** characterized also varies. Apart from the EF 3.0 method, the effect factors of all methods are based on USEtox data. These are obtained from three eco-toxicological databases: the RIVM (Netherlands Institute for Public Health and the Environment) e-tox base; the US-EPA ECOTOX base; and the REACH-IUCLID base (ECHA (European Chemical Agency), n.d.).

As far as **units** are concerned, all methods except ReCiPe use similar impact units: CTUe (or PAF.m<sup>3</sup>.day) for the midpoint, and CDUe (PDF.m<sup>3</sup>.day) for the endpoint. The IMPACT World+ method proposes a different unit for its endpoint impacts: PDF.m<sup>2</sup>. year, expressed in surface area and not in volume, and per year. The purpose of this unit is to homogenize the units of the indicators used for the ecosystem quality endpoint in the IMPACT World+ method, by standardizing for an average depth of 2.5 m.

Differences also exist regarding the **type of eco-toxicological data** used to calculate CFs. The methods use statistical sensitivity distribution (SSD) curves for the species to calculate the effect factors. For all the selected methods, with the exception of EF, these SSD curves are constructed from EC50 values

(concentration at which 50% of individuals are affected). The EF 3.0 method uses EC50 values only for metallic substances. To determine the effect factor for non-metallic inorganics and organics, SSD curves constructed from the HC20 curves of EC10 (10% of individuals affected) are used: this leads to an increase in the effect factor for these substances.

Finally, the raw data requirements for constructing these SSD curves also differ. USEtox (and the methods derived from it) requires a minimum of 3 species and 3 trophic levels, for R (Recommended) substances, the substance is provisional (I) if these requirements are not met. The same is true for ReCiPe, which imposes a minimum of 4 species in (I), without any requirement in terms of trophic levels. EF proposes a data quality score based on the number of species and trophic levels used to calculate the SSD curves.

### 3.2. Adaptation of methods in LCA software

Table 3 shows the different versions of the methodologies available in the software as of 08.12.2021 that were used for the realization of the study cases. Since their realization, the last update of SimaPro (9.3.0.3) introduced the version 2.12 of USEtox, and the version 1.0 of LC-Impact. Note that the EF 3.0 method has still not been updated in SimaPro: the 6000 CFs calculated in 2019 are therefore not yet implemented.

**Table 3 Latest native method versions and versions available in software**

Methods	USEtox	IMPACT World+ (midpoint)	IMPACT World+ (endpoint)	LC-Impact	EF	ReCiPe (2016) (midpoint & endpoint)
<b>Most recent native version</b>	v. 2.12	v. 1.31	v. 1.49	v. 1.0	3.0 (update from November 2019)	v. 1.1
<b>Version available in Simapro (9.2.0.2)</b>	v. 2.02 (v. 2.12 since the last upgrade)	v. 1.29	v. 1.47	Unavailable (Available since the last upgrade)	v. 3.0	V. 1.1
<b>Version available in Open-LCA (1.10.3)</b>	v. 2.02	v. 1.29	v. 1.47	Unavailable	v. 3.0	V. 1.1

In the SimaPro software, the method adaptations are mostly done at the level of mapping between the subcompartments of the native methods and the compartments and subcompartments available in SimaPro. The regionalization available in the native methods is generally not available in the software. Other corrective factors can also be performed.

### 3.3. Case study

Two case studies were performed to compare the results and CFs of the different methods, in their native and software versions (SimaPro 9.2.02.):

- 1) Comparison of the impact of 1 kg of emitted substance (8 substances studied) towards the different sub-compartments of air, water and soil between the different methods (USEtox, ReCiPe, EF, LC-Impact and IMPACT World+).
- 2) Comparison of the impact of two process datasets ("wastewater treatment" and "corn production") between the different methods available in SimaPro (USEtox, ReCiPe, EF, IMPACT World+).

The detail of the results are available in the full report.

### **MAIN RESULTS AND LESSONS LEARNED**

- Metals appear as predominant in all methods (except EF 3.0)
- The midpoint and endpoint CFs are extremely variable depending on the method
- Some substances are not characterized
  - Some metals are not characterized in ReCiPe (Aluminium)
  - EF3.0 is the only method to characterize non-metallic inorganics
- Terrestrial and marine ecotoxicity is only considered in LC-Impact and ReCiPe.

