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Lifecycle Analysis Tools for Advanced Material Choices

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Abstract

Life Cycle Assessment (LCA) is an essential tool for evaluating the environmental impact of products and materials throughout their entire life cycle, from raw material extraction to end-of-life treatment. This paper presents an overview of the key stages of LCA, including goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation. It further reviews the role of LCI databases and LCA software tools in supporting advanced material selection and sustainability decision-making. Attention is given to the differences between databases, the limitations of simplified LCA approaches, and the importance of understanding underlying assumptions before comparing results. The paper concludes that there is no shortcut to a robust LCA, but practical estimates can still provide valuable guidance for sustainable material innovation.

Introduction

I have been asked frequently to find a material with the lowest carbon footprint for a product producer. This question shows a profound misunderstanding of what carbon footprint calculation using LCA methodology brings. With this short paper I give a better understanding of the methodology and the tools that are required.

Life Cycle Assessment

Life Cycle Assessment (LCA) has become an essential tool for companies that want to make informed decisions about sustainability, material selection, and regulatory compliance. At the same time, there is often a misconception that environmental impacts can be calculated quickly and effortlessly using a simple software package or mobile application. In reality, conducting a reliable LCA requires a structured approach, quality data, and a clear understanding of the underlying assumptions and limitations.

An LCA is a method used to quantify the environmental impact of a product throughout its entire life cycle, from raw material extraction to end-of-life treatment. Rather than focusing only on a single manufacturing process or a single environmental indicator, LCA takes a holistic view of the complete system. This broader perspective helps organizations avoid shifting environmental burdens from one stage of the life cycle to another. For example, replacing a fossil-based material with a biobased alternative may

reduce dependence on fossil resources, but it can also influence land use, water consumption, or other environmental indicators. LCA makes such trade-offs visible and therefore supports better decision-making.

While many people associate LCA with carbon footprint calculations, climate change is only one part of the overall assessment. A complete LCA can evaluate impacts related to ecosystem quality, human health, resource depletion, water use, and many other categories. Because these impacts are very different in nature, it is difficult to express the complete environmental performance in a single figure. Nevertheless, several methods exist that aggregate multiple environmental impacts into one overall score, such as carbon dioxide equivalents or eco-cost indicators. At the same time, detailed results remain available so that users can identify specific environmental hotspots and improvement opportunities.

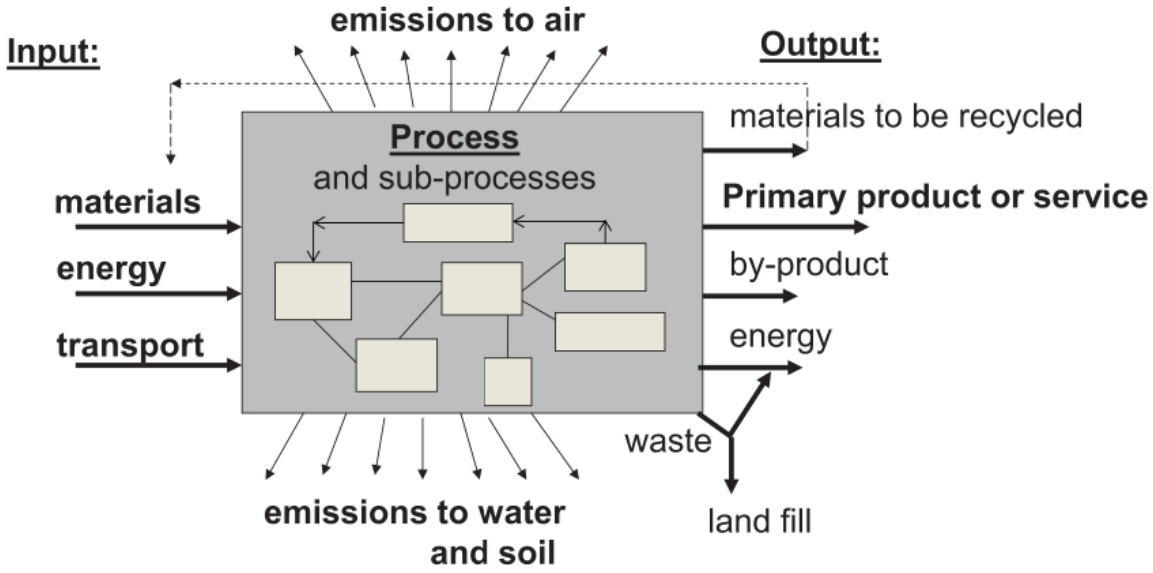


Figure 1: A basic structure of a system in LCA[1]

