SCORE LCA

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# “GREENHOUSE GAS" LCA INDICATOR, DEFINITION AND APPLICATION: THE TIME ISSUE

## SUMMARY

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## SUMMARY

Through a bibliographic review, studies and a simplified case study, the various temporal issues related to the "greenhouse gas" indicator used in Life Cycle Assessment are studied here:

- The distinction between GWP (Global Warming Potential) and GTP (Global Temperature Potential) is made, particularly concerning the temporal nuance between the two indicators, and the associated interpretation is carried out on the case study,
- The time horizon used for the GWP and whether or not Near Term Climate Forcers (NTCFs) are also considered, as these are also temporal issues, for which the sensitivity of the results varies
- Finally, a dynamic approach is considered, both in the inventory and in the characterization (prospective vision, accounting of flows distributed over time and associated temporal characterization factors).

## KEYWORDS

Climate change, GWP, GTP, NTCF, dynamics, building, wood, biogenic carbon.

## SUMMARY

# Introduction

The impact of greenhouse gases (GHGs) on climate change has become a key issue in many areas. However, environmental impact studies using the life cycle assessment (LCA) method systematically focus on the climate change indicator involving the global warming potential (GWP) of GHGs. This indicator is linked to the radiative forcing of GHGs, integrated over a 100-year horizon, without taking into account their date of emission or absorption (static approach). On the one hand, there are dynamic approaches both in terms of emission inventories and their characterization; on the other hand, complementary indicators have been developed, which take into account other /factors/ phenomena/ consequences/ such as the average rise in atmospheric temperature or the rise in sea level. The question remains as to when the use of one or the other approach is relevant, and research is still ongoing on this issue. Moreover, the tools and methods for effectively taking into account these other indicators or the temporal dimension of emissions (inventory and characterization phases) are not yet available to LCA practitioners.

# Objectives

The aim of this study was to take stock of current or recent research on the consideration of the temporality of GHG emissions and of climate change indicators other than GWP, and to carry out a case study that would make it possible to encompass these different concepts in order to identify their added value (marginal or indispensable) in the interpretation of impact results according to the context, and to develop associated recommendations.

# Scientific state of the art

## Temporal issues related to the choice of the indicator: GWP and GTP

Once the phenomenon of climate change and its contributors have been defined, which notably involve the notion of the carbon cycle and therefore the temporal aspect of CO2 emissions/sequestrations, its characterization is approached by distinguishing the available metrics, of an instantaneous or cumulative nature (thus involving a time horizon to be defined). These indicators are related to various consequences of climate change, and the relative weight of the different GHGs will potentially be very different depending on their lifetime in the atmosphere. The following indicators are used: radiative forcing (GWP), the most widely used and proposed in the first IPCC report (IPCC 1992); temperature change (GTP, Shine et al. 2005); sea level rise (GSP, Sterner et al. 2014); change in precipitation rate (GPP, Shine et al. 2015). These different impacts of GHG emissions otherwise follow a chain of causality. The procedure for calculating the GWP and GTP indicators is then explained: the GWP of a GHG involves its radiative forcing (W.m-2) which depends on the quantity emitted and the lifetime in the atmosphere, integrated over a given time horizon and normalized by the GWP of CO2. The GTP corresponds to the change in temperature occurring a certain number of years after the emission of the GHG, normalized by the change in temperature that would be induced by the same mass of CO2. In addition to radiative forcing, these calculations include climate sensitivity (K/W/m2) and the response time of the temperature change (years). Thus, compared to GWP, GTP has no memory in the sense that it refers to a given moment in time without cumulating the effects of the GHG emitted before the end of the chosen time horizon. As a result, the information on the strong impact of a GHG over a short lifetime is lost compared to the characterization by GWP (the example of methane being telling). However, GTP is now considered as robust as GWP by the IPCC, which recommends its analysis in its fifth report, as well as by UNEP, although more uncertain due to the fact that it reflects/ corresponds to a more advanced effect in the GHG emission causality chain. Compared to the IPCC RCP (Representative Concentration Pathway) scenarios, which show the evolution of the concentration of different GHGs over time, these climate change indicators are calculated downstream.

