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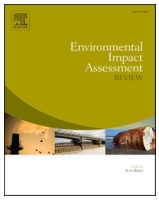

Covering key aspects of time in life cycle assessment (LCA) through a harmonized set of types – From time-conventional LCA to consequential dynamic prospective LCA

Thomas Schaubroeck *

RDI Unit on Environmental Sustainability Assessment and Circularity, Luxembourg Institute of Science and Technology (LIST), 5 Avenue des Hauts Fourneaux, Esch-sur-Alzette, L-4362, Luxembourg

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ABSTRACT

Consideration of time is essential for a better specification and quantification of environmental impacts of product systems in the field of life cycle assessment (LCA), from forecasting future systems to the temporary carbon storage effect in wood products. Yet, such developments are impeded through limited or inconsistent specifications of types of LCA. This viewpoint aims to clear the fog from a theoretical perspective. Three key aspects of time for LCA are brought forward. For each one, different types are specified using definitions selected/derived from literature that are harmonized and allow to cover combinations. The first key aspect is the conceptual reference point in time (around which the system is generated), distinguishing: "retrospective" for (far) past; (near) "present"; and "prospective" for (far) future. Another aspect is specification over time in modelling (whether flows and processes are distributed and adapted over time), with: "static" (one point in time), "dynamic (time)" (time differentiation) and "dynamic (total)" (time evolution). The third is conceptual propagation over time (how processes are linked starting from the reference point), with "attributional" (tracing before and after function start in time) and "consequential" (induced processes after decision). These sets of labels/types can be combined, e.g. "attributional static present" LCA. The latter example could be dubbed "time-conventional LCA" to limit the word string, which is also a general point of concern. Even though our classification is just a proposition and implementation depends on community acceptance, it guides consistent practice, points out future research directions and facilitates communication.

1. Introduction

To better evaluate the environmental impact of product systems, the aspect of time has become more prominent, in particular in the field of Life Cycle Assessment (LCA). A notable example is the consideration of (temporary) storage of carbon, e.g. in biomass-based products (Bjarvin et al., 2025; Dodoo et al., 2026) or concrete carbonation (Xu et al., 2026), and its implications on climate change or its accounting (Levasseur et al., 2011). Moreover, time consideration allows for consideration of more accurate and dynamic effects (Beloin-Saint-Pierre et al., 2020; Schaubroeck, 2022a). On the contrary, the ISO 14040 & 14044 standards (ISO, 2006a, 2006b), key documents in the field of LCA, provide little specification or guidance on the distribution of processes over time, whereas advancement is advised (Schaubroeck, 2022b). Hence, in this work, we will focus on coverage of different aspects of time through LCA types and definitions.

Various literature has touched upon aspects of time in LCA, dating back a long time ago (Hofstetter, 1996; Phungrassami, 2008), but fresh developments, with related new typologies (e.g. prospective LCA) and interest, merit a revisit of certain key aspects. Moreover, even recent works commonly focused on only one aspect of time regarding typology, or rarely two, but no more. Notably, some works only focused on LCA types for future considerations (Arvidsson et al., 2024), others mainly on the dynamic and time-differentiating aspect (Arias et al., 2026; Beloin-Saint-Pierre et al., 2020). Recent efforts focus more on integrating latter two (Lang-Quantzendorff and Beermann, 2025; Müller et al., 2025; Toniolo et al., 2026), although chiefly from a modelling perspective. However, only few combine these with the aspect of propagation of processes over time (Schaubroeck et al., 2021; Weidema, 2003). To allow specification and communication, multiple types of LCA

* Corresponding author.
E-mail address: thomas.schaubroeck@list.lu.

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have been specified to align with these notions (prospective, dynamic etc.). Yet, various notions and definitions are present in literature and are not always consistent, may lack harmonization or are not combinable to cover different configurations of time specification. These latter issues will become apparent when discussing different time aspects in detail in further sections.

In light of above issues, the novelty and aim of this viewpoint would be to provide an overarching complete coverage of key time aspects in LCA through a set of harmonized types and definitions that can be newly combined to that end. Hereto, the following stepwise strategy is executed in this work, corresponding with respective sections:

a. Define aspects of time from scratch that are of relevance in LCA, regardless of (existing) type definitions and their labels (Section 2)
b. Shortly touch upon typologies and ways of classifying LCA (Section 3)
c. Select or specify types of LCA per configuration of time aspect (as specified in step a), and clarify how they can be combined (Section 4)
d. Discuss challenges, further outlook and provide take-home messages (Section 5)

To be clear, in this study, we do not focus on concrete specification(s) of modelling of processes or the system as a whole, considering these time aspects. Recently, Sporchia et al. (2026) provided mainly a concrete elaboration on certain time typology and their combination through the common LCA modelling approach of typical matrix representation and calculations, which is useful and informative through its concreteness. This can help the practitioner, and we often refer to their work throughout the manuscript. Yet, since there is no single LCA model type (with many degrees of freedom in ISO 14040-14044) and it is in fact an open framework (Schaubroeck, 2022a; Schaubroeck and Benetto, 2024), it is fitting to then also leave modelling procedures unspecified to have a more overarching viewpoint when it comes to typologies.

