

## Study N°2023-02 DYNAMIC DIMENSION IN ACV

**English summary**  
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SCORE LCA is an association that has been created to financially support collaborative research on LCA and related topics. It aims to promote and organize cooperation between companies, institutional and scientists in order to support the evolution of LCA methods and its practical implementation at European and international level.

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- The information and conclusions presented in this document were established on the basis of scientific and technical data and regulatory and normative framework in force at the date of the publication of documents.

## 1 Introduction

### 1.1 Background of the study

The differentiated consideration of impacts over time, known as the dynamic dimension, is an essential component to consider in Life Cycle Assessment (LCA). Environmental impacts do not occur uniformly over time and can vary according to numerous factors, such as life cycle stages, seasonal variations, and technological changes. The dynamic dimension enriches conventional LCA methodology by adding a temporal perspective that is essential for a complete and rigorous environmental assessment.

Dynamic LCA is particularly relevant for taking into account :

- **Delayed emissions:** When a life cycle has stages at distant points in time (long-life products), there are delayed emissions effects.
- **Temporal changes in elementary flows:** When a molecule or element is emitted or taken from the environment, it changes over time (degradation kinetics, movement, and interaction with organisms). This results in a change in the characterisation factor (CF).
- **Prospective approaches and technological developments:** Prospective approaches aimed at reasoning in medium or long term require technological developments to be considered dynamically (e.g. composition of electricity mixes in the future, technological developments, etc.).

Currently, for practical reasons, LCAs often neglect the dynamic approach because of :

- **Standards:** Some standards recommend neglecting this approach. For example, ISO 14067 on the carbon footprint of products states that "all GHG emissions and removals shall be calculated as if they occurred at the beginning of the assessment period without taking into account the effect of deferred GHG emissions and removals".
- **Predefined characterisation factors :** The LCA databases offer predefined time horizons. For example, the ecoinvent database offers 100-year, 20-, 50- or 500-year time horizons for global warming potential.
- **Practical difficulties:** The implementation of dynamic LCA is complex, requiring detailed work and discussions in addition to data collection and modelling.
- **Lack of data and budget:** Defining future scenarios in prospective studies requires discussions with various stakeholders and research with technology developers and public authorities to define inventories adapted to the projected situations.

Compared with conventional LCA, the dynamic approach in LCA can lead to significant differences in impacts, particularly in some types of environmental assessment:

- Long-life products
- Products that induce storage
- Products with delayed emissions
- Prospective scenarios requiring dynamic approaches.

### 1.2 Objectives

The objectives of the study were to :

- **Carry out a state of art of current practices** and propose recommendations.
- Identify the **effects of putting in place a dynamic approach**, in particular through the risks of not considering dynamic LCA.
- Propose **technical fiches** to guide the practitioner.
- Illustrate two case studies.
- Propose a paper for integration on Dynamic LCA into standardisation.

## 2 State of the art of current practices

### 2.1 Conceptual definition of the dynamic approach in LCA

**" A Dynamic LCA takes into account in the assessment, where relevant, not only the temporality of the sequence of life cycle stages, but also the temporal variability of impacts models: activity data, emission and consumption elementary flows, characterizations factors, as well as background systems used from databases."**

All LCA should be dynamic, except when it is not relevant, *i.e.* when the contribution of dynamic LCA is not sufficiently different to justify the additional time taken by the practitioner to carry out dynamic LCA.

### 2.2 Typologies of dynamic approaches

Calculating environmental impacts in LCA involves multiplying **aggregate flows (flux agrégés) (AF)** by **characterisation factors (FC)**. These aggregate flows are actually made up of **activity data (DA)** multiplied by **unit processes** - themselves made up of a sum of **secondary elementary flows (FEs)** - and **primary elementary flows (FEp)**.

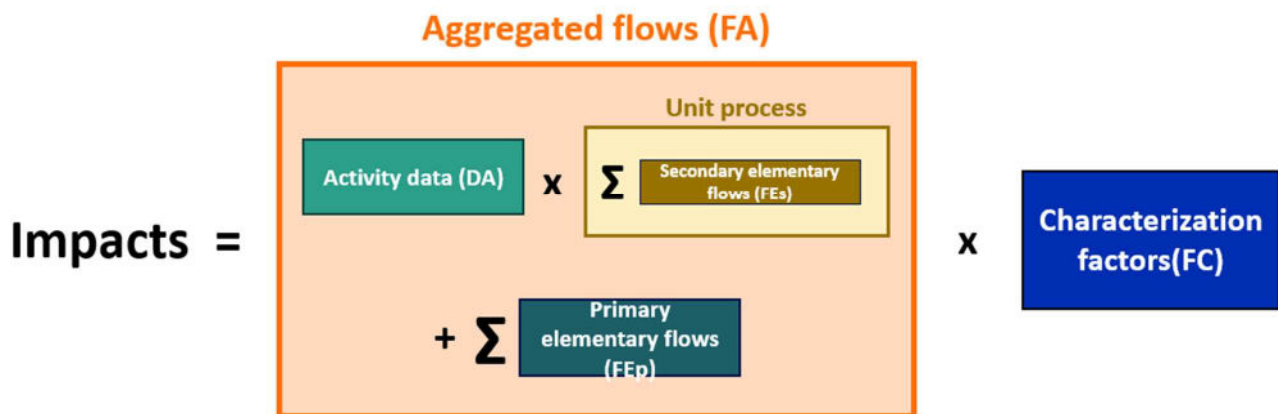


Figure 1 - Components of LCA.