Concerning the characterization factors to be used, a review of the reference systems that have established recommendations has been established: those of the IPCC (2013) remain consensual, but some (such as UNEP/SETAC) recommend the use of factors that take into account the feedbacks of climate change (influence on the global carbon cycle by modifying the rates of respiration and photosynthesis of soils), which are not considered in the IPCC 2013 method.

## The time horizon

After explaining the various climate change indicators and the existing recommendations on the characterization factors to be favored, the place of the temporal dimension in the calculation of GWP and GTP is discussed through the following aspects: choice of the time horizon, radiative efficiency via the dependence on the concentration of GHGs in the atmosphere over time, degradation of GHGs in the atmosphere, climate sensitivity and response time of the climate system. This temporal dimension explains the evolution of the metrics over the course of the IPCC reports.

The time horizon (HT) chosen - to integrate cumulative metrics or to consider the effects of an emission after a given time for instantaneous metrics - can be fixed (time window of HT duration for each GHG) or variable (each GHG emitted at ti is assessed over the HT- ti time window). In both cases, the most commonly used is the medium-term horizon of 100 years, although it is questionable, at the very least, to consider it alone, given that the effects of short-lived GHGs are spread out over time and therefore less perceptible over the 100-year assessment period. Conversely, a short-term horizon (typically 20 years) may lead to neglecting the effects on the climate of longer-lived GHGs. Thus, it seems relevant not to draw conclusions from a study that has only evaluated the effect of GHGs on one or the other of the time horizons, but to compare at least two of them. UNEP thinks in terms of short-term and long-term impacts, which can be characterized by GWP100 and GTP100 respectively, and therefore recommends the use of these two indicators. Characterisation by GWP20 and consideration of Near Term Climate Forcers (NTCF) are recommended as sensitivity studies.

The radiative efficiency of a GHG depends, among other things, on its concentration in the atmosphere and potentially on that of other substances, and therefore varies over time.

Similarly, the degradation of GHGs in the atmosphere takes place over a given time, with the exception of CO2 for which it is not a matter of degradation but of absorption by carbon sinks. Note that the latest models show an increasing saturation of natural carbon sinks (i.e. a higher fraction of CO2 remaining in the atmosphere over time). The degradation equations and the constants involved are explained.

The climate sensitivity and response time of the climate system is also a function of time via the dynamics of heat absorption by the oceans.

## Dynamic approach

These different considerations lead to the /question/ of dynamic characterization factors and prior dynamic life cycle inventories (in the framework of dynamic LCA) and their importance. It is noted that the issues related to the consideration of temporal dynamics are particularly important in the field of building: energy consumption according to seasons and supply mix according to years, dynamics of emissions and capture of biogenic carbon, evolution of characterization factors in time. In general, time-dependent emission profiles can be important to consider, especially for the comparison of products with different profiles, as the results are evaluated over different time periods. It may then be relevant to use a fixed point in time, bearing in mind, however, that an emission occurring later will have less impact than the same emission occurring earlier (Albers et al. 2019).

To carry out a dynamic inventory, the elementary flows must follow a temporal distribution. The evolution of the electricity mix over the years, the variability of the use of certain products or services, or prospective modelling are examples of dynamic life cycle inventories.

Once the inventory has been completed, the dynamic characterization of the impacts on climate change can be carried out. The methods developed so far propose to consider a fixed point in time to define the time horizon of each GHG according to its emission date, which can allow, for example, to estimate compensation times for mitigation of land use emissions, or to calculate the effects of biogenic carbon emissions from long-rotation biomass (Cherubini et al. 2016). The calculation procedure and associated equations are then detailed. In perspective, in order to /obtain fully dynamic characterization factors/ fully transcribe all dynamic phenomena through the characterization factors/, prospective values for the degradation function and for the radiative efficiency of GHGs should also be developed. The illustration of these dynamic issues through the application to the wood energy and building sectors given by Cornillier et al. (2015) is included as an example.

