European Commission

The European Commission's Knowledge Centre for Bioeconomy

Brief on the use of Life Cycle Assessment (LCA) to evaluate environmental impacts of the bioeconomy[1]

Key messages

1. Potential environmental impacts of bioeconomy sectors and the use of bio-based commodities must be monitored, evaluated and forecast in order to ensure that the bioeconomy operates within safe ecological limits (see section 1).
2. LCA is a structured, comprehensive and internationally standardised method used to assess potential environmental impacts associated with a product's life cycle (see section 2).
3. Different modelling principles allow for the development of approaches suited to a broad range of contexts and scales. The LCA modelling approach should carefully consider the goal and scope of the assessment in order to avoid misinterpretation of the results. Benchmarking products, checking compliance with regulatory requirements and evaluating the impacts of strategic decisions may require different approaches (see sections 3 and 4).
4. LCA that supports the implementation of policies should be easy to calculate, have well-defined rules, use a well-defined inventory and be of general validity across temporal and spatial scales. Elements of consequential thinking will benefit LCA that supports impact assessment of strategic policies (see section 5).
5. An open database with attributional LCA results for bio-based commodities, calculated or assembled by the JRC is available (see section 6). The updated Bioeconomy Strategy will help generate more and higher quality data (see knowledge gaps).
6. Despite the uncertainties and limitations, life-cycle-based approaches provide the most comprehensive, structured, consistent and robust means of assessing the environmental performance of bio-based products and systems within safe ecological limits (see section 7).

[1] This brief is based on the JRC Science for Policy report "Biomass production, supply, uses and flows in the European Union. First results from an integrated assessment" (Camia et al., 2018), unless stated otherwise.

1. Why do we need to assess the environmental impacts of the bioeconomy?

The bioeconomy covers all sectors and systems that rely on biological resources, their functions and principles. It includes and interlinks land and marine ecosystems and the services they provide, all primary production sectors and all economic and industrial sectors that use and produce biological resources and processes to produce food, feed, bio-based products, energy and services (EC 2018). On the one hand, activities in the bioeconomy sectors rely on healthy ecosystems to ensure primary production of biomass, and on the other hand, they risk damaging these same ecosystems. It is therefore necessary to monitor, evaluate and forecast environmental impacts associated with the expansion of bioeconomy sectors and the use of bio-based commodities in order to minimise and manage negative impacts on natural capital.

2. What is Life Cycle Assessment (LCA)?

LCA is a structured, comprehensive and internationally standardised method (ISO 2006) that aims to assess the potential environmental impacts associated with a product, a process or a system throughout its life cycle, from extraction of its raw materials to its end of life.

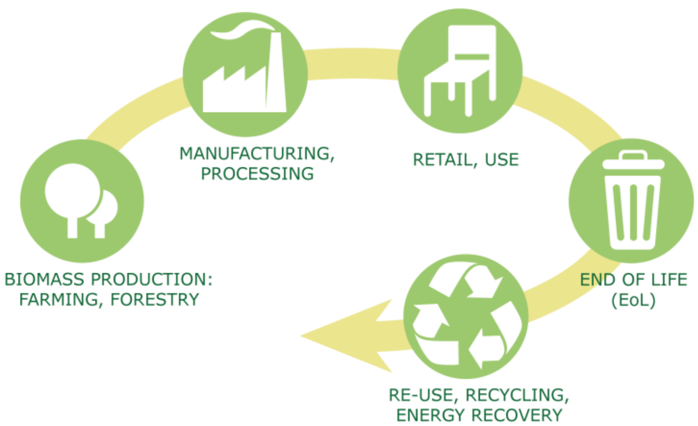

Figure 1: Life cycle stages that could be modelled in LCA

Its objective is to:

- quantify all relevant flows of raw materials consumed and pollutants emitted throughout the supply chain;
- comprehensively assess the potential impacts on the environment and human health of the entire supply chain of a product, and identify hotspots of environmental impacts across the supply chain;
- identify trade-offs between life-cycle stages, impact categories or regions that can lead to a shifting of environmental burdens.