## **3.4. Limitations of the methods**

### **Time horizon**

The time horizon used to calculate the impact of substances is generally infinity (i.e. steady state). Only LC-Impact and ReCiPe propose a comparison with a time horizon of 100 years.

The choice of an infinite impact tends to reflect only the impact of metals because of their persistence in the environment forever.

### **Extrapolation of acute toxicity data to chronic toxicity data:**

Apart from EF 3.0, the effect factors retained for a given substance are based on chronic toxicity data (corresponding to a long exposure in relation to the reproduction time of the species). However, most ecotoxicological databases present data corresponding to acute exposure. USEtox (and the methods derived from it) convert acute values into chronic values using a conversion factor (Acute to Chronic Ratio, ACR), usually equal to 2. This approach is debated: the coefficient is indeed very variable depending on the substance; it can vary from 0.1 to more than 100,000 (Saouter et al., 2017).

### **Robustness of the HC50 value**

In ecotoxicity methods, the effect factor is calculated from the chronic HC50 value (Hazardous Concentration 50), a value that is dangerous for 50% of the species representative of the environment considered. In risk assessment, it is more often the HC5 value that is used, which "protects" 95% of species.

### **Data sources**

Some of the underlying ecotoxicity databases are dynamic: this is the case for the REACH-IUCLID database, where data can be added or deleted at any time.

UNEP-SETAC (Life Cycle Initiative, 2019) has identified this as a major traceability weakness. GLAM strongly recommends that the raw data underlying the calculation of effect factors can be saved and available, regardless of changes in the underlying database.

### **Lack of consideration of threshold effects and environmental concentration**

Because of its objective, the LCA approach does not take into account real exposure: it does not take into account the dilution capacity of the environment, nor the quantity of substance already present in the environment before emission.

### **Linearity assumption of the effect factor**

The use of a linear concentration-response curve is consistent with the additivity assumption of toxicity. The linearity assumption is inherent in the fact that any amount of a chemical emitted will contribute to a potential ecotoxicity impact. However, this assumption of linearity overestimates toxicity at the lower end of the 'S' curve and underestimates toxicity at the upper end (Saouter et al., 2017).

## 4. DECISION TREES AND RECOMMENDATIONS

### 4.1. Decision trees

Decision trees have been constructed to guide the practitioner in the choice of the most appropriate method for his study, in the case of a study specifically on ecotoxicity ( ), or a multi-indicator study (Figure 4). The group would like to express some reservations about the applicability of these trees: the state of the art is evolving rapidly and this is a picture of the methods and software available at the beginning of 2022, and it is a non-prescriptive guide, produced to the best of the group's knowledge.