2. Aspects of time in LCA

At the basis of LCA is the environmental impact assessment of a product system. Such product system and further environmental or social impact propagation, exist out of a network of processes linked/driven through flows, called here “system”, that are related with a certain product or decision of concern. This means that our elaboration covers both the life cycle inventory (LCI) and impact assessment (LCIA) phases and processes. The latter also includes any possible valuation mechanisms, which can also be influenced or driven by time such as discounting or even time cut-off (i.e. setting a time horizon) (Lueddeckens et al., 2020; Yuan et al., 2015). Note that such discounting and cut-offs can also be imposed because of practical limitations, but any certain modelling rule (e.g. linear) can be driven by that, which we do not cover here in general. Such valuation processes are abstract by nature and comprise also the calculation of indicators for which values can be influenced by time, e.g. Global Warming Potential over 100 years. Overall, in any network of processes, certain aspects come into play from a time perspective. We here focus on three aspects (as also shown in Fig. 1).

The **first aspect** deals with when the system occurs or rather the timing (calendar date) of a certain reference point of it. This is a reference point in absolute time and a singular point in time (unlike processes). Such reference point is also relevant to fix as the functional unit (FU) should as well cover when the functionality is provided, and comparison between product systems should take that into account (Pigné et al., 2020; Schaubroeck et al., 2020). This functional unit can explicitly (light provided for one year) or implicitly (100 km transport as FU will last a while) cover a period of time, as already pointed out in old literature (Phungrassami, 2008). A prominent choice selected here for this reference point is then also the start time of the functional unit, labelled “function start”. For LCAs focused on decision-support, it could also be the decision time point. Others could be conceived, but we stick to these two in our work. Furthermore, a reference point needs as well to be selected in time because the network of processes may be spread over time and occurs related to this exact point.

The latter brings us to the **second aspect**: specification of processes over time. This aspect covers the modelling of processes (both industrial and environmental) over time and its flows. A distinction needs to be made between (1) “time differentiation” and (2) “time evolution” of processes. The first, i.e. differentiation, concerns the explicit spreading of processes and flows over time, e.g. process X continuously emits compound Y over Z years. Yet, alteration/evolution of processes can occur, where the processes, their amounts and flows, are changed based on different conditions or state of other processes or background, requiring implicitly time differentiation. A complete picture is the second type of “time evolution” with alterations explicit over time, meaning that it is a more advanced version of the first type.

A **third aspect** is how to propagate this spreading of processes over time, relative to the reference point in time, i.e. when the function start or decision occurs. Are processes cast backward of the reference point or forward, or both? Is it one process after the other or can they overlap?

3. Typologies of LCA – A spectrum of conceptual versus modelling

LCA is a very broad notion, and even in the ISO 14040-14044 standards (ISO, 2006a, 2006b), there are many open methodological choices as things are not (fully) fixed or specified in the texts of these standards, e.g. concerning the intended goal of the study. Matters are further complicated through crucial inconsistencies, which is also why we follow here the open definition of product system, as specified in literature (Schaubroeck et al., 2022). Given the degrees of freedom, many types of LCA have been defined in the past with labels used as adjective/prefix (e.g. consequential LCA), leading to an “alphabet soup” (Guinée et al., 2018). However, what is a bit an overlooked feature of these classification, as also relevant for the topic time, is that certain typologies of LCA relate more with specification of modelling frameworks (heuristic and mathematical procedures, with improved ones leading to better precision or accuracy) and other more with specification of concepts (which theoretical question they answer, i.e. specifying the aim), with lack in clarity or distinction between them. These two notions are explained more in detail by Schaubroeck et al. (2021). In fact, typology concerning conceptual specification relates with “goal” and modelling relates with “scope”, the two separate aspects as defined in the first phase of LCA in the ISO 14040-14044 standards (ISO, 2006a, 2006b). For LCA types that specify modelling framework or related attributes, “IO-based LCA” (Suh and Huppes, 2005) and “multilinear LCA” (Heijungs, 2020) are clear examples. For the conceptual typology, a clearcut example is “consequential” LCA (see Table 1), although it may have often been presumed to present a sole distinct modelling framework. Note that there is an interplay between “conceptual” and “modelling”, in the sense that a concept implicates or restricts modelling specifications, e.g. additivity in attributional LCA necessitates a model that can provide that such as multilinear (Schaubroeck et al., 2021), or a certain LCA model may or may not fit a certain conceptual question. What set further hurdles, is that certain type definitions may contain both modelling and conceptual specifications, as apparent later on in this work. Yet, this classification allows to better distinguish and guide users in grasping LCA typology, especially related to time.