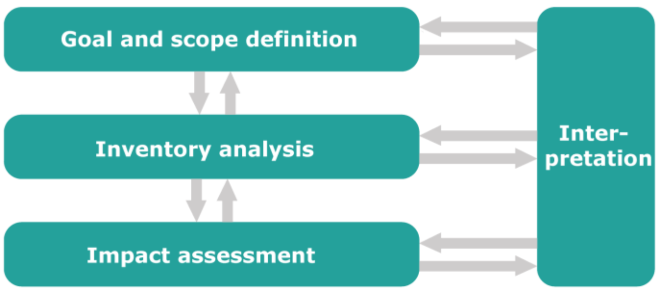

Figure 2: The phases of an LCA study (as per ISO 14040)

LCA is implemented in four phases: (1) goal and scope definition; (2) life cycle inventory (LCI); (3) life cycle impact assessment (LCIA); and (4) interpretation of the results. It follows an iterative approach, i.e. the interpretation of the preliminary results helps refine the first three phases towards the final results.

Specific European standards apply to bio-based products, e.g. EN 16760 (Bio-based products - Life Cycle Assessment) and CEN/TR 16957 (Bio-based products – Guidelines for Life Cycle Inventory (LCI) for the End-of-life phase), and other relevant issues, e.g. ISO 14067 (Greenhouse gases – carbon footprint of products). The Product Environmental Footprint initiative (EC 2013a) represents another step towards harmonising the application of LCAs.

3. Which modelling principles are used in LCA?

Two main modelling principles are used in LCA practice. **Attributional LCA (A-LCA)** assesses the environmental impacts associated with all stages in the life cycle of a product, a process or a system, from cradle to grave (i.e. from raw material extraction through processing, manufacture, distribution, use, etc.). **Consequential LCA (C-LCA)** identifies the consequences of a decision within the relevant system on other systems and processes of the economy. Figure 3 illustrates the main differences between the two principles.

	ATTRIBUTIONAL LCA	CONSEQUENTIAL LCA
OBJECTIVE	• To depict **potential environmental** impacts of a system over its life cycle	• To identify the **consequences** that a decision has on other systems, in the background and outside the boundaries.
MODELLING	• It uses **historical, average, measurable data** of known/knowable uncertainty. • It includes all processes identified as relevant contributors to the system being studied. • The analysed system **is modelled as it is** (or forecasted to be).	• The modelling is driven by market mechanisms, and potentially includes political interactions and changes in consumer behaviour. • It models the studied system around these consequences, **as a hypothetical, generic supply chain.**

Figure 3: Characteristics and objectives of the two main LCA modelling principles
Source: Adapted from EC (2010)

This theoretical distinction between the two principles has often led to confusion and debate within the scientific community. The next two sections highlight how LCA studies can, in fact, follow a spectrum of possible modelling approaches, depending on the context and scope, and support decision-making.

4. How can we avoid misinterpretation of LCA results?

The ISO standards for LCA (see section 2) give practitioners considerable freedom to define the model, conduct the assessment and ensure that the approach followed is appropriate for the goal and scope of the assessment. This needs to be validated during the interpretation phase (see Figure 2), during which the practitioners must also evaluate the robustness of the results, regardless of the modelling approach, and explore the effects of various assumptions and value choices through sensitivity analyses and uncertainty propagation analyses. They should also clarify the limitations of the study and of recommendations made in order to avoid generalisation of conclusions beyond the goal and scope of the study. The Product Environmental Footprint initiative (EC 2013a, 2013b), and the development of a range of Product Environmental Footprint Category Rules (PEFCRs) in collaboration with industry and other stakeholders, represent important steps towards harmonising LCA-based studies for product comparisons[2]. Nevertheless, the misinterpretation of LCA results remains a real risk with potentially serious consequences.