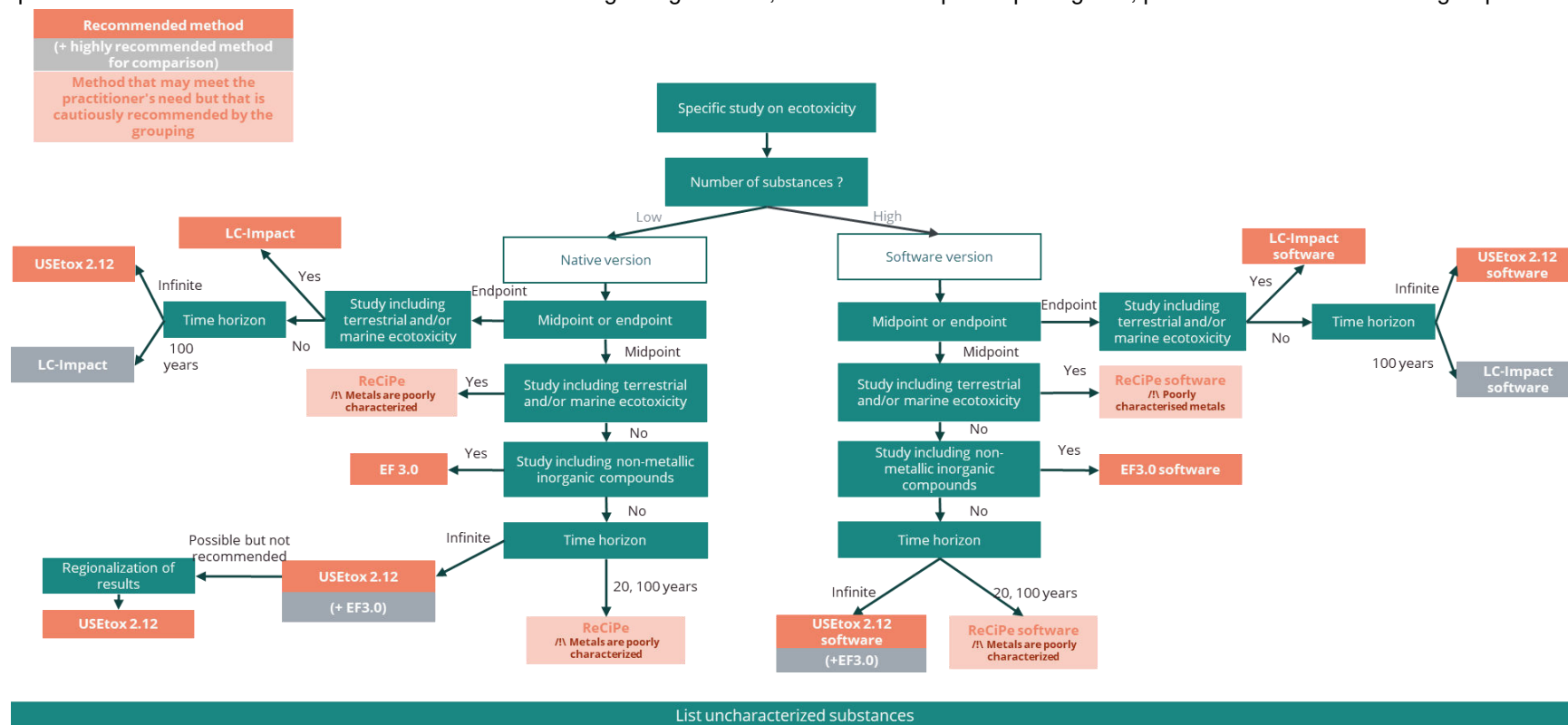


Figure 3 Decision tree for a specific ecotoxicity study.

