



Life cycle assessment of decarbonization options—towards scientifically robust carbon neutrality

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1 Background

Climate or carbon neutrality is a key concept to tackle climate change in both public and private organizations (we use the term carbon neutral as synonym for climate neutral for the purpose of this editorial). The Paris agreement (UNFCCC 2015) includes the goal to reach carbon neutrality. According to the Intergovernmental Panel on Climate Change, limiting global warming to 2 °C requires global carbon neutrality by 2070, while a 1.5 °C target requires global carbon neutrality by 2050 (IPCC 2018). Carbon neutrality describes a state in which the activities of an individual, products, or an organization (e.g., company, city, country) result in net-zero emissions of CO₂. The net-zero implies that they the activities do not release any greenhouse gases or that the GHG released after decarbonizing are removed and sequestered (IASS 2015).

To achieve carbon neutrality, decarbonization strategies are needed. Most scholars and stakeholders argue for a hierarchy of decarbonization approaches. As an example, Andrews defines the four steps of Avoid (carbon intensive activities), Reduce (material and energy demands by increasing efficiency), Replace (fossil fuels and materials by renewable alternatives), and Offset (those emissions that remain after the previous steps) (Andrews 2014). Other scholars propose just two or three steps, but there seems to be a general agreement on two issues—also reflected by the United Nations Climate Change Race to Zero Initiative (UNFCCC 2021):

- Reduction priority: all reduction measures take priority over compensation measures as they are less prone to assumptions, more tangible, more time-independent and verifiable.

- Compensation necessity: all decarbonization strategies need compensation measures as there is no alternative way to achieve net-zero emission. While they are the lowest priority and should be limited to cover the “unavoidable” residual emissions, they are also a necessity for becoming carbon neutral.

For both options, a life cycle perspective is inevitable. All decarbonization steps need to embrace the life cycle perspective in order to be effective, in order to avoid double-counting, in order to avoid carbon leakage and ultimately problem-shifting as well as green-washing. While we hopefully all agree on this principle, it is less obvious what we can already offer as LCA community in terms of solutions and what we still need to address in terms of remaining challenges for a scientifically robust assessment of carbon neutrality. The intention of this editorial is twofold. First, we want to encourage a more proactive role of this community in the carbon neutrality and decarbonization debate as we have important and relevant knowledge to contribute. Second, we want to encourage further research efforts to tackle the substantial accounting challenges that are still unresolved.

2 Scientific state-of-the-art and challenges

In this section, we present a high-level overview of the scientific state-of-the-art and identify some of the remaining challenges according to the decarbonization strategies Avoid, Replace, Reduce, and Repair (Offset).

2.1 Avoid

The strategy to avoid carbon-intensive activities or inputs is from an LCA standpoint either uncritical or identical with the replacement strategy. It is uncritical, if activities or inputs are avoided without any substitution or replacement. In reality, this is probably a rather rare case. If for example

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company cars are avoided, it is from an LCA perspective only an avoidance case, if not only the cars, but also the associated business trips are avoided. To be more precise, all functions related to the company cars must be avoided. If the business trips were “avoided” by web-meetings, then it is already a replacement strategy as the environmental burden of the company cars were not avoided, they were just replaced by the burdens associated with the web-meetings.

From an LCA perspective, there is no big issue here as real avoidance options are associated with no accounting problems. However, almost all avoidance strategies are in reality replacement strategies, the challenges associated with them are discussed in Sect. 2.3.

2.2 Reduce

For the reduction strategies, a similar notion applies as for the avoidance strategies. Again here, if an activity or a required material or energy demand of a product system or organization is reduced by increasing the efficiency of the process or the value chain, this is easily translated into smaller numbers in an associated LCA (ISO 14040 2006, ISO 14044 2006, Finkbeiner 2006) or carbon footprint (ISO 14067 2018, Finkbeiner 2009) of it. Compared to a full avoidance, the likelihood to achieve such reductions in reality is significantly larger. However, as in the case of the avoidance strategies, as soon the reduction is not only about using less in an otherwise identical process, i.e., if there are other processes or inputs necessary to achieve the reduction, it has to be treated as replacement case.

2.3 Replace

The replacement option should be the “home game” for LCA. There are thousands of LCAs in this context and either perform a hotspot analysis of a product or organization to derive improvement options or compare alternatives in order to suggest the replacement of one over the other. In that sense, our community can bring a lot to the table when it comes to a scientifically robust evaluation of replacement options. The most important one is obviously the life cycle perspective per se as we know that removing the tailpipe from a vehicle and calling it “zero-emission” vehicle does not mean it has zero emissions in real life; it may have even more.

Greenhouse gas accounting or carbon footprinting as such are per definition in conflict with the LCA principle of comprehensiveness which requires the consideration of all attributes or aspects of natural environment, human health, and resources. This limitation may lead to trade-offs (Finkbeiner 2009). Nevertheless, LCA methodology provides the baseline for carbon footprinting and is therefore an inevitable contribution to any serious decarbonization approach.