We speak of a **complete** Dynamic LCA when all the elements making up the LCA are dynamic, and of a **partial** Dynamic LCA when only certain elements are. It is important to consider all the relevant dimensions in which dynamism can be incorporated in order to guarantee a correct approach to dynamic LCA.

The possible types of dynamic LCA are presented in the table below:

**Table 1 - The 4 types of dynamic LCA.**

Typology	Description	Lead actor	Example
<b>Activity data</b>	Variability in the activities of the studied system	LCA Practitioner	- Consumption of 10L of water in winter and 0L in summer - Reduction from 10 to 5 kg of metal per functional unit over 15 years
<b>Unit processes</b>	Variability in the choice of inventory process	LCA Practitioner	- Gradual switch from fossil fuel to renewable energy over 20 years - Replacement of steel parts with plastic parts in a car

	Variability in secondary elementary flows within the process	Database developer	- Reduction of an emission linked to a change in the yield of a chemical process
Primary elementary flows	Variability in the materials/energy entering/leaving an inventory process	LCA Practitioner	- Variation in the quantity of a pollutant in water
Characterisation factors	Variability in the indicator assessed	Experts developing characterisation models	- Winter/summer distinction for water consumption - Evolution of the GWP <sup>1</sup> of methane over the years

## 2.3 Key issues

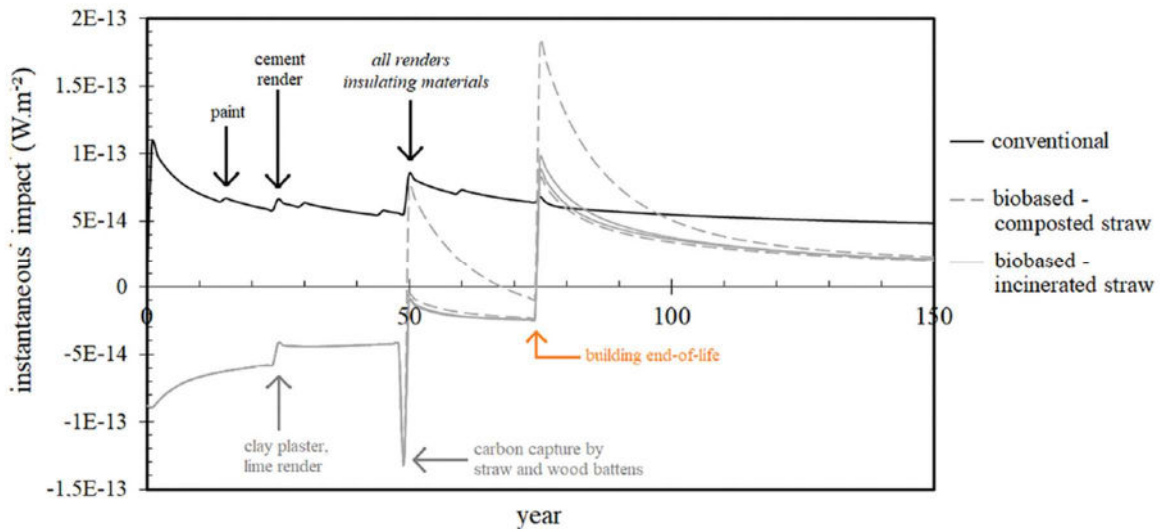
In conventional LCA, in order to assess the future or changing impacts of an activity over time, it is common to define a time horizon representing the period over which these impacts are assessed. This time horizon is generally fixed. Dynamic LCA brings nuances and temporal variability to the definition of these time horizons.

### 2.3.1 Delayed emissions<sup>2</sup>

An emission today cannot be compared directly with a future emission by reporting it at  $t_0$  time after first emission. Indeed, the impact of an activity at  $t$  time have effects that change over time.

For example, the storage of carbon in long-life bio-based materials is not properly taken into account in conventional LCA<sup>3</sup> : it is assumed that wood captures CO<sub>2</sub> during its production and releases it at the end of its life due to its incineration. This assumption ignores the fact that when wood is used in long-life products (e.g. buildings), **it immobilises** carbon throughout its life, preventing it from entering the atmosphere .

Taking time-shifted emissions into account in dynamic LCA leads to presentations of results such as those illustrated in Figure .