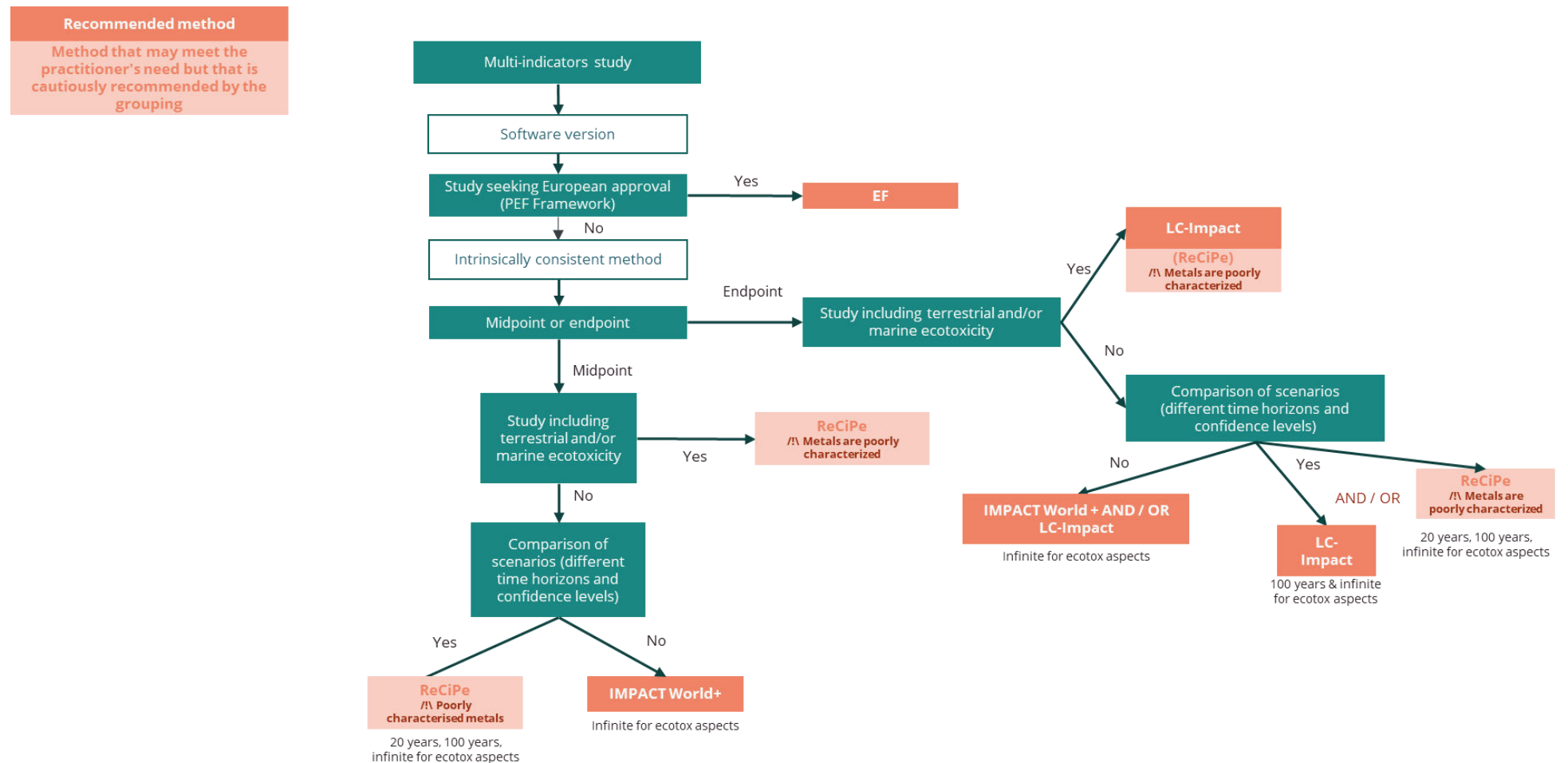


Figure 4 Decision tree for a multi-indicator study including ecotoxicity impact.

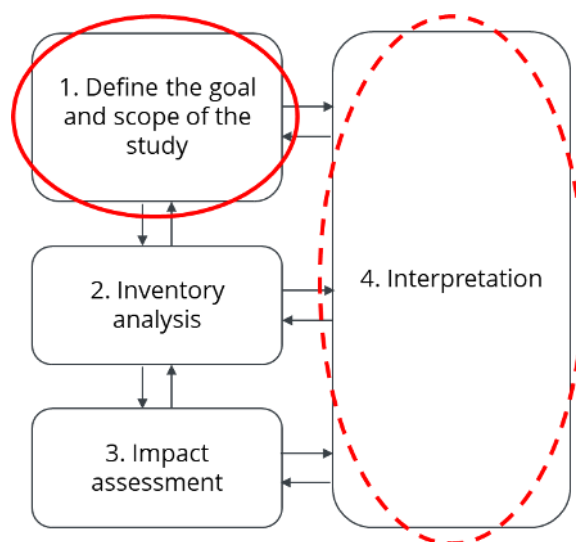
## 4.2. Recommendations

### 4.2.1. Selection of the ecotoxicity assessment method

#### – General recommendations

The LCA framework is key for ecotox analysis and in particular:

- Properly defining the purpose and scope of the study:
  - Ecotoxicity focus or multi-indicator LCA?
  - PEF compliant study or conventional LCA?
  - Many substances or few?
- Take time to interpret as there may be many substances:
  - If possible, avoid unspecified substances
  - List uncharacterized substances
  - Characterize the most important ones
  - Beware of differences between native and software versions
  - It is recommended to use a second method for projects focused on ecotoxicity or multi-indicator studies with high ecotoxicity issues.



