Chapter 2
Main Characteristics of LCA

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Abstract Life cycle assessment (LCA) has a number of defining characteristics that enables it to address questions that no other assessment tools can address. This chapter begins by demonstrating how the use of LCA in the late 2000s led to a drastic shift in the dominant perception that biofuels were "green", "sustainable" or "carbon neutral", which led to a change in biofuel policies. This is followed by a grouping of the LCA characteristics into four headlines and an explanation of these: (1) takes a life cycle perspective, (2) covers a broad range of environmental issues, (3) is quantitative, (4) is based on science. From the insights of the LCA characteristics we then consider the strengths and limitations of LCA and end the chapter by listing 10 questions that LCA can answer and 3 that it cannot.

Learning objectives After studying this chapter the reader should be able to:

- Explain the relevance of LCA as a tool for environmental management.
- Explain four main characteristics of LCA.
- Demonstrate an understanding of strengths and limitations of LCA by providing examples of environment-related questions that LCA can answer and questions that LCA cannot answer.

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2.1 Why Is LCA Important? Biofuel Case

LCA has a number of defining characteristics. Before elaborating on these characteristics a real life case is presented to show how the use of LCA provided new insights and led to major changes in policy. This is the case of first generation biofuels used in the transport sector.

The use of biofuels is not a new trend. They were used in the form of wood and peat before the industrialisation and were pretty much the only source of fuels then. This changed with the emergence of cheap fossil fuels, first in the form of coal, later followed by oil and natural gas. By the end of the twentieth-century fossil fuels had become the dominating source for meeting the world's primary energy demand. At the same time the transportation sector of developed nations was responsible for an increasing share of the total national energy demands [e.g. EC (2012)]. While electricity and heat increasingly were supplied by other sources than fossil fuels, a similar transition could not be observed for transportation energy (IEA 2015).

The 2000s witnessed a renewed interest in using biofuels in the transportation sector, spurred by increasing oil prices, the question of energy security and concerns over climate change. Biofuels were seen as potentially cost competitive with gasoline and diesel and they were considered means to reduce dependencies on large exporters of oil, many of which were (and are) located in politically unstable regions of the world. In the early 2000s biofuels in the transportation sector were also generally considered much better for the climate than fossil fuels. The reasoning was that the CO_2 emitted from the combustion of biofuels has a "neutral" effect on climate change, because it belongs to the biogenic carbon cycle, meaning that it used to be in the atmosphere before being taken up, via photosynthesis, by the plants that were the sources of the biofuel and that it will be taken up by new plants again. By contrast, CO_2 emitted from the combustion of fossil fuels originates in carbon that belongs to the much slower geological carbon cycle and can be considered as effectively isolated from the atmosphere, because it would have stayed in the ground for millions of years, had it not been extracted to be used as fuel.

While the distinction between biogenic and fossil CO_2 is important, LCA studies (Zah and Laurance 2008; Fargione et al. 2008; Searchinger et al. 2008) have shown that it was a mistake to:

(1) consider the use of biofuels in the transport sector inherently "climate neutral"
(2) disregard potential increases in environmental problems other than climate change from a transition from fossil fuels to biofuels.

Regarding the first point, LCA takes a life cycle perspective when evaluating environmental impacts of a product or a system. In this case it means not only considering the use stage of the biofuel, i.e. where its chemical energy is transformed to kinetic energy in a vehicle's combustion engine, but also considering the industrial and agricultural processes prior to the delivery of the biofuel to the fuel tank of the vehicle (see Fig. 2.1).

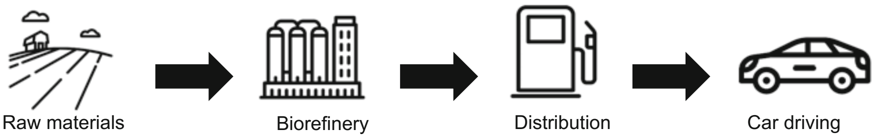

Fig. 2.1 Graphic representation of the biofuels life cycle from feedstock to end user (Icons made by Flaticon from www.flaticon.com)

When taking a life cycle perspective it is clear that no biofuel is "climate neutral", because of the inputs of fossil fuels needed in industrial processes prior to the use stage. In addition, a consequence of the increased demand for biofuel crops may be the conversion of natural land (such as forest) to cultivated land and this releases the carbon bound in the natural biomass (e.g. wood) and the soil as CO_2. Sometimes the conversion of natural land happens as an indirect consequence, i.e. forest is being cleared to make room for the crops that used to be cultivated at the piece of land now used for biofuel crops. This means that a country that increases its production of biofuel crops, at the expense of a decrease in food crops may indirectly contribute to a loss of natural land (e.g. forest) somewhere else, possibly on a different continent, due to the mechanisms of international trade.