The dynamic approach is particularly relevant for systems involving the biogenic carbon cycle, notably to better assess the real compensation of emissions obtained by carbon sequestration over a given time, while the static approach limits the relevance of this assessment. However, for the time being, there is no consensus as to which dynamic flux modelling approach to adopt and how to integrate it into current environmental assessment methods. Indeed, more or less complex methods for developing biogenic carbon emission-sequestration profiles have been proposed, which take into account biomass growth dynamics but may also include soil organic carbon dynamics or economic models. As highlighted by recent work (Fouquet et al., 2015; Albers et al., 2019), the choice of the order of modelling of the carbon cycle (sequestration-emission or emission-sequestration) also has a very important impact, in attributional LCA, on the results of dynamic modelling of climate change: sequestration followed by emission tends to decrease the impacts compared to the hypothesis of climate neutrality, whereas modelling emission then sequestration tends on the contrary to increase these impacts. The nature of the forest (sustainable management or not) indicates in particular the perspective to adopt (historical or future) to account for carbon sequestration. In a consequential LCA, these questions do not arise.

A bibliographic review of the most recent versions of standards, guidelines and methodological guides is then carried out, updating the inventory of the SCORE LCA 2013-02 study. The existing references are LCA guidelines, sectoral reference systems and carbon footprint calculation reference systems. Secondly, the scientific publications that have dealt with dynamic LCA and the proposed approaches are summarized by detailing the sector and the objectives, the time horizon and the characterization factors used (GWP and/or GTP), the dynamic nature of the LCI and the characterization, and finally the case study used and its results.

# Case study

## Introduction

The considerations of the previous points lead to a case study on the life cycle of a wood-frame building (single-family house of 130 m²). Only the wooden components were modelled (Simapro 9.1.1.1 software, Ecoinvent 3.6 database) and the life cycle includes the following stages: growth of the forest, felling, joinery and construction of the house, use of the house (41 years), end of life (burial, incineration or sending to a sorting platform). In particular, the use phase consists of the heating of the house, 100% electric, in order to test the use of prospective electric mixes. For the fraction of wood bought back by particleboard factories at the end of its life, the 15804+A1 standard stipulates to consider a re-emission of CO2: this end-of-life pathway is then modelled by a flow of biogenic CO2 corresponding to the quantity of carbon contained in the fraction of wood bought back. For buried wood, a 15% degradation of the wood over 100 years is considered.

## GWP: scope and time horizon

First, a characterization of the static GWP is carried out using the IPCC 2013 GWP 100a v1.03 factors, which implies that the "carbon dioxide, in air" and "carbon dioxide, biogenic" fluxes are not characterized because they are considered to be neutral for the climate. Thus, the main GHGs contributing to GWP are identified, and their respective contribution is compared to the proportion of GHGs emitted that they represent (in mass).
The following sensitivity analyses are then conducted for the static approach:

Comparison with the result provided by the previous method IPCC 2007 GWP 100a (which does not characterize the fluxes "Carbon dioxide, in air" and "Carbon dioxide, biogenic"): the result is very close (1.1% difference), the method used among the two does not change the conclusions of the present case study.

Taking feedbacks into account: CFs incorporating feedbacks vary from 11 to 23% compared to CFs without feedbacks. However, the difference in results over the life cycle of the house is only 2%, rather related to the fact that the emissions of substances affected by the feedbacks are low in the system studied.

o To illustrate the potential larger variations that can be generated by taking into account feedbacks, two other systems are analysed, in which the substances adapted to take into account feedbacks are emitted in larger quantities: 1 kWh of the French low-voltage electricity mix (intensive in fugitive SF6 emissions at the level of transformers), and 1 kg of beef by live weight (intensive in CH4 and N2O emissions). For the first system, only a 1.5% variation of GWP is observed, against 12% for the second one: thus, depending on the system studied and the GHGs involved (nature and quantity), the feedbacks can induce a significantly different result for GWP.