**Figure 5** The 4 stages of LCA according to ISO 14040 and 14044 (based on ADEME © <https://expertises.ademe.fr/economie-circulaire/consommer-autrement/passer-a-laction/dossier/lanalyse-cycle-vie/comment-realise-t-acv>)

The following recommendations are valid regardless of the study setting:

- take ecotoxicity into account in LCA, despite the identified limitations. Not to do so would make the LCA incomplete.
- verify whether the data used are sufficiently complete, accurate, up-to-date and of sufficient quality for the substances and compartments considered.
- use as much as possible 2 different methods in order to compare the results

- **Multi-impact study**

In the case of a multi-impact study, for which ecotoxicity is one of the impacts considered, the group recommends the use of a global method (covering all impact pathways), intrinsically consistent (for which all impact pathways have been harmonized and designed to be comparable), within a software package: **LC-Impact, IMPACT World+ and ReCiPe**. The EF method, although presented as global, is not recommended for multi-impact, as it compiles elements of different methods, not designed to work together.

- **Specific study on ecotoxicity**

USEtox 2.12 is the recommended method for the specific consideration of ecotoxicity. It is the most documented and transparent consensus method.

The EF method is not recommended as a first approach: it uses non-consensus "robustness factors", and some fate factors can be modeled.

- **Number of substances present in the study**

In case the study involves a large number of substances, the group and the experts recommend<sup>1</sup> to use the versions contained in the software as a first approach, because of the complexity of using the native versions.

In the case of a study with a smaller number of substances, it is advisable to use the native versions, whose latest developments are often not included in the software<sup>2</sup>.

- **Recommendations for the use of software versions**

In the case of using software, it is recommended to check if the most recent version of the method used is available. If not, it is advisable to refine the results presented by the software version, using the native versions for the substances most used in the process, and/or which stand out most in the software analysis.

- **Study for European homologation (PEF)**

In the context of a study seeking to meet the European criteria (study carried out within the framework of the Product Environmental Footprint, PEFCR), it is essential<sup>3</sup> to use EF3.0.

- **Study including terrestrial or marine ecotoxicity**

Only LC-Impact and ReCiPe characterize terrestrial and marine ecotoxicity. It is recommended to use **LC-Impact**, which offers more recent developments than ReCiPe (which does not characterize certain metals). However, it is advisable to remain very cautious on these indicators because they present higher levels of uncertainty than those of the ecotoxicity of fresh water.

- **Number and types of substances characterized by the methods**

It is recommended to select the method that characterizes the most modeled substances in the set of interest. Therefore, the ReCiPe method is not recommended as a first approach, as it does not characterize some metals (Aluminum, Iron, etc.)

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<sup>1</sup> Interview with Peter Fantke, conducted on 25/03/2022

<sup>2</sup> The time between the update of the native version and the corresponding update in the software can take a few months.

<sup>3</sup> Interviews with Erwan Saouter, Peter Fantke, Ralph Rosenbaum.

In the case of a specific ecotoxicity study involving non-metallic inorganic compounds, **EF3.0 is the only** method characterizing these substances.

- **Cases of uncharacterized substances**

In the case of uncharacterized substances in the inventory (grouped by substance types or archetypes ("unspecified")), it is necessary to identify them. The use of groups of substances or archetypes is not recommended.

It is strongly advised to list the uncharacterized substances in the methods used, to determine if they could have a significant impact on the result. If so, it is possible for the practitioner to calculate or have calculated the characterization factors and manually enter the CFs into the software/methods.

- **Regionalization of results**

The regionalization of results is not yet suitable for operational use<sup>4</sup>. It is not recommended as a first approach, because it concerns the fate factor. However, most of the uncertainty lies in the effect factor.

In the case of a dedicated ecotox study, where regionalization of results would be required, **the native USEtox method is the only one possible**. However, it should be kept in mind that this work must be done in Excel and can be very tedious.

- **Scenario / time horizon**

LC-Impact and ReCiPe allow comparison of time horizons. These considerations are secondary to the choice of a method that best characterizes the substances in the study. For example, in a study involving aluminum, choosing ReCiPe over USEtox (on the grounds that ReCiPe allows comparison of time horizons) would be a mistake because ReCiPe does not characterize this metal.