4. LCA types per key aspect of time and their combination

Many definitions of LCA types exist in literature. The primary idea here is to preselect the ones that are combinable, and through their combination can cover all configurations of all key aspects of time, specified in Section 2. A second criterion for selection is finding those that are following the criteria for definition selection set out by

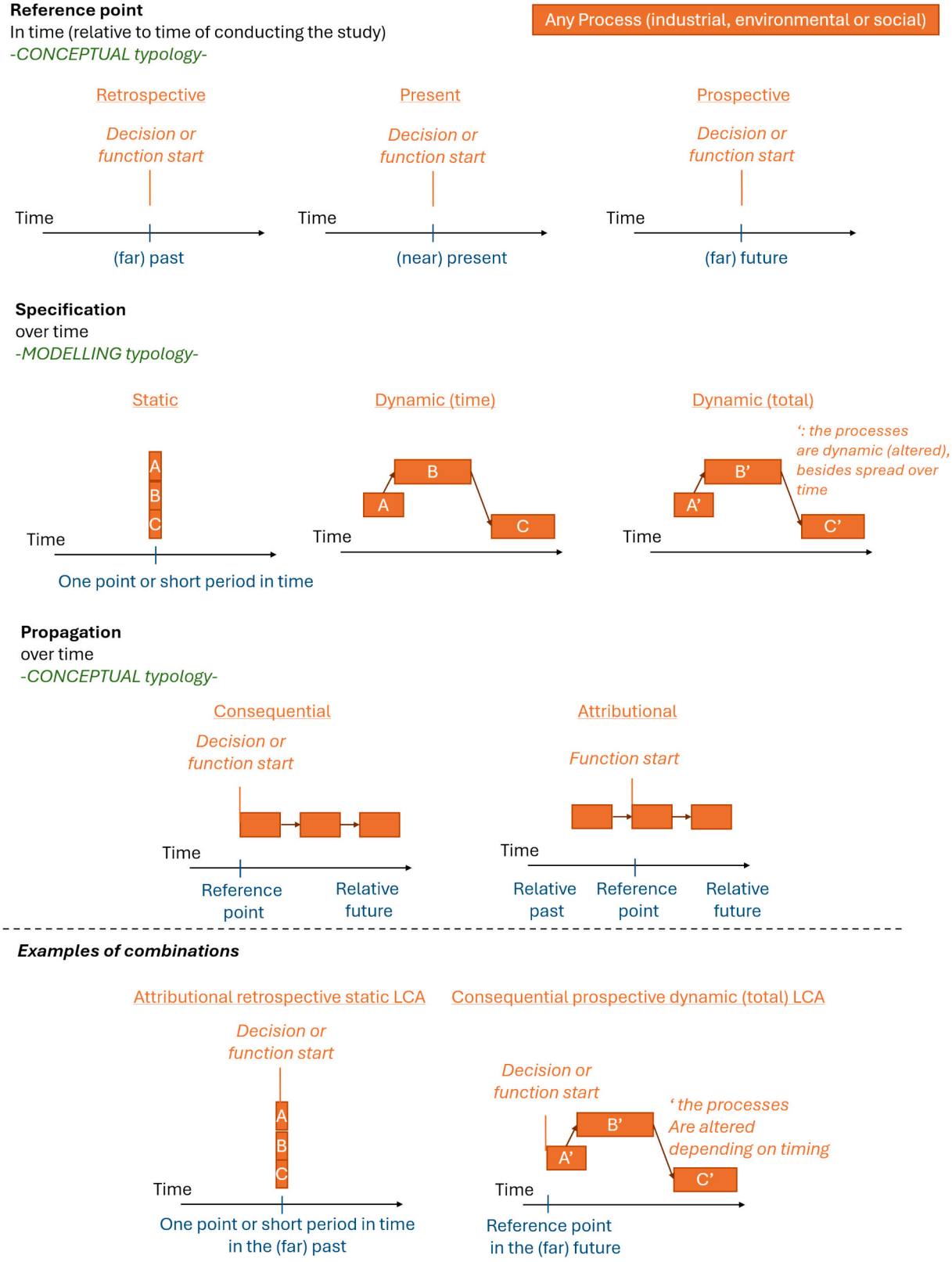

Fig. 1. Simplistic scheme of different configurations, with associate labels, for the three key aspects of time (reference point, specification and propagation) in life cycle assessment. At the bottom, examples of combinations of these are shown. The orange blocks depict processes, which is not necessarily restricted to industrial ones.