**Figure 2 - Results of a dynamic LCA comparing a wall built using bio-based materials (grey) and conventional materials (concrete and glass wool, black) for climate change (in radiative forcing), taken from (Zieger, Lecompte and Hellouin de Menibus 2020).**

<sup>1</sup> Global Warming Potential (GWP).

<sup>2</sup> See also SCORELCA study No. 2015-01 on Taking the "time" dimension into account in LCA.

<sup>3</sup> Except when biogenic CO<sub>2</sub> is considered.

## 2.3.2 Allocation of future and uncertain benefits

Taking into account delayed emissions makes it possible to allocate more fairly future environmental benefits. In conventional LCA, by reporting all future impacts to time  $t_0$ , we lose all information on the dynamics of the life cycle over the lifetime of the product under study. This practice can lead to decisions that appear to be in line with sustainable development, when in fact they are not.

*In conventional LCA for construction sector, the life cycle impacts of two construction materials such as wood and concrete will be close in terms of climate change because, on the one hand, the recycling of concrete offsets the significant impacts of its production and, on the other hand, the emissions at incineration of wood offset the benefit of carbon storage during tree growth.*

*However, if we take dynamics into account, we can see that wood has a benefit on climate change over several decades (grey curve in the Figure), whereas concrete contributes to global warming from the very first year (black curve in the Figure).*

**The dynamic approach provides a more detailed comparison between these two materials. It is essential to take account of the delay of emissions if the impacts are significantly different.**

## 2.3.3 Time horizon for characterisation factors

In conventional LCA, the characterisation models define characterisation factors corresponding to an **average impact over a period of time**, which are therefore unchanged over time.

*For example, for climate change, the most commonly used characterisation model (i.e., IPCC 2021) recommends converting these emissions into "CO2 equivalents" using CFs established over a 100-year time horizon.<sup>4</sup>*

The choice of a 100-year time horizon is disputed in the literature. (Lawrence, et al. 2012). A time horizon of 20 years better reflects the emergency of reducing global warming in the short term, and the concern about irreversible tipping points.

However, this choice is criticised because the choice of a 20-year time horizon neglects the impacts on future generations, which contradict the principles of sustainable development: indeed, climate change will not stop after 20 years.

Depending on the time horizon, the results will vary greatly:

**Table 2 - Climate change results (in kg CO2-equivalents) for two different construction materials according to the time horizon considered, taken from (Zieger, Lecompte and Hellouin de Menibus 2020).**

Type of LCA	Time horizon	Concrete + glass wool (kg CO2-eq/UF)	Biobased (kg CO2-eq/UF)
Conventional	100 years	79.8	26.3
Dynamics	20 years	60.0	-56.5
	100 years	70.8	[-22.2 ; -9.8]
	500 years	71.8	[9.8; 14.3]
	1000 years	71.2	[11.1; 13.7]

<sup>4</sup> In summary, the model takes into account an average GWP of GHGs over 100 years, with a weighting of 1% for the first hundred years, followed by 0% beyond that period.

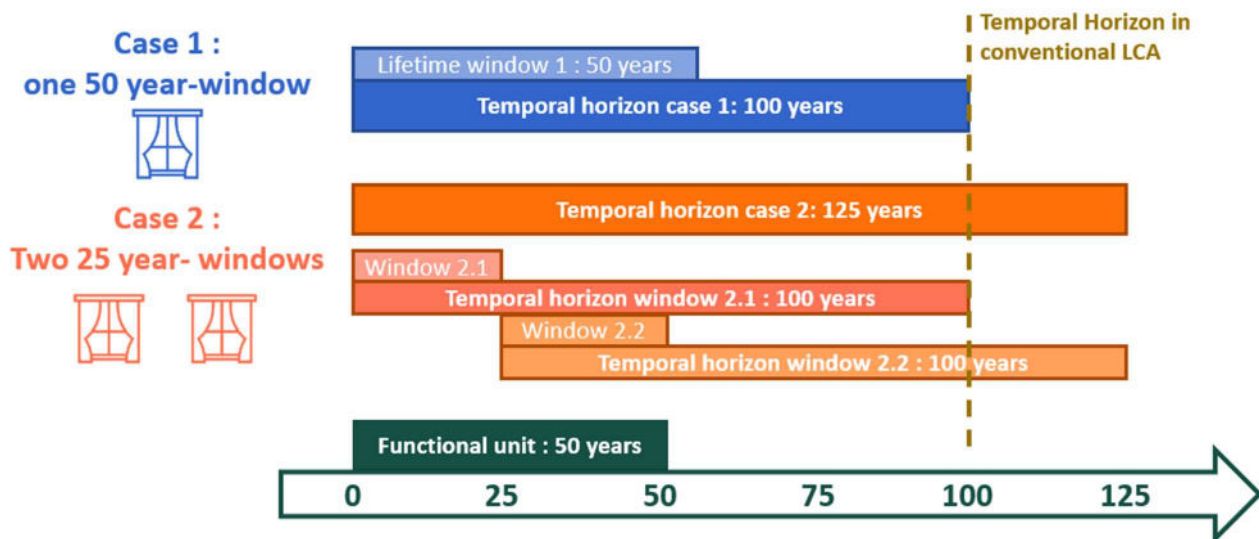
## 2.3.4 Time horizon for comparison

The time horizons for the life cycle and for impact characterisation must be taken into account and cautiously chosen for a fair comparison.

