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But when? Temporal compression in life cycle accounting for carbon dioxide removal

Conference session: Life Cycle Assessment

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If the fundamental purpose of carbon dioxide removal (CDR) is to mitigate global warming via the decrease of atmospheric greenhouse gas concentrations, then the key metric of CDR is the amount by which atmospheric GHGs decreased, the so-called “net removal”.¹ Thus, life cycle greenhouse gas accounting² (LCA), a modelling methodology used to estimate all GHG emissions associated with a system regardless of when or where they occur,³ arises as a necessary assessment tool to determine whether it is possible for a given CDR activity to result in net removal.

Conventional (or so-called “static”) LCA does not distinguish between emissions/impacts that happen at different points in time. This is a feature, not a bug: all impacts are weighted equally and characterized to the same time-horizon, thus giving an even treatment of impacts across a system's lifecycle and compressing them into a single-point “global warming potential” (GWP) metric. However, CDR systems display a diversity of intertemporal dynamics⁴ that define many of the relative advantages and disadvantages of each system. This nuance is lost or distorted in the temporal compressions that occur in static LCA, even beyond those occurring due to the limitations of the conventional GWP-100 characterization factors.⁵ In particular, as each emission or extraction—regardless of when they occur—uses a characterisation factor with the same time-horizon, static LCA has an inherently inconsistent impact time-horizon, thus distorting when a system exhibits net removals.

Critical questions about CDR that are not answerable via static LCA include:

- When does a system [begin to] result in net removals? (the so-called “carbon payback period”)

¹ Net removal = atmospheric CO₂ extracted and stored – all GHG emissions directly and indirectly associated with extraction and storage.

² Formally, a life cycle assessment should encompass encompassing multiple impact categories to provide a comprehensive picture of a system's environmental impacts and trade-offs. However, I am presently only referring to the estimation of life cycle impacts from greenhouse gases.

³ Including emissions of the activities themselves, as well as upstream emissions from supply chains and downstream emissions of use, waste disposal, and end-of life.

⁴ Including the rate of CO₂ uptake, the expected duration of CO₂ storage, the risk of reversal, and the timing of associated emissions relative to the timing of uptake and storage.

⁵ Such as the averaging of disparate impact profiles within the time-horizon, cut-off of impacts beyond the time-horizon, the zero-rating of biogenic CO₂ emissions, the inability to account for the impacts of temporary storage, and their dependency on the concentration of atmospheric greenhouse gases.

- When does a system stop resulting in net removals? (e.g., due to reversal or accumulated associated emissions, such as from ongoing monitoring and maintenance. This is of particular importance for systems where storage is fundamentally temporary or has a high risk of reversal.)
- When does a system exhibit peak impact or benefit?

Furthermore, as most forms of CDR are not yet implementable at the desired scale, CDR LCAs are predominantly ex-ante, assuming efficiencies and economies of scale which are not currently realized. Yet, LCAs on CDR rarely make explicit reference to the temporal boundaries or time-frame of the system and its impacts or consider the future developments of the background economic or climate systems. This often results in an unacknowledged "tomorrow's technology today" situation with a future foreground system but present-day background system.

Many LCA researchers are working on improving the handling of system temporality in LCA, such as via dynamic LCA,⁶ prospective LCA,⁷ and improved characterisation factors for temporary or delayed impacts,⁸ but static LCA with conventional characterization still dominates CDR literature. The relatively simple methodology of static LCA and its ability to answer the foundational question of a CDR system means that this is likely to continue. Therefore, I provide the following recommendations for improving the treatment of temporality in static LCAs on CDR systems:

1. Be explicit with temporal boundaries and assumptions, including the time frame of the system, duration of activities, the [projected] maturity of the CDR technology, the modelled duration of storage and impact time-horizons.
2. Storage monitoring and maintenance should be included, either for the entire storage for CDR requiring active maintenance or for as long as needed to ensure storage security.
3. Functional units should specify the storage medium and considered storage duration.
4. For systems with long rotation biomass, delayed uptake, or temporary storage, consider corrective characterization factors alongside standard factors
5. Characterize GWP over multiple time horizons.
6. Discuss temporality in the contribution analysis and perform sensitivity and uncertainty analyses on temporal characteristics-and variations in background systems.
7. Indicate the carbon payback period of a system.

⁶ Where impacts are considered over a fixed time-horizon, using dynamic characterization factors that account for when in the time-horizon the emissions occur.

⁷ Which alters background system databases to allow an LCA to explicitly consider technological developments under different scenario futures, such as the shared socioeconomic pathways.

⁸ Such as for the rate of biomass [re]growth, short-lived climate forces, temporary storage of CO₂, or for changing atmospheric GHG concentrations.