Building a reliable LCA requires four key stages. The first stage is the definition of the goal and scope. This includes determining the purpose of the study, selecting the functional unit, and defining the system boundaries. Depending on the availability of information, a study may cover the complete life cycle or only part of it, such as a cradle-to-gate assessment. The second stage is the Life Cycle Inventory (LCI), where all inputs and outputs are quantified. These include raw materials, energy consumption, emissions, waste streams, transportation, and other relevant flows. The third stage is the Life Cycle Impact Assessment (LCIA), in which the inventory data are translated into environmental impacts using established calculation methods. Finally, the results are interpreted, hotspots are identified, and decisions can be made regarding material selection, process optimization, or product redesign.

Life Cycle Inventory

The quality of any LCA depends heavily on the quality of the inventory data. Therefore, mapping the system correctly is one of the most important parts of the process. Companies need to understand which materials are being used, how much energy is consumed, which waste streams are generated, and how these elements interact throughout the product life cycle. Data can be obtained from several sources. Primary data can be measured directly within production facilities, while secondary data can be obtained from scientific literature or from dedicated LCI databases. These databases contain environmental information for thousands of materials, processes, energy systems, and transportation modes. Once all relevant sub-processes have been identified and quantified, their contributions can be combined into a complete inventory model.

For companies seeking quick insights during product development, streamlined or fast-track LCA approaches can be useful. Databases such as Idemat allow designers and engineers to compare common materials and estimate environmental impacts without building a complete LCA model from scratch. Such approaches are particularly valuable in the early stages of product development, when different material options are being evaluated. For example, a designer may compare recycled plastics, PET, PMMA, metals, or other alternatives to identify potentially lower-impact solutions. These methods can provide useful direction and support decision-making, but they remain estimates. They do not capture detailed supplier information, process-specific data, or ingredient-level variations.