This point is illustrated in **Figure 3**. Suppose we want to know whether it is better to have one window lasting 50 years (case 1) or two windows lasting 25 years (case 2). The functional unit is 50 years (in dark green), and the time horizon of the characterisation method used is 100 years.

If the 100-year time horizon of the method used is assumed, part of the impacts associated with the second window of case 2 will be cut, since the impacts of this window are delayed 25 years. The total impacts of case 2 are therefore underestimated.

In dynamic LCA, the choice of a longer time horizon (e.g. 200 or 500 years) would take into account all the impacts of both systems and thus ensure a fairer comparison between the two cases.<sup>5</sup>



**Figure 3 - Diagram showing the management of time horizons in the case of time-shifted emissions, using an example of a window with different lifetimes.**

## 2.4 Summary : Dynamic approaches and keys issues

**LCA practitioner** cannot directly apply dynamic LCA on all elements that can be subject to dynamism because some aspects are specific to the data developers (primary elementary flows) or to the characterisation model editors (characterisation factors).

**Collaboration between stakeholders is therefore essential for the development of dynamic LCA.**

<sup>5</sup> The choice not to consider a time horizon of 125 years is deliberate. In fact, this time horizon is far too specific to the practical case in question. Dynamic LCA must not lead to the creation of a multitude of new indicators. For this reason, we recommend considering restricted time horizons of 20, 50, 100, 500 and 1000 years, based on the work of (Joos, et al. 2013) and leave it up to the practitioner to choose the time horizon best suited to his or her case study.

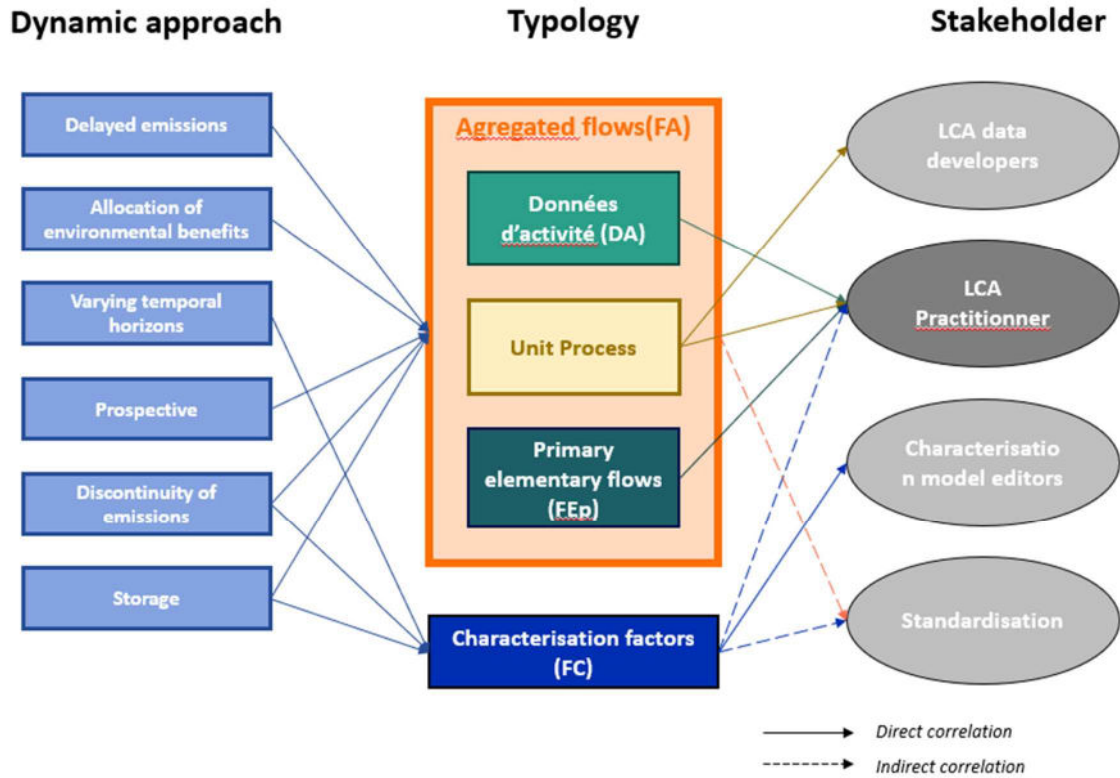


Figure 4 - Dynamic approaches classified by type and stakeholder.