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[2] See http://ec.europa.eu/environment/eussd/smgp/index.htm

For example, an attributional LCA methodology is used to assess the greenhouse gas emissions associated with biofuels compared to those of fossil fuels, in order to evaluate compliance with the Renewable Energy Directive (EU 2018) and the Fuel Quality Directive (EU 2009a). This approach is appropriate for the specific regulatory goal that focuses on the comparison of the greenhouse gas profile of products. Purely A-LCA studies of bioenergy systems, however, are unable to capture the complex interactions between bioenergy, climate, and ecosystem services (e.g. market-mediated effects, bio-geophysical or time-dependent effects; EC 2016). Consequently, the same modelling principle may be less suitable for answering different questions, e.g. for performing a strategic assessment of the climate mitigation potential of a large-scale deployment of biofuels in Europe. Ignoring the differences of modelling approaches may result in the misinterpretation of LCA results and lead to suboptimal decisions with wide-ranging consequences. Lessons learnt during the past decade by LCA practitioners working on bioenergy are helping to improve the LCA modelling principles for bio-based commodities. For instance, they suggest that the real climate change mitigation potential of bio-based commodities can only be revealed if biogenic carbon, counterfactual uses of biomass and land, and indirect effects are considered.

5. What are the differences between LCA as a regulatory and as a strategic assessment tool?

Since the 1990s, LCA has been used to support a variety of policies (Sala et al., 2016). Figure 4 illustrates various examples of different LCA modelling approaches to support policy.