Regarding the second point, LCA considers multiple environmental issues (and sometimes social issues, see Chap. 16) when evaluating a product or a system. This is an important attribute in the case of biofuels because the release of nutrients from fertilizer use and synthetic chemicals from pesticide use, lead to eutrophication and toxic effects on freshwater ecosystems and elsewhere, and because the cultivation requires large amounts of land and water for irrigation, which can lead to biodiversity loss and water scarcity. Social impacts from an increased production of biofuels have also been reported in the form of increasing food prices.

The insights provided by LCA were a key reason for the rapid change in perspective on biofuels by policy-makers and media that began around 2008. For example, in 2010 the European Commission amended its legislation on biofuels by introducing a set of sustainability criteria, which relates to life cycle emissions of greenhouse gases and prohibits the conversion of land with previously "high carbon stock" and "high biodiversity" for the production of biofuels (EC 2010).

With the above text, we are not arguing that the transportation sector should abandon biofuels as a strategy to reduce its use of fossil fuels and climate impacts. We are merely trying to show that the world is not black and white and that a more holistic perspective is required when evaluating and guiding technological changes.

2.2 Main Characteristics

Having made a case for LCA with the topic of biofuels, we now turn to describing its main characteristics in slightly more technical terms and end the chapter by listing its strengths and limitations.

2.2.1 Takes a Life Cycle Perspective

The life cycle metaphor is borrowed from the field of biology. For example, the life cycle of a butterfly starts with an egg, which bursts and lets a caterpillar out that turns into a pupa from which a butterfly emerges that eventually dies after laying eggs for the cycle to be repeated. In much the same way a man-made object starts its lifecycle by the harvesting and extraction of resources, followed by production, use and eventually management of the object as waste, which marks the end of the life cycle. Recycling or reuse can be seen as “new eggs” for the life cycles of other man-made objects. The objects studied in LCA are often physical products and the term “product system” signals that a life cycle perspective is taken, i.e. that all the processes required to deliver the function of the product are considered. For example, the function of a car fuel is to propel a car. As illustrated in the case above, the delivery of this function requires a number of industrial and agricultural processes that can be conceptually organised in stages of the life cycle of a biofuel (see Fig. 2.1). The core reason for taking a life cycle perspective is that it allows identifying and preventing the burden shifting between life cycle stages or processes that happens if efforts for lowering environmental impacts in one process or life cycle stage unintentionally create (possibly larger) environmental impacts in other processes or life cycle stages. As shown above, the substitution of fossil fuels with biofuels reduces impacts on climate change from the use stage but increases climate change impacts from the harvest and extraction stage. Although LCA is mostly used to study product systems, it can also be used to study more complex man-made objects, such as companies (see Chap. 22), energy-, transport- or waste management systems (see Chaps. 26, 27 and 35) and infrastructure and cities (see Chap. 28). In all applications the assessment takes a life cycle perspective having the function of the studied entity as focal point.

2.2.2 Covers a Broad Range of Environmental Issues

In LCA, the comprehensive coverage of processes over the life cycle is complemented by a comprehensive coverage of environmental issues. Rather than focusing exclusively on, say, climate change, which generally receives most attention these days, LCA covers a broad range of environmental issues, typically around fifteen (see Chap. 10). These issues include climate change, freshwater use, land occupation and transformation, aquatic eutrophication, toxic impacts on human health, depletion of non-renewable resources and eco-toxic effects from metals and synthetic organic chemicals. The core reason for considering multiple environmental issues is to avoid burden shifting, which is also why a life cycle perspective is taken. Here burden shifting happens if efforts for lowering one type of environmental impact unintentionally increase other types of environmental impacts.

As shown above, decreasing impacts on climate change by substituting fossil fuels with biofuels has the potential to cause an increase in other environmental issues such as water scarcity, eutrophication, land occupation and transformation.

2.2.3 Is Quantitative

LCA results answer the question "how much does a product system potentially impact the environment?" Part of the answer may be "the impact on climate change is 87 kg of CO_2 equivalents". The quantitative nature of LCA means that it can be used to compare environmental impacts of different processes and product systems. This can, for example, be used to judge which products or systems are better for the environment or to point to the processes that contribute the most to the overall impact and therefore should receive attention. LCA results are calculated by (1) mapping all emissions and resource uses and, if possible, the geographical locations of these, and (2) use factors derived from mathematical cause/effect models to calculate potential impacts on the environment from these emissions and resource uses. The first step often involves thousands of emissions and resource uses, e.g. "0.187 kg CO_2, 0.897 kg nitrogen to freshwater, 0.000000859 kg dioxin to air, 1.54 kg bauxite, 0.331 m^3 freshwater…". In the second step the complexity is reduced by classifying these thousands of flows into a manageable number of environmental issues, typically around fifteen (see above). Quantifications generally aim for the "best estimate", meaning that average values of parameters involved in the modelling are consistently chosen (see Chap. 10).