Table 1
Harmonized set of LCA types according to time aspects, following preselected definitions. Note that further modelling characteristics are then deduced from these and are not (all) explicitly listed here (e.g. prospective LCA implicates the need to adapt life cycle inventory and impact modelling to future conditions). Each type can be combined with another one for a certain aspect.

Time aspect & LCA types	Original preselected definition	Reference	derived definition
Reference point in time			
Prospective	"The absolute timing of a product provision or decision, leads to a distinction between subtypes of LCA. If this is done in the past, we speak of a retrospective LCA and when done in the future, a prospective LCA"	(Schaubroeck et al., 2021)	function start or decision happens in the (far)* future (relative to the time at which the study is conducted)
Retrospective	"The absolute timing of a product provision or decision, leads to a distinction between subtypes of LCA. If this is done in the past, we speak of a retrospective LCA and when done in the future, a prospective LCA"	(Schaubroeck et al., 2021)	function start or decision happens in the (far)* past (relative to the time at which the study is conducted)
Present		Deduced, as in complementary to other definitions	function start or decision happens in the (near)*present
Specification over time**			
Static		Deduced, as in complementary to other definitions	System presumed to occur at one point or short period in time, i.e. its processes are occurring all at once, and without dynamics.
Dynamic (time)/ time-differentiated	"LCA studies where relevant dynamic of systems and/or temporal differentiation of flows are explicitly defined and considered"	Beloin-Saint-Pierre et al. (2020), part of its definition, *focused on "*temporal differentiation of flows are explicitly defined*"	System is spread over time, i.e. its processes are differentiated over time.
Dynamic (total)/ time-explicit/time-evolving	"an approach to LCA which explicitly incorporates dynamic process modelling in the context of temporal and spatial variations in the surrounding industrial and environmental systems"	Collinge et al. (2013);	System is spread over time and evolves over time (implicating e.g. altered modelling of future processes)
	"LCA studies where relevant dynamic of systems and/or temporal differentiation of flows are explicitly defined and considered"	Beloin-Saint-Pierre et al. (2020) definition as a whole (covering "and" condition)	
Propagation over time			
Consequential	"The consequential approach attempts to provide information on the environmental burdens that occur, directly or indirectly, as a consequence of a decision (usually represented by changes in demand for a product)."	(Sonnemann et al., 2011; UNEP-SETAC, 2011)	processes are propagated in a consequential manner into the relative future after decision or function start
Attributional	"The attributional approach attempts to provide information on what portion of global burdens can be associated with a product (and its life cycle)" "The system analysed ideally contains processes that are actually directly linked by (physical, energy, and service) flows to the unit process that supplies the functional unit or reference flow"	(Sonnemann et al., 2011; UNEP-SETAC, 2011)	Attributional processes are interlinked with the function start, proceeding and preceding it, and thus happen in its relative past and future

* As mentioned in the text, a time span of 5 years before and after the timing of the study is proposed as (near) present, whereas beyond it is considered as retrospective or prospective.

** We also defined in the main text "dynamic (change)", as in only covering dynamics of processes as us, without explicit temporal differentiation. Yet, since time is the focus of this work, it is not explicitly mentioned in the table.

Schaubroeck et al. (2021), with no other work having presented such an argued selection. Note that definitions that are not selected by us are not necessarily wrong, but just regarded as less relevant to advance the field in covering all aspects of time. The final set of selected definitions is presented in Table 1 and Fig. 1. Here we discuss them per key aspect, keeping in mind compatibility with other key aspects of time.

4.1. Reference point in time

Regarding the reference point in time, this is a conceptual matter as it covers when the propagation of the system starts from that point, regardless of modelling efforts. Much research has now been about quantifying future impacts with prospective LCA, but its core definition is still debated. A key and popular (much cited) work for its definition is that of Arvidsson et al. (2024), which focuses on terminology. Its core definition of prospective LCA is: "LCA that models the product system at a future point in time relative to the time at which the study is conducted". The latter definition is not wrong, but it is not open to spreading the product system over time, making it not in line with our criteria. Hence, we did not select it. The static/instantaneous consideration of product system in the definition of Arvidsson et al. (2024) can be regarded as a modelling restriction, but conceptually it is questionable as product systems and processes are naturally spread over time. However, older literature had already provided fitting definitions, that are open to combination with the other two key aspect (differentiation over time and (propagation over time). Weidema (2003) already made clear that prospective and retrospective LCA just deal with having as reference point future and past actions, respectively. Yet, the notion of "action" is different from "decision" as used in consequential LCA definitions (see Section 4.3), and for attributional LCA, action is to unspecific and unrelated with product life cycle. Hence, we therefore follow a slightly adapted definition of Schaubroeck et al. (2021), presented in Table 1, from which we can derive that prospective and retrospective LCA, respectively, is an LCA where function start or decision happens in the (far) future or past, respectively. The only thing that should be added, based on Arvidsson et al. (2024), is that this is "relative to the time at which the study is conducted". The discussion on "action" versus "decision" in CLCA is considered out of scope of this work, but could be relevant to explore.