## 2.5 Sectors using the dynamic approach.

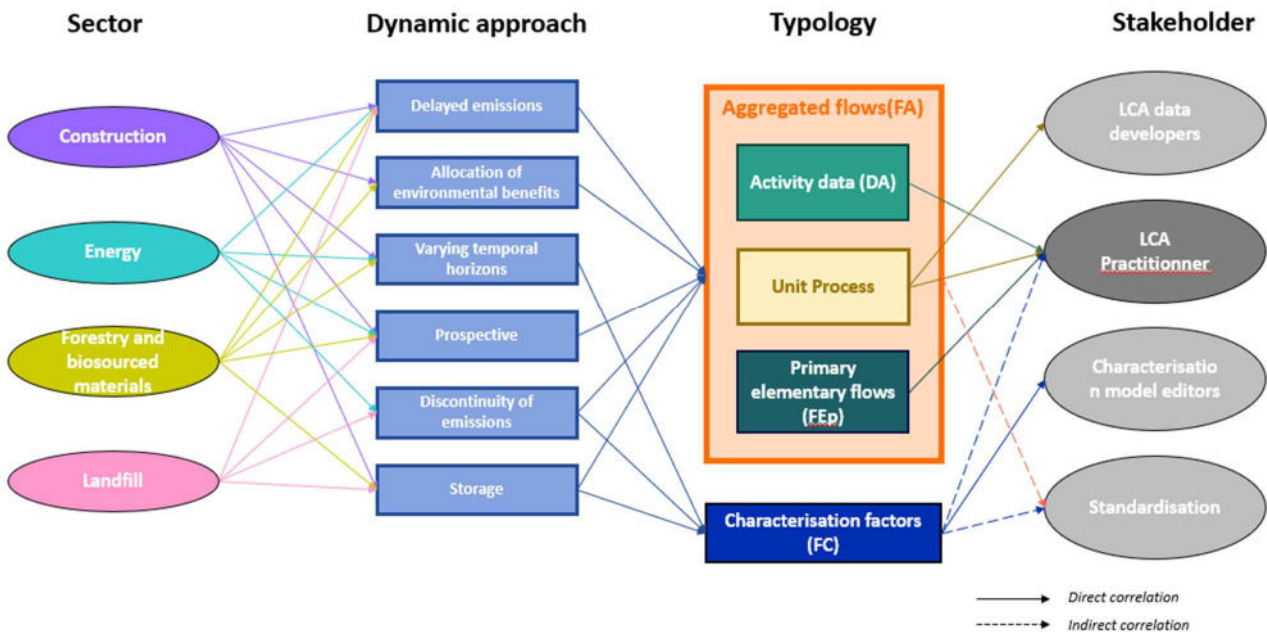


Figure 5 – Main sectors and type of dynamic approach used.

## 2.6 Relevant impact categories to the dynamic LCA

### Climate change

The main key points where dynamic approach can be integrated :

- **The choice of a time horizon different from the 100 years**, set by the most common characterisation model, *i.e.* IPCC 2021.
- **The management of delayed emissions**
- **The carbon storage** in bio-based materials

### Toxicity

The relevance of the dynamic approach is linked to changes in the properties of the toxic substance and in exposure conditions. The key points of the dynamic approach are therefore :

- **The time horizon considered for substances.**
- **Changes in the characterisation factor over time**

### Resource depletion

Mineral resources are not depleted in the strict sense of disappearing. There is no loss of material, but their accessibility varies because of their dispersion or storage in the technosphere or in waste. The dynamic LCA approach to resource depletion must focus on two main aspects:

- **The management of delayed emissions : the date on which the resource was used** (or made available again) is essential.
- **The adjustment of the characterisation factors** to reflect this effective loss of availability

### Use of water

The dynamic challenge of water consumption needs to check the correlation or decorrelation between the consumption period and favourable or unfavourable weather conditions. Dynamic LCA makes it possible to consider seasonal approaches, particularly in terms of **characterisation factors**.

## 3 Criteria for deciding to carry out a dynamic LCA.

Four main criteria have been identified for conducting an LCA

- **Systems that vary over time**
- **A particularly long-life cycle**
- **Significant impacts after time t0**
- **Environmental phenomena that vary according to the time of emissions**

The Figure proposes criteria for considering when to carry out a dynamic LCA:

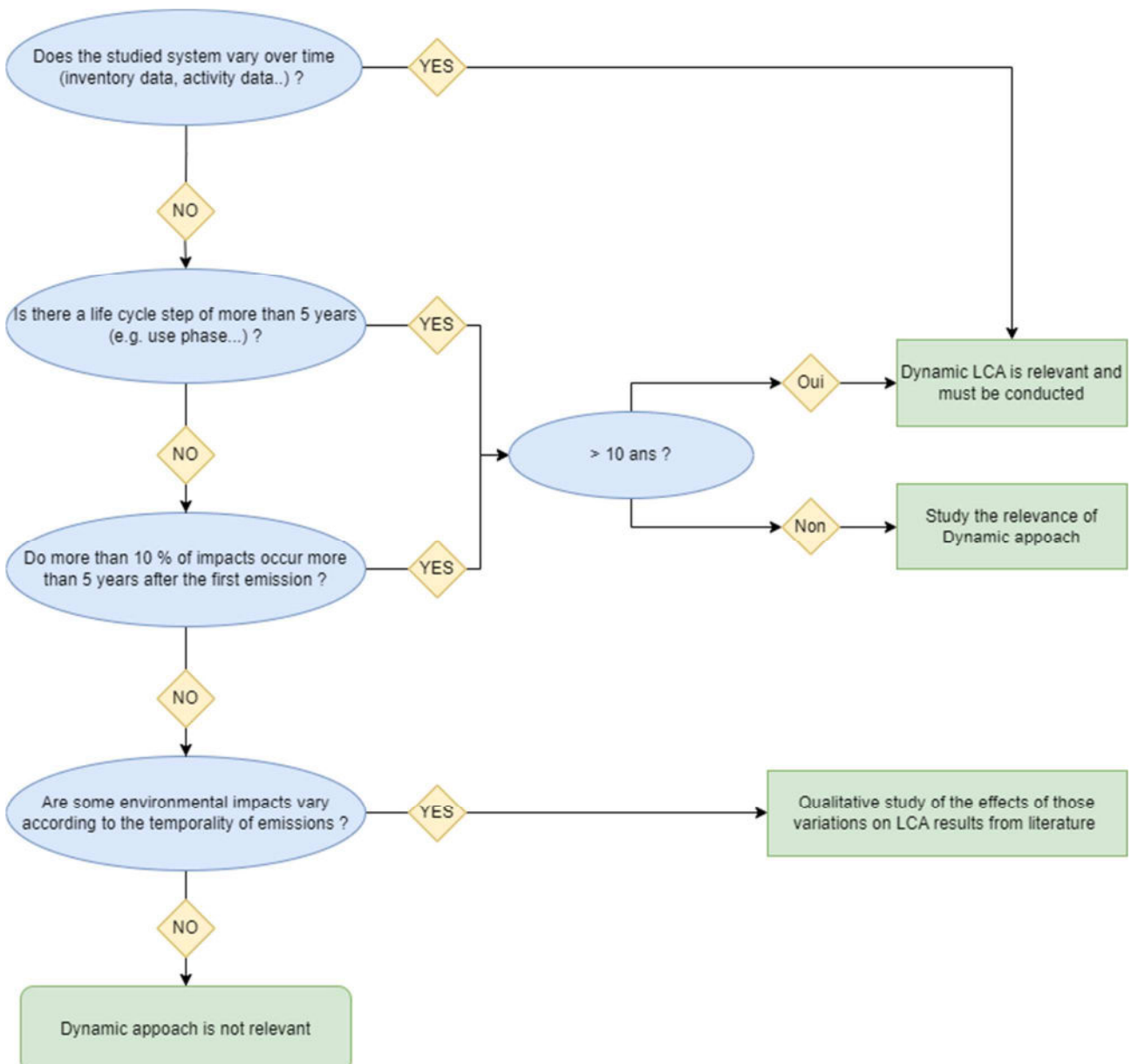


Figure 6 - Decision support flowchart for the dynamic LCA approach.

## 4 Risks of not considering dynamic LCA

### 4.1 Risk of comparing materials unfairly

When comparing materials, consider Dynamic LCA helps to consider

- **Storage or immobilisation of resources**
- **Delayed emissions, which will therefore have different impacts over time**

### 4.2 Risk of wrong decisions for prospective

Neglecting future effects can lead to poor choices.

*Example:*

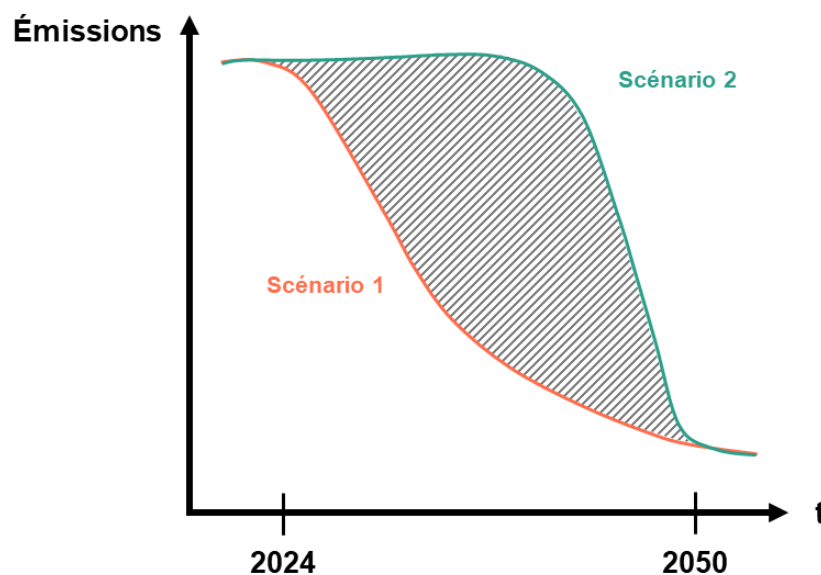
- *carbon compensation by planting trees, but without really ensuring how long the forest will grow.*
- *in buildings, insulation is recommended, but if the electricity mix is decarbonised, the issues will not be of the same order.*