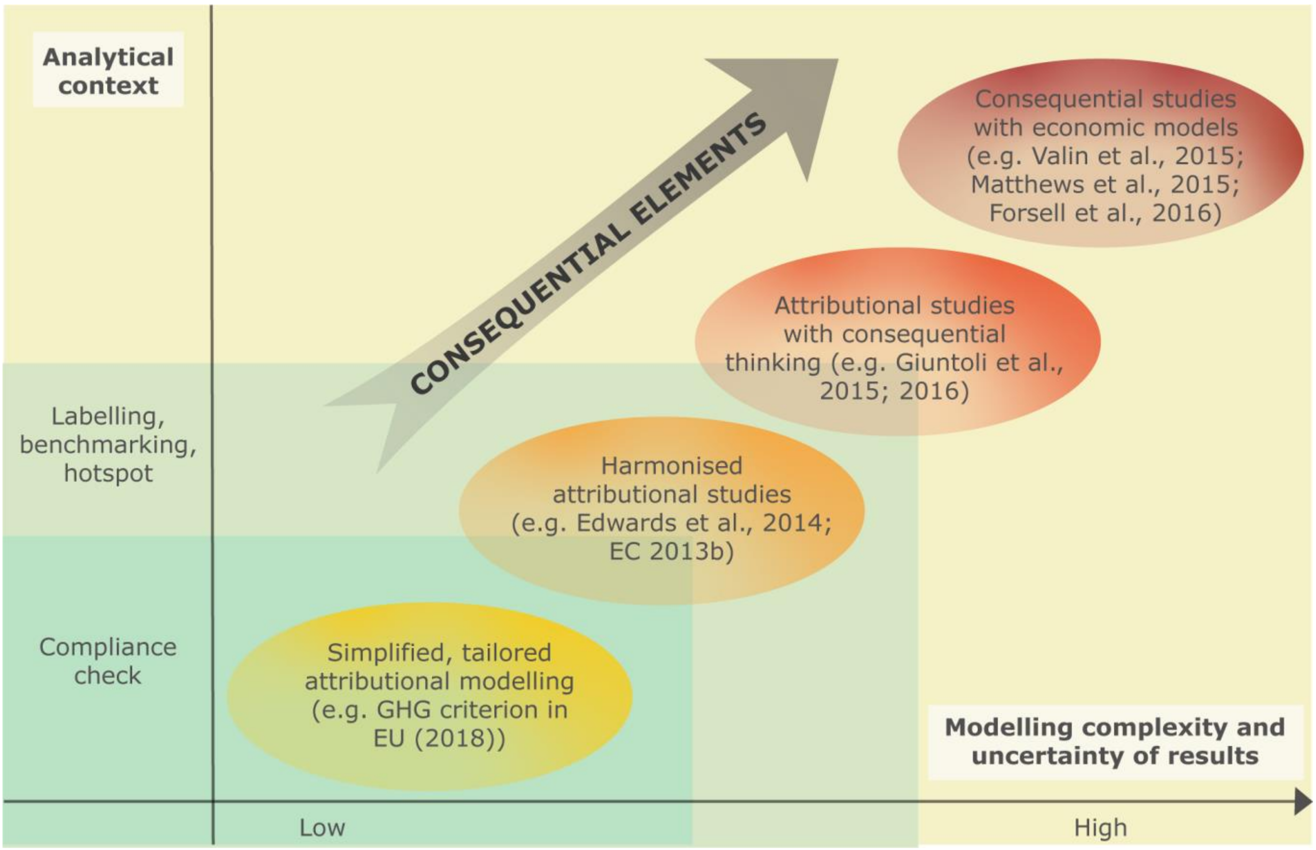

Figure 4: Examples of LCA studies used for policy support and LCA methodology implementation in EU policy, classified according to analytical context and modelling complexity.

LCA models that support the implementation of specific legislative instruments respond to the specific requirements defined within the instrument itself (e.g. compliance check in the Renewable Energy Directive). Those are mainly based on attributional LCA approaches. They should be easy to calculate, well-defined, use a well-specified, easily accessible and stable inventory, and be of general validity across the temporal and spatial scales covered by the legislation (Plevin et al., 2014). Various applications of attributional LCA have already been included in European legislation with multiple purposes such as labelling (e.g. EU 2009b) and benchmarking products, and performing hotspot analyses (e.g. EU 2018, EC 2013a,b).

On the other hand, LCA models that assess the impacts of strategic policy decisions can benefit from elements of consequential thinking. Studies that aim to assess large-scale impacts on the overall economy usually rely on economic models that cover multiple sectors of the economy, large geographic scales, and all relevant ecological processes (Valin et al., 2015; Plevin, 2016). Such studies have been undertaken to support the impact assessment of EU policy options (e.g. Valin et al., 2015; Matthews et al., 2015; Forsell et al., 2016) and focus on capturing as many interlinked consequences and feedbacks as possible across scales, sectors, and environmental burdens, to avoid unintended consequences of policy decisions.

An intermediate approach is emerging that is based on attributional modelling but incorporates elements of consequential thinking. These assessments are easier to implement than large numerical models, but can still identify risks and mitigation strategies (Giuntoli et al., 2015; Giuntoli et al., 2016). A list of methodological recommendations to carry out a strategic assessment of bio-based commodities is presented in Chapter 7 of Camia et al. (2018).

The horizontal axis in Figure 4 represents the modelling of complexity and uncertainty of the results. Attributional studies are usually subject mainly to statistical uncertainty linked to input values and inventory details; adding consequential elements increases scenario uncertainty linked to forecasting future developments. Brandão et al. (2014) summarise this concept by stating that attributional modelling may be more precise, while consequential modelling may be more accurate.

6. Are LCA results for bio-based supply chains available?

In the framework of the JRC Biomass Study (Camia et al., 2018), a database[3] has been compiled that includes attributional LCA results calculated or assembled by the JRC for multiple bio-based commodities. The database currently consists of 380 supply chains.

The bulk of the database comprises bioenergy supply chains and focuses on greenhouse gas emissions. However, the database also contains numerous datasets concerning bio-based chemicals, wood industry products, pulp and paper, waste products and a sample of food commodities (Figure 5). The values in the database should be interpreted as an indication of potential impacts rather than a rigorous compilation of comparable results.

7. Why does LCA remain the tool of choice for the assessment of bio-based commodities?

Any approach that attempts to model complex socio-ecological systems such as those that characterise the bioeconomy includes uncertainties. Nonetheless, life-cycle-based approaches provide the most comprehensive, structured, consistent and robust way of assessing the environmental performance of bio-based products and systems. While there are gaps in methodological approaches, as well as in data availability and quality, no other approach offers an environmental assessment of similar breadth and depth. The possibility to select different LCA modelling principles allows practitioners to develop LCA approaches that are suitable for a broad range of decision contexts and scales. By carefully considering the goal and scope of the assessment, and by choosing the appropriate LCA modelling approach, the risk of misinterpretation of the results can be limited.