Yet, besides prospective and retrospective LCA, it is also needed to

specify a "present" LCA. Such "present" LCA would consider the reference point (function start or decision) to occur in the near present, related to the timing of the study. We use the term "near", since of course it cannot actually occur in the relative present as this is *Now*. Present refers to the (near) current time set of conditions. Hence, prospective and retrospective LCA refer to (far) future and past conditions respectively. This also leads to the question where the time cut-off is of (near) present. This is an arbitrary question. In practice, we consider that 5 years seems the maximum acceptable for calling something near present in LCA-terms, which is also the common validity period for a third-party verified Environmental Product Declaration report (Acampora et al., 2026; International EPD System, 2025; ISO, 2026), but it may also be shorter. This 5 year time span for "present" LCA, i.e. 5 years after and before (10 years range), might still imply that modelling and data are adapted for slightly different years. This illustrates the challenge when not introducing a modelling typology, but it is less likely that such huge alterations will take place.

Despite the focus for this key time aspect being conceptual, a lot of definitions of prospective LCA have drawn from practice and modelling frameworks. It seem to have been often synonymized with the practice of using Integrated Assessment Models (IAMs) to adapt the LCI background system, notably adapting the ecoinvent background database using Premise (Sacchi et al., 2022). Yet, a restrictive interpretation of prospective LCA to only such latter modelling approaches, falls sort of the conceptual nature of prospective LCA and the many other modelling advancements that are needed. An example is that eventually also environmental processes should be modelled considering altered future background environmental conditions, as done by Baustert et al. (2022) for water scarcity. Sporchia et al. (2026) provide a basic matrix representation (Eq. (4) in their work) for (static) prospective LCA, which does not consider augmented matrices, making it clear that the "prospective" implication can be rather in the data fed to the matrices and modelling behind it. Related to prospective LCA is also the notion of ex-ante LCA and anticipatory LCA, on which there has been debate and confusion regarding their difference with prospective LCA (Arvidsson et al., 2024; de Souza et al., 2023). Ex-ante is in our work a subtype of foreground prospective LCA (see Section 4.5) that focuses on analyzing emerging technologies and includes the forecasted upscaling through modelling of inventories, with these upscaled processes normally happening in the future (otherwise there would be no need for upscaling modelling). Yet "ex-ante prospective" LCA can be used as a label to emphasize that there is both a reference point in time in the future and upscaling of certain foreground processes. We do not go deeper into "anticipatory LCA", but regard it as a less popular term and overlapping with "prospective", and therefore redundant.

4.2. *Specification over time*

As a network of interconnected processes does not happen instantaneously in reality, the specification over time of a system in LCA should be ideally always strived for to reflect reality accurately. This is echoed by the ISO definition of "life cycle" in the amended ISO 14044 (ISO, 2020):"consecutive and interlinked stages, from raw material acquisition or generation from natural resources to final disposal", where "consecutive" implies a distribution over time. Ideally, every LCA should have a specification over time of a system, but it is challenging to achieve. Hence, this means that the typology for this key aspect of time relates a priori with the modelling framework, not with conceptual focus or the research question. For certain conceptual specifications (e.g. only consider climate impact until 100 years after start point) it may be required, but all LCAs should strive for a specification over time. It is different from pinpointing the reference point, where one can be interested in a product provided at present or at future, which is just a different aim.

Concerning terminology and typology, things are complicated here, as well in literature, which also relates with a (lack of) distinction between (1) time differentiation, (2) time evolution. The difference between latter notions has already been highlighted in Section 2. The same word "dynamic" has been used for both of them, which is also apparent from the key definition by Beloin-Saint-Pierre et al. (2020): "LCA studies where relevant dynamic of systems and/or temporal differentiation of flows are explicitly defined and considered". Notice the crucial wording "and/or", which means "dynamic LCA" may cover either one of both arguments or a combination, and is thus unspecific on this matter. We can thus, based on their definition, distinguish between three types of "dynamic" LCA. Given the complexity of labels and types for this topic, we propose a way out that still uses "dynamic" given its popularity/uptake, but with a specification between brackets. Yet, besides these, we add the straightforward synonyms of time-differentiated and time-evolving, which might be more usable. To give an exemplary idea we refer to modelling frameworks that present it in terms of matrix computation, which is the common modelling approach in LCA, but other mathematical frameworks are possible. The three types are:

1. "**Dynamic (change)**" The consideration of dynamics without explicit time differentiation exists (e.g. one can consider the changing electricity mix over a broader period of time but still present it at just one time point by the average). "This relates with the first argument of Beloin-Saint-Pierre et al. (2020): "LCA studies where relevant dynamic of systems" … "are explicitly defined and considered". Conventional matrix calculations as such, Eq. (1) in manuscript of Sporchia et al. (2026), will not include dynamicity, but instead aggregated data for one time step (without time differentiating) could be used as retrieved from evolving data or from dynamic models, e.g. agent-based modelling or system dynamics (Koide et al., 2026; Schaubroeck and Benetto, 2024).
2. "**Dynamic (time)**"/"time-differentiated", which only relates with temporal differentiation. This relates with the second argument of the definition of Beloin-Saint-Pierre et al. (2020): "temporal differentiation of flows are explicitly defined and considered". A concrete representation in terms of matrix computation is Eq. (6) in the work of Sporchia et al. (2026) when it comes to the inventory.
3. "**Dynamic (total)**"/"time-evolving", which covers both aspects, and thus besides temporal differentiation also dynamics, as in changes in processes and amounts, i.e. with both combined "time evolution". This relates with considering the version of definition of Beloin-Saint-Pierre et al. (2020) with both: "LCA studies where relevant dynamic of systems" and "temporal differentiation of flows are explicitly defined and considered". A concrete representation in terms of matrix computation is Eq. (5) in the work of Sporchia et al. (2026), and Eq. (15) by extension since they also mention "one could envision a dynamic LCA where all matrices are augmented reflecting all time steps", referring to that equation.

Yet, dynamics are only considered in this work with an explicit differentiation over time, covering "time evolution" and thus the first type, "dynamic (change)", is not of focus here. Moreover, "static" would refer to anything that is not differentiated over time, and all processes occurring instantaneously, which is thus not possible for "dynamic (time)" or "dynamic (total)", but is still valid for "dynamic (change)". Yet, the difference between "static" LCA and "dynamic (change)" is that the latter covers explicitly dynamics and the former hence implies considering the system and its processes as explicitly continuous or constant, i.e. in steady state. The latter might be (quasi) valid for certain processes, but this is not the case at system level, incl. product system (covering resource extraction, EoL etc., i.e. "the life cycle") and environmental processes (e.g climate change impact of CO_2 emission). The definition of dynamic LCA by Collinge et al. (2013), another key literature reference, seems to cover directly the "time evolution" type, i.e. "dynamic (total)". Recently, the notion of "time-explicit" has also been introduced by Müller et al. (2025) with related tool (Diepers et al., 2026), which is conceptually in fact the same as "time evolution" and

thus "dynamic (total)", where both processes may alter and are differentiated over time. Given the recent popularity of this term, we however also propose to accept this synonym. Some further specification are made in the latter work (Müller et al., 2025) on actual modelling in studies that are labelled "dynamic", but we look at the actual definitions regardless of limitations in certain case studies or works. These authors, Müller et al. (2025), also introduce a novel impressive time-explicit modelling framework but here we aimed to regard their definition from a general perspective, i.e. detached from very specific modelling approaches. Furthermore, the three types of time-related effects (transition dynamics, process dynamics and dynamic impacts), specified by Lang-Quantzendorff and Beermann (2025), relate also with configurations of this second key aspect in time as they are time-related modelling matters. Their classification is at a more granular level, distinguishing process dynamics from transition dynamics, and impact from inventory. It is regarded as a supplementary or parallel classification.

Our proposed definitions for specification over time, do not delimit combinations with other configurations of the other two key aspects. Concerning combination with the reference point in time (first key aspects), its implications are very different between time-evolving (dynamic(total)/time-explicit) and those that are not ("static", dynamic (time) and dynamic (change) LCA). For the latter, it is presumed that the reference point is, besides the time of occurrence (static or dynamic (change) LCA) or the starting point (time-differentiated LCA), also the time that defines the background state and conditions (e.g. CO_2 concentrations or technology level) for all processes. For dynamic (total) or time-evolving LCA the reference point in time serves only as an absolute anchoring point from where to start to differentiate the processes time, and the background conditions and state of these processes are dependent on each of their timing. Notice that in dynamic (total) LCAs, there can also be readily processes in the future or past (relative to when conducting the study), and thus in need of similar adaptations as done in prospective or retrospective LCA. For example, even in a prospective dynamic (total) attributional LCA (e.g. wood product with provision in 2040), there can be processes that trace back for years even to the past (e.g. wood growth could have started in 1950s since forest rotation periods can last hundred years), of which relevant flows and impacts should ideally be adapted to those past conditions.

