Framework for dynamic carbon accounting: development of complete carbon balances in LCA

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1. Introduction

Low carbon strategies promote the use of renewable energy carriers and biomaterials originating from dedicated and residual forestry and agricultural biomass (e.g. energy crops, woody residues, perennial grasses) [1], as, allegedly, carbon neutral options to displace/offset an energetically equivalent amount of fossil carbon. Life cycle assessment disregards the temporal variability of biogenic carbon (C_{bio}) flows, justifying the carbon neutrality hypothesis, and thus resulting in zero net CO_2 emissions [2–4]. Further challenges in carbon modelling are connected with carbon inputs to the soil contributing to soil organic carbon (SOC) and its associated land use/occupation [5].

The purpose of this work is thus to contribute to the methodological development of dynamic LCA, which incorporates the time dimension in the environmental assessment of products. The objective lies on developing a comprehensive framework for dynamic carbon inventories of biomass supply chains under consideration of the time-dependent growth dynamic, yields, land use and management practices.

2. Materials and methods

The proposed framework is aligned with the classic LCA framework, but emphasising the LCI phase, with the purpose of timing disaggregated annual C_{bio} flows of biomass use and consumption. The application of dynamic models allows developing temporal emission profiles of bioproducts, accounting for the temporal variation of the carbon exchanges from and to the atmosphere; representing a full lifetime carbon accounting. The dynamic inventories are further assessed with time-dependent characterisation factors proposed by Levasseur and colleagues [6] to estimate time-sensitive climate change effects and contrast them with static approaches.

Figure 1 illustrates the proposed framework, building on dynamic inventories, by considering: a) upstream models for non-linear biomass growth, above- and belowground C_{bio} sequestration, SOC dynamic associated to land uses, including management practices and yields; and b) downstream models for case-specific end-of-life release pathways, eventually delaying the GHG emissions due to long service life in the use phase.

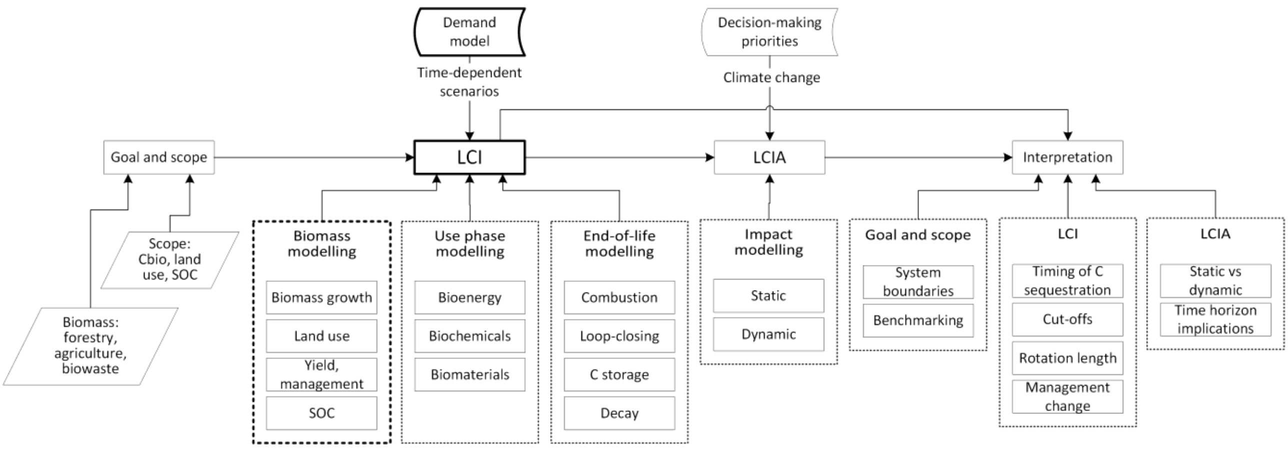

Figure 1: Proposed framework for dynamic carbon modelling of biomass-sourced products, emphasising on biomass, use phase and end-of life carbon modelling for full lifetime accounting within the life cycle inventory

Moreover, the framework is designed to be coupled with outputs from any demand model (i.e. specifying technical flows concerning the amount of biomass supply/use in a studied system or bioproduct) to develop complete dynamic carbon inventories (fossil + biogenic). The model coupling allows informing on time-dependent scenarios based on socio-economic flows to estimate the consequences of decision-induced changes (i.e. energy transition policies). The framework was tested with case studies on French energy policy, which propose alternative pathways of biomass-based (i.e. from forestry and agriculture) energy and transport.

3. Results and discussion

The overall results showed that both C_{bio} sequestration and SOC dynamic are case-specific, as the modelling and land use requirements depends on the biomass-type (e.g. plant growth and yields) and management practices (e.g. rotations, thinning, residue removal rates). It can be generalised that annual crops do not require dynamic growth modelling due to the one-year divergence point, however the C_{bio} content can be estimated from the yields for SOC modelling referring to account for the residual proportion (including roots) of the plant as input to the soil.

The mitigation results are sensitive to the model parameters (e.g. temperature and soil texture in SOC models), as well as to the modelling approaches undertaken concerning the setting of the temporal boundaries (future or historic time perspective for forest carbon sequestration), shortening the rotation length, and variations in the residue removal rates.

Coupling carbon models with demand models, such as partial-equilibrium, is useful for prospective evaluations and incorporation of socio-economic indicators in the assessment. However, adjustments are required in the simulations years to avoid, for instance, drastic cut-offs at the end of the simulation.

4. Conclusions

This work contributes to the improvements of the time-dynamic LCA methodology towards more robust decision support in defining actions to mitigate climate change. Accounting for dynamic flows allows developing C-complete GHG inventories and valuing C_{bio} sequestration of biomass systems to reduce uncertainty and bias in the climate change effects and mitigation results. Current static assessment approaches are inconsistent with the temporal boundaries and actual impacts, which may mislead decision-making in mitigation efforts. The temporal dynamic of biotic resources is non-negligible and should be taken into account.

The framework can be further developed by exploring the spatio-temporal dynamic of land use modelling and how temporal profiles of EOL pathway scenarios concerning net energy recovery and efficiencies, recycling loops (both closed- and open loops) (e.g. [7,8]), as well as secondary materials entering other life cycles (e.g. fertilisers, soil amendment, animal feed, wood fibres, etc.), which avoid or displace the use of primary raw materials.

5. References

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