### 4.3 Risk of cumulation of emissions due to late decision-making

In decision-making frameworks, for both public organisations and private companies, it is common practice to set targets for reducing emissions by 2030 or 2050 and to communicate these, for example through SBTi (Science Based Targets initiative) targets.

The approach does not take into account the dynamic issues between the declaration and implementation of emission reduction measures. In fact, the longer it takes for an emission reduction measure to be put in place, the more the initial situation continues to emit, which can lead to a significant accumulation of emissions.

This limit is shown in **Figure 7**. Two scenarios start from the same emissions level in 2024 and hypothetically reach the same emissions reduction target in 2050. However, implementation does not take place at the same time (scenario 1: immediate, scenario 2: late). The difference between these two scenarios is represented by the grey area, which corresponds to the accumulation of emissions in scenario 2 compared with scenario 1 as a result of the later decision.



**Figure 7 - Representation of two scenarios with the same emission reduction targets but different temporal effects. The hatched area represents the difference in emissions between the two scenarios.**

## 4.4 Risk of neglecting some toxic molecule effects

As the time horizons are fixed, the effect of certain very toxic substances in the short term is neglected, whereas the effect of other toxic substances in the long term is overestimated.

## 4.5 Risk of lack of critical review on impact categories

The values established by characterisation models attempt to model environmental issues, which has the effect of inducing a certain simplification.

Some parameters need to be discussed when interpreting the results. This is particularly true for the time horizons defined by the characterisation models.

## 5 Recommendations: How should dynamic LCA be used?

10 methodological fiches have been drawn up, each covering one action for carrying out the dynamic approach. They are accompanied by an additional note and are listed according to the five stages involved in carrying out an LCA, as follows:

1. Goal and scope definition
  - Fiche 1 - Positioning emissions over time
  - Fiche. 2 - Considering a common time horizon when comparing systems
  - Fiche 3 - Defining future scenarios
2. Data collection
  - Fiche 4 – Introducing temporal variation in activity data
  - Fiche 5 - Introducing temporal variation in elementary flows
3. Life Cycle Inventory
  - Fiche 6 - Introducing temporal variation background processes
4. Impact assessment and characterisation
  - Fiche 7 - Considering appropriate time horizons for characterisation models
  - Fiche 8 - Using characterisation factors to take into account the variability of impact over time
5. Interpretation
  - Fiche 9 - Presentation of dynamic results
  - Fiche 10 - Performing sensitivity analysis to show the importance of taking the time factor into account

The flow chart below helps to select which methodological fiche follow in which case :