However, digging a bit deeper into the application of LCA for scientifically robust carbon neutrality assessment, we have to face a number of challenges. First of all, some general methodological challenges on LCA (Finkbeiner et al. 2014) and carbon footprinting still apply today. Recent harmonization approaches at the ISO (Finkbeiner 2013a), UN (LCI 2021), or European level (Bach et al. 2018; Lehmann et al. 2015; Galatola and Pant 2014; Finkbeiner 2013b) did not resolve many of them and some are crucial for assessing decarbonization strategies:

- Accounting of (renewable) energy

The standards relate to the requirement of “no double-counting.” This is technically plausible but difficult to implement. How can a commissioner or practitioner provide proof that the renewable energy used or bought is not double-counted? Do Certificates of Origin in the EU really guarantee absence of double-counting? Are there equivalent mechanisms outside Europe? How and in which time intervals are then the necessary residual mixes available in LCI databases?

- Accounting for biomass/biogenic carbon

The use of biomass is a common strategy for decarbonization, but there are several accounting challenges on top of the well-known issues of consistent biogenic carbon accounting and the treatment of delayed emissions. How do we deal with GHG emissions from land use? Do we allow biomass-balanced products (Jeswani et al. 2019), i.e., the accounting of virtual rather than physical properties in analogy to renewable energy?

- Accounting for recycling

The different methodological options for end-of-life allocation and the associated discussions are well known since decades (Allacker et al. 2017; Koffler and Finkbeiner 2018). They affect the decarbonization debate as well as either recycling credits for the provision of secondary material sources are used to reduce the carbon footprint or the use of burden-free recycled products is chosen as decarbonization strategy. Which of the end-of-life recycling approaches is most robust for decarbonization? If mass-balanced accounting for biomass is allowed, can this also be applied to recycled products? Do we need an additionality criterion in order to achieve real-world improvements?

- Accounting for “green suppliers”

There is less methodological discussion about selecting “green” or low-carbon products or suppliers for reducing the GHG impact of products and organizations. There is emerging practice in industry as well as public bodies (green public procurement) to apply this strategy. As there are more specific efforts involved by the purchaser, it seems common LCA practice to account for reductions associated with this measure. However, methodo-

logically, it is the same issue as discussed for renewable energy and potential double-counting issues arise, if the chosen supplier also contributed to the average datasets in the secondary LCI database. How can we tackle this issue?

- Accounting for avoided emissions

There is since several years the discussion about avoided emissions accounting and several frameworks and guidelines have been produced for it (ICCA 2013; METI 2018). The term refers to estimating and disclosing the greenhouse gas (GHG) emissions impact of a product relative to the situation where that product does not exist. While technically the avoided emissions are argued as a reduction of impact due to a particular product (e.g., insulating your house leads to a reduction of energy demand for the house, which might be even larger than the production burdens of the insulation), they are methodologically similar to offsets in the sense that they require a baseline scenario that determines the result at least as much as the product performance itself. There is also the challenge of “benefit” allocation between provider and owner of the product with associated double-counting challenges. Shall we treat then avoided emissions like offsets? Shall we exclude them from carbon neutrality accounting altogether? Are the developed guidelines suitable and sufficient for a potential carbon neutrality application of avoided emissions?

Looking at this non-exclusive list of methodological issues reveals a number of scientific challenges for our community which are of utmost importance for the carbon neutrality debate. Many of them are related to value choices and as usual, depend on the goal and scope of a particular application. Therefore, standardization could not reach consensus on specifying clearer rules as different value choices can be appropriate for different applications of an LCA. However, for the specific application to carbon neutrality claims, we should try to agree on a robust set of rules as otherwise we will continue to have carbon neutrality according to the rules of the Wild West. This will not be an easy debate as can be already seen in the current negotiations of the upcoming ISO 14068 on carbon neutrality. There are quite a number of different interests and different communities (certifiers, GHG consultants, companies, public bodies, etc.), which makes it important, that we as LCA community are represented there as well.

While there is no scientifically correct or ideal solution for value choices, the current carbon neutrality situation may call for a cautious, conservative and robust approach for setting them. As examples for value choices, that help to ensure robust accounting, it could be fixed, that

- accounting for renewable energy needs clear certificates of origin and double-counting is avoided by excluding all renewable energy shares from residual energy mixes, i.e., energy mixes in secondary databases are provided without any renewable energy share;
- accounting for biogenic carbon needs to be explicit without any discounting or even subtraction of delayed emissions and without consideration of mass-balanced credits unless the avoidance of double-counting is ensured;
- recycling is only accounted for based on physical recycled content; and
- any avoided emission scenarios are not accounted as reduction by the provider, the benefit is exclusively allocated to the user.