4.3. Propagation over time

This is probably the least addressed aspect of time in literature. Many time-related works deal with dynamic or prospective LCA, but this key aspect is not so well regarded. Foremost, it directly relates with another type of (conceptual) question, namely the way processes are interlinked, which is also a core aspect in the system specification. This brings us to the prominent types of attributional LCA (ALCA) and consequential LCA (CLCA) (Sonnemann et al., 2011; UNEP-SETAC, 2011), of which selected definitions are presented in Table 1. The argumentation of the selection of these definitions (and not others) for ALCA and CLCA, and the relevance of their distinction, has already been provided in other works (Schaubroeck, 2023; Schaubroeck et al., 2021). The propagation over time is very different for these two approaches, ALCA traces interlinked processes into the past and future, relative to the function start point. CLCA propagates processes into the relative future of the decision. Note that in both ALCA and CLCA, the propagation over time in the life cycle impact assessment is purely consequential (Schaubroeck et al., 2021). This difference between ALCA and CLCA over time is exemplified by Sporchia et al. (2026) in Section 6.5 of their manuscript in terms of matrix algebra, by having only zero values for elements that cover the relative past in consequential LCA, whereas in attributional LCA this is not the case. These notions indirectly include the consideration of a reference point (first key aspect of time), for example function start for ALCA and decision for CLCA. They are also open to further specification in time of processes (second key aspect of time). However, for "static" consideration for the second key aspect of time, namely specification over time, there would be no explicit propagation over time, but implicitly the processes would still be induced/linked following either attributional or consequential logic.

4.4. Combinations of types and typologies

Having specified different key aspects of time and their configuration with associated LCA types and terms, this now presents the opportunity to provide combinations of these to cover all time-related specifications, i.e. highlight and cover different time-related research questions and certain modelling efforts. Examples are shown in Fig. 1. The most common LCA for current reporting standards, such as Environmental Product Declaration (Acampora et al., 2026; ISO, 2026, p. 14025), relate with an "attributional present static LCA", where the inventories are for the (near) present period ("present"), processes are presumed to occur at the same point in time ("static") and are tracing back and forward along the product life cycle, just not in time, starting from function start ("attributional"). Completely different would be a "consequential prospective dynamic (total) LCA", where the environmental consequences of a (far) future decision ("prospective") are studied, with propagation over processes in its further relative future ("consequential") and a modelling framework that explicitly spreads and dynamically alters processes and flows over time ("dynamic (total)"). Concrete combinations of types, focused on matrix representation, are also given by Sporchia et al. (2026).

4.5. Modelling heterogeneity

Conceptual typology and specification can more readily lead to discrete types, as the case in our work for anchoring point in time (retrospective, near-present and prospective) and propagation over time (attributional and consequential) Yet, given the complexity to implement practical LCA modelling frameworks or case studies that align with types, often only parts of the full LCA model are imposed certain time-related characteristics. This is prominent for the key aspect of specification over time since it is focused on modelling, and in practice a spectrum exists instead of solely clearcut discrete types, because of practical limitations. It is very rare and practically very challenging for an LCA to cover time differentiation or evolution for its full system, i.e. all its processes and their flows. In this context of modelling effort, a difference is often made between foreground, the network of processes of products system that are directly related to the object of study and that are commonly better specified, and the background, i.e. the processes that support the foreground system. For example, time-differentiation is practically only done for the foreground system, but operational tools are available for the background system, of which prominent ones are: Temporalis (Cardellini et al., 2018), related Timex (Diepers et al., 2026), and DyPLCA (Pigné et al., 2020). The latter "DyPLCA" framework is the only one that has an associated temporal database for a full background database (ecoinvent) (Pigné et al., 2020), allowing to conduct time-differentiation for the full product system. Alternatively, out of practical limitations, one can also impose ime-related modelling on selected processes for which time-related consideration is most relevant, e.g. as done by Collet et al. (2011), but that comes at the risk of overlooking many ime-related implications, e.g. systematic minor changes might induce a large effect. When it comes to prospective LCA modelling (i.e. not just the conceptual notion), through the software Premise (Sacchi et al., 2022), many studies have readily adapted the background system (here ecoinvent database) to certain futures. In general, a full implementation over both foreground and background is advised, considering especially the interaction that can occur between foreground and background. To better aid in such specification, we propose to add the modelling prefixes "foreground", "background" and "fully" or "full-system" (for the full system) to definitions. Examples are "foreground prospective" LCA, which upscaling in ex-ante would belong to, or "background prospective" LCA. These extra

prefixes only deal with practical modelling.