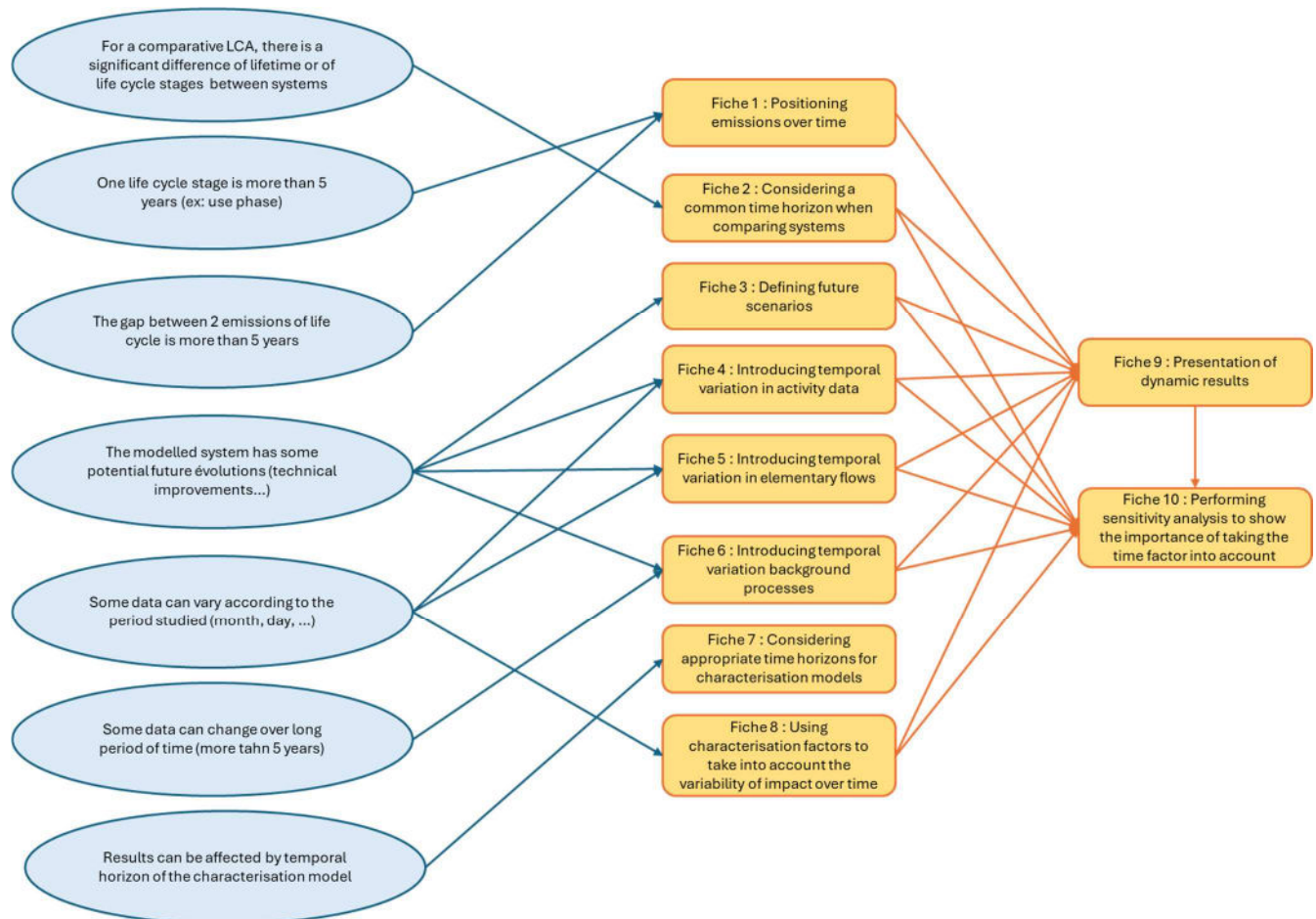


Figure 8 - Diagram to help select the relevant technical data sheets for a dynamic LCA.

## 6 Avoiding pitfalls in Dynamic LCA

### 6.1 Over simplify

There are a number of cases where it is appropriate to use a dynamic LCA approach, the aim being to enhance the environmental relevance of studies involving significant temporal variability (long-life products, seasonal energy consumption, etc.) that is poorly represented in conventional LCA.

However, by oversimplifying the approach, there is a risk of drawing conclusions that are themselves contrary to the objectives of sustainable development. It is therefore important, when establishing a dynamic LCA approach, to think carefully about its consequences for the final results.

### 6.2 Neglect uncertainties

Dynamic LCA involves, by definition, modelling future and therefore uncertain temporal elements. As highlighted in Fact Sheet No. 10, it is always recommended that practitioners apply sensitivity analyses, working by scenario, to highlight these uncertainties, with the aim of making the environmental assessment more relevant. These sensitivity analyses can be applied to the time horizons considered, the ranges of values used for activity data or inventory processes, etc.

However, it is up to the LCA practitioner to weigh the potential benefits of a sensitivity analysis against the time and budget constraints available.

## 7 Limits of Dynamic LCA today

### 7.1 Limited availability of operational tools

For Dynamic LCA to be applied by practitioners, it is important to have operational tools. At present, however, there is no tool that can be used to carry out a complete Dynamic LCA. There are, however, a few tools available:

- Climate Change Impact Tool (**CCI-tool**) developed by INSA Toulouse, which can be used to construct an inventory in the form of a time series of data (in Excel).
- The Excel tool called "**dynCO2**" developed by the CIRAIG, which allows the temporal distribution of emissions to be taken into account using an integrated dynamic inventory.
- The **ECOFACT** tool, developed by the Pré Sustainability consultancy, which provides real-time energy data at different timescales (hourly, daily, etc.).
- The DyPLCA and Temporalis tools, which make life cycle inventories more dynamic, but which are still under development.

### 7.2 Considerable time and budget

Taking account of dynamic effects in LCA requires more time and budget than conventional LCA. It is not always appropriate to undertake a dynamic LCA. If the relevance is validated, it is necessary to identify which aspects of the LCA need to be implemented.

If dynamic LCA develops (along with associated tools), its application will become increasingly fluid.

### 7.3 Lack of case studies in the literature

There is still a lack of examples of dynamic LCA applications in the literature to provide a robust method for dynamic LCA.

**It is necessary to motivate the scientific community to adopt dynamic approaches in their LCAs, even if these are only partial. This makes it possible to adapt the methodologies being developed and to highlight some recurring blocking points.**

## 8 Further work

According to the importance of Dynamic LCA in some particular cases, a note has been established to give arguments for the integration of some specific part dedicated to Dynamic LCA at standardization level .