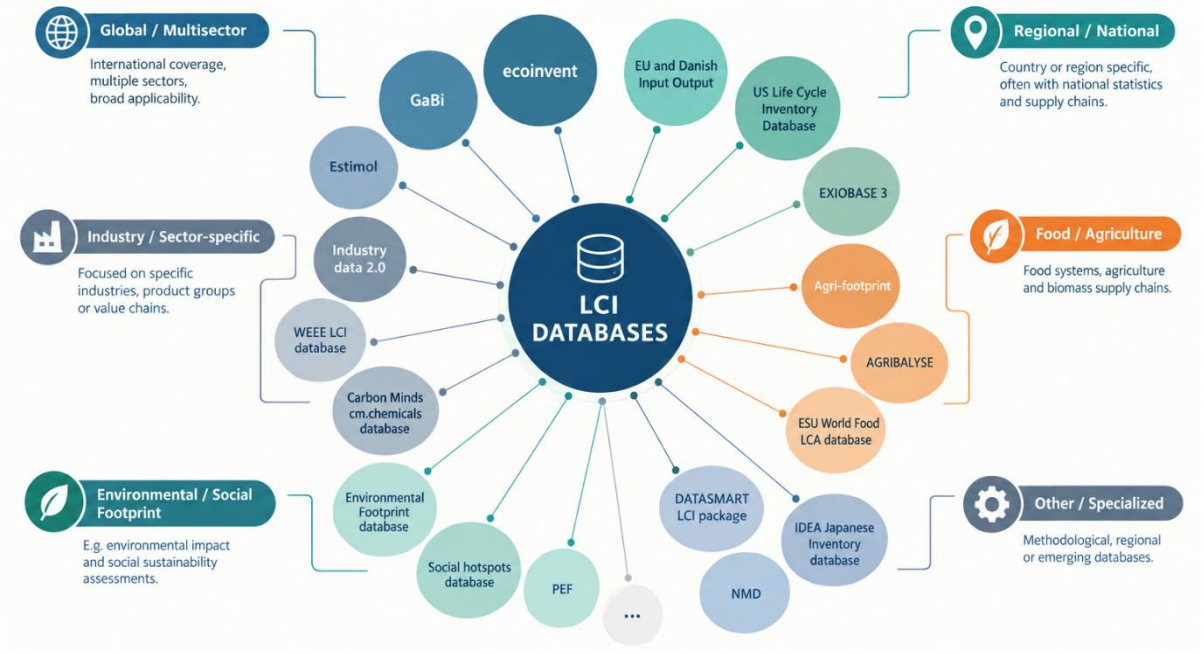


Figure 2: Overview of LCI database landscape

When greater accuracy is required, dedicated LCI databases become essential. Well-known examples include Ecoinvent and GaBi, although many other databases exist and the number continues to grow. An important aspect that is often overlooked is that the same material can produce different results depending on the database that is used. This does not necessarily mean that one database is correct and another is wrong. Different databases may use different system boundaries, regional assumptions, allocation methods, data sources, or reference years. As a result, a material modeled in one database can have a different environmental profile than the same material modeled elsewhere. Consequently, when conducting LCA studies or comparing results from different sources, the database selection and version must always be taken into account.

This also means that comparing LCA results without understanding the underlying methodology can be misleading. If two manufacturers present environmental impact results for similar products, it cannot automatically be concluded that the product with the lower number is more sustainable. A proper comparison requires insight into the goal and scope definition, the selected databases, the system boundaries, the allocation methods, and the impact assessment methodology. Without this transparency, numerical results can easily be misinterpreted.

Scenario building and calculation

Once inventory data are available, different scenarios can be modeled and compared. For example, a baseline product based on virgin rubber and conventional electricity can be compared with alternatives containing recycled rubber, renewable electricity, mechanical recycling routes, or extended product lifetimes. Scenario analysis is one of the strongest features of LCA because it allows companies to evaluate improvement opportunities before implementing changes in practice. In this way, LCA becomes not only a reporting tool but also a strategic decision-support tool for innovation and sustainability.

A wide range of software platforms are available to perform LCIA calculations, including SimaPro, GaBi, openLCA, Ecochain, oneClickLCA, and many others. Each platform has its own strengths and target applications. Some focus on research-grade assessments, while others are optimized for specific sectors such as construction, packaging, or manufacturing. Universities and research organizations increasingly use open-source environments such as Activity Browser for Brightway2, which provide complete transparency and flexibility. These tools allow researchers to customize datasets, automate calculations, integrate laboratory measurements, and perform advanced scenario or sensitivity analyses. However, they also require significant expertise in LCA methodology, data analysis, and programming.

For many organizations, practical LCA estimates can already be obtained using publicly available databases, production information, and spreadsheet-based calculations. Although these estimates do not replace a verified LCA study, they can provide valuable guidance during material development and innovation projects. They help companies identify promising opportunities, focus resources on high-impact areas, and develop more sustainable products at an earlier stage of development.

Conclusion

In conclusion, there is no shortcut to creating a robust and credible LCA for a new material or product. Reliable results require high-quality data, appropriate databases, suitable software tools, and a clear understanding of methodological choices. LCI databases continue to expand, software solutions continue to evolve, and sustainability requirements continue to become more demanding. As a result, organizations must move beyond simplistic carbon footprint claims and develop a deeper understanding of how environmental impacts are calculated. Most importantly, LCA results should never be compared blindly. The methodology behind the numbers is often just as important as the numbers themselves.

Circular Rubber Platform

This work was conducted within the framework of Circular Rubber Platform, a global community dedicated to accelerating innovation and knowledge sharing in rubber circularity. The platform brings together more than 130 organizations and hundreds of professionals worldwide with the shared objective of making rubber circularity the norm. Through knowledge exchange, practical tools, and collaboration across the value chain, the platform supports companies in making better sustainability decisions and accelerating the transition toward a circular rubber economy.

References

[1] Joost G. Vogtländer , LCA, a practical guide for students, designers and business managers, Sustainability Impact Metrics, 2023