Besides foreground versus background modelling differences, another distinction is whether time modelling implications are imposed on LCI (human/industrial) and/or LCIA (environment, social) modelling. A striking example is that in many dynamic LCA, time-differentiation is applied to the LCI, where the product system or inventory is thus spread over time, but then time-dependent/dynamic characterization factors (CF) are applied in LCIA, which change depending on the timing of the elementary flows. This, in its totality, is reflected in Eq. (6) of Sporchia et al. (2026). A step further is the explicit spreading of the impact processes over time, e.g. operationalized for climate change impact (Tiruta-Barna, 2026, 2021) or toxicity considering the residence time of pollutants in compartments (Shimako et al., 2017). Similarly, for prospective LCA, prospective adaptations can either be reflected in LCI and/or LCIA, with only few cases also considering prospective CF (Barbosa Watanabe and Cherubini, 2026; Baustert et al., 2022). One could distinguish between label prefixes "inventory" and "impact" when only one of the two is covered, e.g. "prospective background inventory LCA".

Yet, overall, the totality of these practical LCA modelling discrepancies and combinations, is difficult to capture in clear typologies and labels of LCA. One could have within a single LCA, a foreground time-differentiated LCI, a background prospective LCI, and static (non-prospective) LCIA/CF. To put a label on such latter cases is a challenge ("time-differentiated foreground inventory, background prospective inventory, static impact" LCA). Hence, on the one hand, container notions can still be used for modelling implications, notably the notion of "dynamic" LCA for any LCA that goes beyond a static consideration when it comes to specification over time, which follows exactly the definition of Beloin-Saint-Pierre et al. (2020)for dynamic LCA. On the other hand, one may pick the typologies or aspects that are the main advanced element in the study, e.g. time-differentiated inventory LCA even though time-dependent CF are applied.

5. Discussion

The main strength of the specification of LCA types and related definitions in this work, is that they are harmonized, newly cover the three defined key aspects of time and can be combined. These consistent types/labels, provide readily more clarity on what a specific LCA entails and focuses on, from a time-related perspective. Yet, there are two challenges. The first main challenge of the "label" combination is that it results in long names, e.g. there are thus already at least three labels for time alone, e.g. "consequential prospective dynamic (total)" LCA. If one adds other specifications, e.g. foreground or background, the word string becomes even longer. Yet, this was to be expected due to the open nature of LCA method, even in the ISO 14040-14044 standards. The second challenge is that when it comes to modelling heterogeneity and its related labels, a vast spectrum of combinations is possible (as especially the case for time specification as a time aspect). We propose three solutions. First, a way out is to merge certain combined types and labels into new ones, even though that could again result in an amplitude of labels. For example, "static attributional present LCA" could be dubbed as "time-conventional" LCA. Second option is to have an agreed upon systematic technical sheet for LCA, where all information on type per aspect is specified and summarized in a clear way, covering also system boundaries etc. The latter could better cover the extensive set of combinations, especially with regard to the modelling heterogeneity, but would not lead to concise labels that could be easily communicated. Third is to still rely on container notions, such as the definition of "dynamic" LCA that covers any LCA that is not static. No solution is perfect, and we may better end up with a combination of them.

Nevertheless, our classification helps to pinpoint certain combinations that are still quite underexplored and very new. For example, consequential prospective and consequential dynamic LCA or the combination, have been hardly worked out, with certain key exceptions (Jouannais and Elliot, 2026; Lancz et al., 2024; Maes et al., 2023). In particular, the aspect of time propagation, and differentiation between attributional and consequential, in combination with both the other two key aspects (e.g. consequential dynamic prospective LCA; See Fig. 1), provides a particular novel direction. Hence, the set of definitions also guide the way for new, more consistent and relevant advancement in the field of LCA. Moreover, for concrete practitioner guidance, we referred in different sections mainly to one recent work (Sporchia et al., 2026). Because it is just one single piece of work, the reader might thus get less lost in literature, albeit their work focused on the matrix calculation approach solely. Yet, they also give an overview of prominent tools and software for dynamic and prospective LCA. If the practitioner has very few experience, we advise to start from elaborate works that start from scratch (Heijungs and Suh, 2002).

Finally, the presented final set of definitions is a thought-provoking proposition. Yet, the fixing of definition is partially based on non-scientific conventions such as through authoritative guidelines or standards. We can only plea for this set to be fixed since it is harmonized, coherent and combinable, or at least to spark or swiften further discussion and consolidation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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