NTCFs (Near Term Climate Forcers, i.e. primary aerosols, precursors of tropospheric ozone formation or secondary aerosols that can influence the climate by absorption or scattering of solar radiation and by other complex chemical and physical interactions) are taken into account: the factors proposed by IPCC 2013 GWP100a are used to characterize the impact of these substances, adding

manually that of black carbon because it is not inventoried in SimaPro. The impact result decreases by 15% when they are taken into account, mainly because of NOx and SO2 despite the small quantities emitted. On the other hand, carbon black has an insignificant impact (<0.01%).
- Change of time horizon (20 years, 500 years): the impact decreases by a maximum of 18% from 20 years to 500 years, with a 13% decrease between 20 and 100 years, mainly due to CH4; the 6% decrease between 100 and 500 years is rather due to NOx.

## GTP

Comparison to GTP: the GTP 100a factors from the IPCC 2013 report Annex Table 8.1.A are implemented in SimaPro to be able to evaluate this indicator. The comparison focuses on the conclusions obtained in the case of modelling a prospective evolving electricity mix for the house use phase, depending on whether it is assessed with GWP or GTP (i.e. do the use of GWP and GTP lead to the same trends/conclusions?). For the exercise, the M1 scenario ("Diffuse distribution of renewable energies on the territory") of RTE's "Energy Futures 2050" Long Term Forecast is modelled with a 5-year time step until 2060 and Ecoinvent background data for each energy source. The static mix for comparison is the French Ecoinvent 3.6 mix. The difference in impact between the two scenarios (static or evolving mix) is almost identical with both indicators, and in the same direction: the evolving mix scenario has less impact with the GTP.

## Dynamic approach

In a second step, a comparison of the results of the static analysis with those of a dynamic analysis is carried out. Concerning the use of a dynamic inventory alone, the example of the evolving electricity mix is used to illustrate the impact of its use on the result of the use phase (GWP or GTP of the evolving mix lower than that of the static mix). When using a dynamic characterization of the impacts using the DYNCO2 v2.0 tool. (Note that not only are emissions from electricity generation per year modeled, but also emissions from background activities are made dynamic, due to the use of Ecoinvent data; Normally, only the emissions related to electricity production should be entered in DYNCO2), by entering the main emissions of the mix contributing to the GWP over a time step of 5 years, the impact reached after 100 years is much lower than the one obtained with the static characterization, and the latter would eventually be reached after a very long time (> 2000 years). The emissions of the main GHGs over time using the prospective mixes are plotted and the two main electricity sources in the mixes contributing to their GWP are identified.

Finally, different /methods/hypotheses/ of wood life cycle modelling (tree growth and end of life) are compared and, for each, their results with the static and dynamic approaches:

Wood reuse modelled by biogenic CO2 emission in the same year as incineration and landfill (standard 15804+A1) : with the assumption that the growth of the forest takes place over 45 years, with a constant carbon removal each year (linear accumulation) - having previously calculated the carbon content of the wood and the quantities emitted in the form of CO2 at the end of its life and identified the quantities of CO2, CH4 and N2O emitted via the SimaPro modelling in order to be able to inform them in DYNCO2 - the static result is positive, in particular because of the re-emission of a part of the carbon in the form of methane; On the other hand, in dynamic mode, the impact is still very negative 100 years after the last emission, due to the fact that CO2 capture from the first year of growth is integrated over longer time horizons.

oA sensitivity analysis to the carbon sequestration equation over time (linear so far) is conducted by considering the vegetation growth rate equation of Cherubini et al. (2011) as a function of time and rotation period (which gives a sigmoidal annual CO2 removal curve: compared to the linear dynamics, the difference in impact (100 years after the last emission) is 1%, i.e. negligible.

Wood reuse modelled by considering its ultimate end of life (incineration) after the reuse period (40 years): the impact obtained is even more negative than in the modelling by a biogenic CO2 re-emission, because the emissions linked to the incineration taking place 40 years later have a lower characterisation factor

Growth of wood parallel to the heating of the house (with the prospective mix), and end of life of the house after the 41 years of use (without reuse): Emissions related to the production of electricity (tending towards decarbonisation in the example of the prospective mix used) take precedence over the total impact, the capture of carbon by the growth of the wood being useful only to "counterbalance" the emissions related to the end of life of the latter. Offsetting the emissions linked to the production of electricity would require planting a very large number of trees, and moreover avoiding a GHG-emitting end-of-life for the latter.