#### 4.2.2. Interpretation of results

Particular care should be taken when interpreting the results regarding the following:

- **Level of uncertainty and robustness**

The level of uncertainty and therefore robustness varies between and within methods. The EF3.0 method proposes CFs whose calculation takes into account a robustness factor (which is disputed by some researchers<sup>5</sup>), in particular for metals.

- **Terrestrial and marine ecotoxicity**

Regarding marine and terrestrial ecotoxicity, there is no international consensus on the calculation of CFs.

- **Lack of characterization of certain substances**

It is essential to mention an uncharacterized substance and to take this into account during the interpretation. A distinction must also be made between uncharacterized substances and characterized substances with a zero impact (CF = 0).

- **Analysis by substance type**

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<sup>4</sup> Interview with Erwan Saouter, conducted on 21/02/2022

<sup>5</sup> Interviews with Peter Fantke and Ralph Rosenbaum

As recommended by the GLAM consensus, it is important to study the results for each type of substance (organic, metallic inorganic, non-metallic inorganic) separately in an ecotoxicity study.

- **Area of validity of ecotoxicity in LCA**

LCA gives an "environmental pressure indicator", which is different from the toxicological and ecotoxicological reality. Therefore, the consideration of ecotoxicity in LCA is not a measure of environmental impact, but a tool for comparing processes and products studied<sup>6</sup>.

The consideration of ecotoxicity in LCA is most relevant when comparing products of similar type / with similar substance categories, in order to choose the least problematic option.

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<sup>6</sup> Interview with Erwan Saouter, conducted on 21/02/2022

## CONCLUSION

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This study first allowed us to draw up an inventory of existing methods and indicators of ecotoxicity in LCA, then to analyze the foundations of these indicators, to understand the methodological choices and the calculation methods before testing the methods on case studies, and finally to establish recommendations for practitioners.

The first part of the study highlighted the differences between ecotoxicity assessment methods and the variability that could exist between the results. The recommendations were therefore able to provide practitioners with the keys to choosing the method(s) best suited to their needs.

Thus, the selection and application of the method depend on the scope and ambitions of the project (single- or multi-indicator study(s), midpoint or endpoint, characterized substances), but must also be done according to the level of ecotoxicity issue:

- For a project focused on ecotoxicity or multi-indicators but with a strong ecotoxicity stake (cosmetics sector, agriculture, food industry...), it is recommended to deepen the work by using the native version of the chosen method, by comparing the results with a second recommended method, and/or by trying to find in the literature or to develop (in-house or with the help of an expert) ecotoxicity characterization factors if they are not available in the methods.
- On the contrary, for a multi-indicator project where the ecotoxicity issue is less important (e.g. building, energy), the use of a multi-indicator method may be sufficient. Multi-indicator methods such as LC-Impact, IMPACT World+ or ReCiPe are indeed built in a global logic, allowing a comparison between indicators.

In both cases, caution should be exercised when interpreting the results. In particular, it is essential to list uncharacterized substances, or groups of substances (VOCs, DOCs, unspecified archetypes).

The ecotoxicity assessment methods still have significant limitations, which will only be partially overcome with the upcoming updates that will take into account the GLAM recommendations. Some subjects will still need to be improved in the coming years, such as the choice of the time horizon and the interpretation of the difference in results between metals and organic substances, and the still very limited consideration of marine and terrestrial ecotoxicities.

Despite these recognized limitations, excluding the ecotoxicity indicator from an LCA would make it incomplete and could lead to ignoring an important aspect of the environmental impact of a product, whose global limits have been exceeded ("*novel entities*" Persson et al., 2022). In order to better interpret the ecotoxicity results of LCA and to avoid not (or wrongly) taking into account certain elements, practitioners are encouraged to dialogue with the risk assessment teams. Indeed, if the two approaches are not substitutable, they should rather work together to enrich each other. It should also be remembered that LCA gives an "environmental pressure indicator", which is different from the ecotoxicological reality. The consideration of ecotoxicity in LCA is not a measure of environmental impact, but a tool for comparison between processes and products.