2.2.4 Is Based on Science

The quantification of potential impacts in LCA is rooted in natural science. Flows are generally based on measurements, e.g. water gauges or particle counters at industrial sites or mass balances over the processes. The models of the relationships between emission (or resource consumption) and impact are based on proven causalities, e.g. the chemical reaction schemes involving nitrogen oxides and volatile organic compounds in the formation of atmospheric ground level ozone (smog) or on empirically observed relationships, e.g. between the concentration of phosphorous in a lake and the observed numbers of species and their populations. On top of its science core, LCA requires value judgement, which is most evident in the optional step of assigning weights to different types of environmental problems to evaluate the overall impact of a product system. LCA strives to handle value judgement consistently and transparently and in some cases allows practitioners to make modelling choices based on their own values, for example with respect to the number of years into the future that environmental impacts should be considered in the assessment.

2.3 Strengths and Limitations of LCA

A main strength of LCA is its comprehensiveness in terms of its life cycle perspective and coverage of environmental issues. This allows the comparison of environmental impacts of product systems that are made up of hundreds of processes, accounting for thousands of resource uses and emissions that are taking place in different places at different times. However, the comprehensiveness is also a limitation, as it requires simplifications and generalisations in the modelling of the product system and the environmental impacts that prevent LCA from calculating *actual* environmental impacts. Considering the uncertainties in mapping of resource uses and emissions and in modelling their impacts and the fact that calculated impacts are aggregated over time (e.g. tomorrow and in 20 years) and space (e.g. Germany and China) it is more accurate to say that LCA calculates impact *potentials*.

Another strength in the context of comparative assessments is that LCA follows the "best estimate" principle. This generally allows for unbiased comparisons because it means that the same level of precaution is applied throughout the impact assessment modelling. A limitation related to following the "best estimate" principle is, however, that LCA models are based on the average performance of the processes and do not support the consideration of risks of rare but very problematic events like marine oil spills or accidents at industrial sites. As a consequence, nuclear power, for example, appears quite environmentally friendly in LCA because the small risk of a devastating disaster, like the ones that happened in Chernobyl, the Ukraine or Fukushima, Japan, is not considered.

A final limitation worth keeping in mind is that, while LCA can tell you what (product system) is better for the environment, it cannot tell you if better is "good enough". It is therefore wrong to conclude that a product is environmentally sustainable, in absolute terms, with reference to an LCA showing that the product has a lower environmental impact than another product. Chapter 5 elaborates on the relationship between LCA and sustainability.

The above characteristics mean that LCA is suitable for answering some questions and unsuitable for answering others. Box 2.1 provides examples of questions that LCA can and cannot answer.

Box 2.1. What LCA can and cannot answer
Examples of questions LCA can answer:

1. Is paper, plastic or textile bags the most environmentally friendly option for carrying groceries back from the supermarket?
2. From an environmental point of view should we use glass fibre composite or steel for the car body?
3. How can the overall environmental impact of a refrigerator be minimised with the least effort?

4. What is the most environmentally friendly way to package and transport food?
5. From an environmental perspective, should plastics be incinerated or recycled and which parameters do the conclusion depend on?
6. Where is the environmental optimum in the trade-off between minimising heat loss and minimising the use of impact-intensive materials in a window (see illustrative case on window frames in Chap. 39)?
7. Should a plastic zipper be added to cheese packaging to reduce household food waste and thereby reduce the overall environmental impacts of cheese?
8. Is it more environmentally friendly to do the dishes manually or using a dishwasher?
9. Should a company target its own processes, its suppliers, its customers or the waste management sector in the effort of reducing the environmental impact of its products?
10. Are electric cars more environmentally friendly than conventional internal combustion engine cars and what are the important parameters deciding this (see Chap. 27)?

Examples of questions LCA cannot answer:

1. Should taxes on old diesel cars be increased to reduce emissions of particles and thereby reduce hospital spending on treating lung diseases?

Explanation: LCA cannot be used to compare the societal disadvantages of higher taxes with advantages of less pollution. Cost benefit analysis combined with Health Assessment Studies would be a better tool for answering this question.

2. Do current emissions from a specific factory lead to pollutant concentrations above regulatory thresholds in nearby aquatic ecosystems?

Explanation: LCA is not designed to evaluate impacts of a single emission source on local ecosystems and contains no information on regulatory thresholds. Chemical risk assessment is a more appropriate tool for answering this question.

3. Do total global emissions of endocrine disruptors cause polar bears to become hermaphrodites?

Explanation: LCA is not designed to assess a specific effect on a specific organism from a specific group of chemicals. It would be more meaningful to measure the concentration of endocrine disruptors in (deceased) polar bears and compare those measurements with observed occurrences of hermaphrodite individuals.

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Author Biographies

Anders Bjørn part of the LCA community since the early 2010s. Main focus is interpretations of sustainability and integration of sustainability targets in LCA to enable absolute sustainability assessments.

Mikołaj Owsianiak involved in development and application of life cycle impact assessment methods in sustainability assessment of technologies. Has worked on issues associated with: soils (remediation), metals (toxic impact assessment), biodiesel (fate in the environment), and carbonaceous materials (biochar and hydrochar).

Christine Molin active in the field of LCA since 1992. Special interest in the development and dissemination of LCA and in the use of LCA in small and medium sized enterprises.

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