Finally, the influence of the temporal dynamics between the time of sequestration and the time of GHG emissions - until now considered as occurring in this order - is analyzed: emissions related to the end of the wood's life are modeled in DYNCO2 as occurring in the first year, and sequestration takes place in the second year via the forest's growth. Compared to the case where storage is considered first, the conclusion is quite different: the GWP impact 100 years after the last emission (i.e. at year 101) is positive, whereas it was negative when considering capture first.

## Conclusions

- The changes in the characterization factors provided by the IPCC, report after report, are significant. However, the differences observed in the case study are minor.
- The most commonly recommended and used time horizon is 100 years.
- More and more studies recommend the use of the GTP indicator, at least as a complement to GWP.
- The temporal dynamics associated with characterizing the impacts of GHG emissions lead to significant variations in results and interpretation,
- In particular, the temporal dynamics of biogenic carbon fluxes in the inventory phase lead to consequences whose effects on climate need to be assessed dynamically.

These last two points, as well as a series of publications in the building sector, lead us to believe that a case study in this sector is particularly interesting to illustrate the corresponding methods, results and recommendations.

- In our case study, the use of GTPs does not change the conclusions compared to the conventional use of GWPs.
- Similarly, the inclusion of the NTCFs does not change the overall conclusions of the study.
- On the other hand, taking into account the temporal distribution of GHG emissions, using dynamic GWPs, has a significant impact on the results.
  - In particular, the accounting of biogenic carbon, and the sequestration/release phenomena associated with it over time, leads in our case study to a significant reduction in the impact of climate change. By extension, we can also envisage significant impacts linked to the use of this dynamic approach in the case of long-lived fossil products (e.g. plastic elements used in construction).
  - It should be noted that from an operational point of view, the integration of this dynamic in the SimaPro software is not feasible (except to integrate a characterization factor per year of emission and per GHG, which would significantly complicate the inventory phase). This integration requires the use of multiple tools (at least two: an LCA tool and a dynamic calculation tool) which makes the approach not very ergonomic.
  - The use of the DYNCO2 tool in the present work allowed a first dynamic approach, on a :

- free of charge,
- of Excel type, for a good ease of handling and a simplicity of use
- based on the 5th IPCC report (2013): 207 characterized substances
- impact calculation based on an annual emissions inventory
- requiring knowledge of the emissions of each substance in the system (in life cycle), using LCA software to obtain inventories of the various substances emitted
- requiring a basic knowledge of LCA software to extract relevant information
- whose calculations and recordings are quite long (a few minutes),
- and which, in a concrete way, multiplies by 2 to 5 the time spent on the evaluation.

## Recommendations

The recommendations from this study are as follows:

The use of dynamic GWPs leads to potentially significant changes compared to a static approach. We recommend limiting the use of dynamic GWPs to cases where biogenic carbon or delayed fossil carbon emissions are present, and only as a complement to a static approach.

This implementation allows to anticipate the regulatory requirements, e.g. those related to the RE2020 in the building sector.

If the IT expertise is available internally to the LCA team, we recommend comparing the functions of the DYNCO2 tool with those available in Brightway2 Temporalis before implementing dynamic LCA. This tool could address the limitations identified in this study when using DYNCO2.

This type of tool should make it possible to distinguish emissions related to building infrastructures (which should only be reported in year 1) from those related to dismantling (in the last year), and emissions related to infrastructures needed throughout the production process (such as transport), in each year. These elements, not available in the SimaPro / DYNCO2 couple, make the analysis inaccurate (although these elements play a role at the margin).

Regarding the temporal sequence of capture and emissions, the conservative view is to consider emissions first, then capture.

In addition, we recommend that a time horizon of 100 years after the last emission be set as a practical matter. This ensures that GHG emissions are not excluded from the impact calculation.