These proposals may appear unfair to certain stakeholders and their particular interests. Any fixing of value choices will have the effect, that some stakeholders have concerns. However, if a scientifically robust accounting for carbon neutrality is a serious target, this is a price that has to be paid.

2.4 Repair (Offset)

There is a broad debate on the quality and effectiveness of different compensation mechanisms, projects, and providers. A full discussion of these goes beyond the scope of this editorial. Main aspects of the analyses and criteria for compensation options include additionality, longevity, and verifiability. Also, the lack of properly considering a life cycle perspective has been already addressed (Arendt et al. 2020).

Formally, as of now, the LCA community could say that carbon offsets are none of our business as it is currently not allowed to include any offsets in the carbon footprint of products or organizations. However, if we want to contribute to a carbon neutral world, there must be some consistency in the calculation of the damage (environmental burden) and the calculation of the environmental repair (offsets). Only a consistent accounting framework ensures that the balance is even and not distorted by inconsistent accounting rules.

As a consequence, the LCA community should have a say in the accounting rules for offsets. Some of the most obvious examples for this issue can be taken from technical measures, which can be both reductions and offsets. The use of renewable energy (e.g., from a wind park) in the region of a producer is accounted for as reduction. If technologically exactly the same wind park is setup somewhere else, e.g., in India, it is accounted for as an offset. What is the scientific rationale to treat the accounting of the exact same wind park differently?

In addition, the quality of offsetting projects will be decisive for achieving carbon neutrality in reality and not

just on paper. For establishing quality criteria and proper accounting rules, our community should play a much more prominent role.

3 Conclusion

From the perspective of the one and only scientific journal entirely devoted to LCA, the focus on single-issue topics like climate change and carbon footprinting comes with some ambivalence. As mentioned in a previous editorial on the introduction of the carbon footprinting section of the journal, some LCA purists might not want to see single-issue topics in this journal, because it is per se in conflict with the principle of comprehensiveness which requires the consideration of all attributes or aspects of natural environment, human health, and resources (Finkbeiner 2009). On the other hand, carbon neutrality is supposed to be one of the mega-trends of this century, which offers the potential to get life cycle approaches into organizations and decision-making contexts which pure LCA did not reach yet. It may offer the opportunity to increase the audience and relevance of our community, and at the same time, we have something to contribute to get things right.

As a community, we often focus on the things that are unresolved or even argue on all the different approaches available for this or that. When it comes to carbon neutrality, I assume that most readers of this journal are in fairly well agreement on a number of principles. They include the following:

- Life cycle completeness: carbon neutrality accounting has to consider the complete life cycle of products and organizations, i.e., partial footprints of products should not be used as a basis for carbon neutrality claims and organizations have to include their Scope 3 emissions.
- GHG completeness: there is a rather academic debate on theoretical differences between carbon neutral, climate neutral, and the net-zero concept, while any separate treatment of just CO₂ or carbon-related emissions makes no scientific sense. All other GHGs have to be included, they can be expressed as CO₂ equivalents and a carbon footprint according to ISO clearly includes all GHG and not only CO₂ (ISO 14067 2018).
- Avoidance of trade-offs: despite the importance of climate change, all the other environmental interventions associated with decarbonization strategies should be assessed. While trade-offs cannot always be avoided, they should be minimized.
- Priority for physically tangible, absolute reduction: any decarbonization that leads to a physically tangible, absolute reduction of GHG impacts is preferred over relative claims that relate to economic instruments or virtual baseline scenarios.
- Offsetting resistance and empowerment: accounting for offsets has to be kept and reported separately from the carbon footprint calculation, while offsetting schemes should be empowered by introducing a life cycle perspective and proper accounting rules, which are consistent with the carbon footprint calculation.

To implement these principles into carbon neutrality practice still needs some thoughts and scientifically robust solutions. To foster these, we announce here the Special Issue on “Decarbonization and carbon neutrality” and publish the associated call for papers in the next section.

4 Call for papers for the special issue “Life Cycle Assessment in the context of decarbonization and carbon neutrality”

With this editorial, we like to launch the special issue “Life Cycle Assessment in the context of decarbonization and carbon neutrality” as a forum to contribute to the issues raised above. Vanessa Bach (Chair of Sustainable Engineering, TU Berlin) and Stephan Krinke (Volkswagen AG) will serve as special issue editors and invite Research Articles, Short Original Communications, Review Articles, Commentaries, and Discussion Articles on all aspects relating to this topic. Relevant topics include:

- Introduction and discussion of standards and guidelines for carbon footprinting and carbon neutrality.
- Application and case studies of decarbonization including examples that show the trade-offs with other environmental aspects.
- Contributions to the methodological challenges for decarbonization and carbon neutrality claims, especially
 - methodological solutions for renewable material and energy accounting,
 - assessments and methodological aspects of compensation and offsetting approaches as well as
 - avoided emission accounting.

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