[3] The database can be accessed at: https://ec.europa.eu/knowledge4policy/dataset/jrc-alf-bio-biomass-db-lca-supply-chains-2018-protected_en

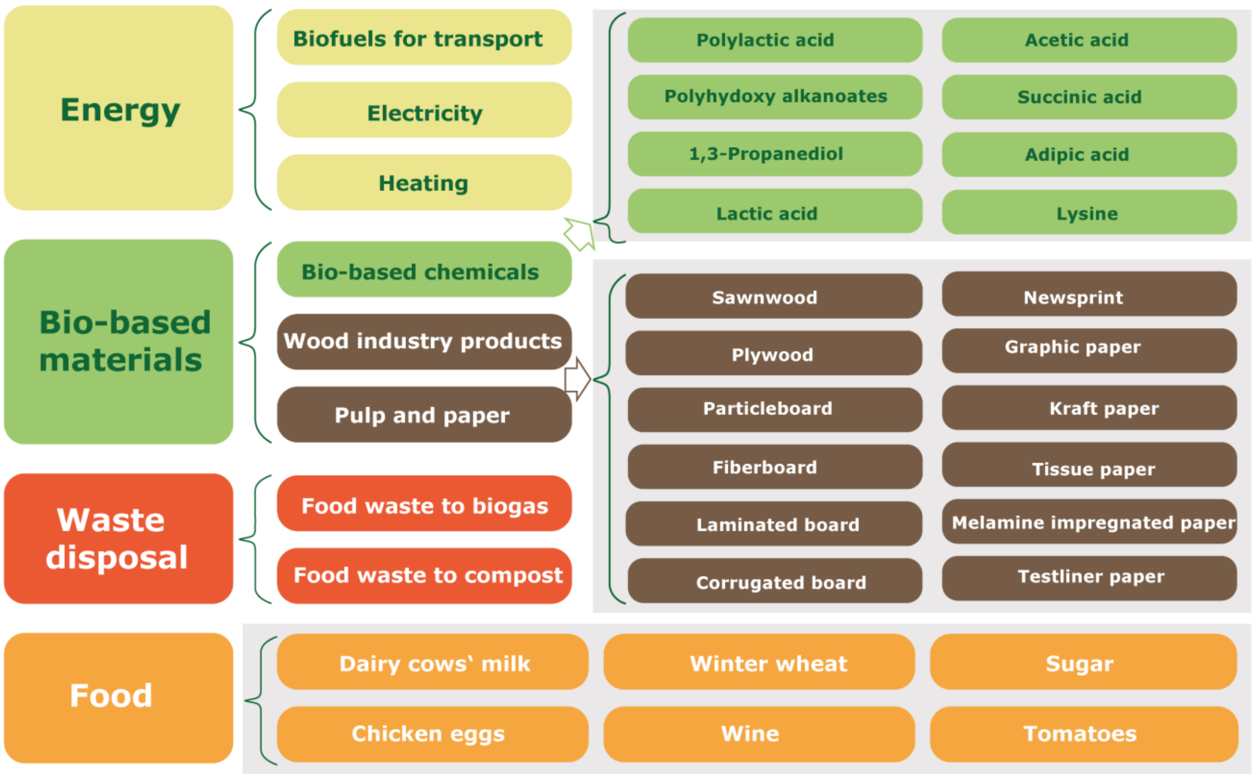

Figure 5: Commodities contained in the JRC database of the environmental impacts of bio-based supply chains [3]

Knowledge gaps

1. The LCA practitioners should better communicate to a wider audience the importance of applying the appropriate LCA modelling approach to meet the goal and scope of the assessment. This would help avoid the misinterpretation and inappropriate use of LCA results. Using the Environmental Footprint method developed by the European Commission as a reference for LCA studies in the EU can help ensure replicability, harmonisation of models and data, as well as transparency, especially if the aim is to compare products.
2. More high quality and consistent inventory data (e.g. for bio-based polymers) is required to be able to broaden the list of bio-based commodities that can be assessed by LCA. The updated Bioeconomy Strategy will contribute to that goal with its action 1.4 (EC 2018).
3. Quantification and modelling of some non-climate impact categories (e.g. biodiversity) need to be improved to evaluate trade-offs and avoid shifting of environmental burdens.
4. The effects of uncertainty and value choices should be more explicitly acknowledged and investigated.

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