ASSESSING THE SUSTAINABILITY OF A CIRCULAR BIO-BASED ECONOMY: LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) has become prevalent in sustainability standards, policies and legal framework in recent years. The method provides a mean to quantify the environmental performance of products and services. There are, however, heated debates on many methodological choices within LCA. This technical brief presents LCA's connection to the bioeconomy and the circular economy, important methodological aspects in this respect, and how LCA can take part in policy making.

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1. Measuring bio-based economy

In 2003, the European Commission, in its Communication on Integrated Product Policy (EC COP 2003) stated that Life Cycle Assessment (LCA) is the best available framework for assessing potential environmental impacts of products. The Thematic Strategy on the sustainable use of natural resources (EC 2005) underlined the preference for LCA to guide policy related to product choices. Even though LCA practitioners report little integration of LCA in the development of environmental public policy (Seidel 2016), there are numerous examples of integration of LCA or LCA-based thinking in policy development, laws or regulations, for instance in the case of biofuels and the EU's Renewable Energy Directive (EC 2008). The directive includes instructions for how to calculate life-cycle greenhouse gas emissions from biofuels, and specifies which results are acceptable from a climate policy point of view.

The method Life Cycle Assessment (LCA) has been instrumental in advocating the use of biobased renewable resources instead of fossil resources. Creutzig et al. (2015) showed the environmental performance of different energy products from biobased and fossil resources where the results were used as background material for the IPCC AR 5 (IPCC 2014). In biofuel policies, including EU's Renewable Energy Directive (EC 2008) and the renewable fuel standard in the US, LCA-based carbon accounting methodologies are required for reporting.

LCA is product-oriented and provides quantitative information about the environmental performance of provision of products or services in a life cycle perspective. This is done through capturing all the energy and material flows of all processes involved in delivering a product or service, also those processes that are involved in life cycles supplying energy or material to the life cycle under scrutiny. The standard method comprises four distinct stages: 1) goal and scoping; 2) life cycle inventory; 3) impact assessment; and 4) interpretation. Although these stages seem to be given in a chronological order, LCA is truly iterative and there is always a need to jump back and forth between the different stages.

Traditional environmental regulatory regimes employ the "polluter pays" principle. This means that facilities responsible for emissions are obliged to either lower their emissions or pay fines to continue emitting. LCA concerns the use of products and services and thus shifts responsibility from producers to users. At the same time, it extends the responsibility of producers to include concerns about the impacts generated upstream (at suppliers and suppliers' suppliers) and downstream (at users and at end-of-life stage).

Although the methodological framework of LCA has reached a mature stage, there are still elements of the methodology that are heavily contested. Some of these discussions are particularly relevant in relation to the bio-economy. Connecting bio-economy to circular economy might spur new debates, for instance related to allocation.

2. Addressing different environmental challenges

The results of an LCA are normally presented for several environmental impact categories that address different environmental challenges such as global warming, acidification or resource consumption. For biological resources used in a circular economy, an important aspect may be the recycling of nutrients such as nitrogen, phosphorous and potassium. The nutrients can represent scarce resources in some areas and may also cause problems with eutrophication in oceans, lakes and waterways when the concentration is too high.

Through applying LCA, one is able to avoid two so-called problem shifts; meaning than an environmental problem is shifted from one life cycle stage to another or that one environmental problem is substituted with another. A typical example of a life cycle stage shift is different automotive engine technologies. Some fuel types will have no or very little emissions in the use phase of a vehicle, e.g. a battery powered by electricity or a fuel cell powered by hydrogen, but the emissions related to producing the car or the fuel might far exceed the total emissions from "traditional" fossil fuels. Shifting of environmental problems might occur when substituting fossil fuels with biofuels. In most cases, the biofuel will have less impact related to climate change, but impacts in other environmental impact categories such as acidification and eutrophication might be higher. The weighting of which impacts are of higher importance is typically a problem to be handled by the policy domain.

3. The division between nature and society

One of the difficulties, method-wise, with a transition to bioeconomy is to identify the boundary between nature and industrial systems. When is a resource part of nature and when is it part of the industrial system? In an LCA, material and energy flows are responsible for impacts when they enter the industrial system (techno-sphere) from the nature (biosphere) in the form of resource use, and when they enter nature from the industrial system in the form of emissions and waste.

This divide between the biosphere and the techno-sphere can be easy to distinguish when materials from nature are going into a human-made factory. The divide is much harder to spot for agricultural and forestry systems, because where does the work of nature end and the work of the farmer begin?

As another example of the divide between nature and society, the influential report of the Ellen MacArthur Foundation (2013) includes the biosphere in the bio-based part of the circular economy. In their model, the cycling of biological material and essential nutrients may be considered ecosystem services – services which are useful to societal and industrial systems but provided by natural ecosystems. The circular bioeconomy then relies both on industrial and natural systems, and it is not necessarily easy to draw the line between them.

4. Assessing a stable or a changing system

There are two main types of LCA that can be performed, commonly referred to as *attributional LCA* and *consequential LCA* (EC JRC 2010).

Attributional LCA (ALCA) is used to document the environmental performance of a stable product system where all mass and energy flows can be traced back to its origins and where changes in sales of the product have small consequences for other product life cycles. Consequential LCA (CLCA) is used when one is investigating how product systems create economy wide changes, for instance in substituting energy sources. The ILCD handbook (EC JRC 2010) devotes much space to describe for which decision-making situations each of the types is best suited. In general, ALCA is the preferred type of LCA to document the potential environmental impacts of single products, while CLCA should be used to investigate the system-wide environmental consequences of bigger changes, such as for instance the composition of fuel sources used for the car fleet.

Brander et al. (2009) warn that the use of LCA in policy without distinguishing between ALCA and CLCA may lead to a range of problems, for instance the wrong method applied for the application, a combination of the methods within the same framework, or unfair comparison of LCA results. They state that EU's Renewable Energy Directive seems to be consistent in its use of ALCA but that this may not be the appropriate framework for calculating the total changes in greenhouse gas emissions.

In practice, a typical difference between the two types of LCA is the use of average data in ALCA and marginal data in CLCA. This means that electricity consumption in Norway typically will be from a hydro power plant in ALCA but from a Danish coal fired power plant in CLCA. There is not one of the types of studies being more correct than the other from the outset, but the user of the study needs to have a clear understanding of what the results should be used for. Policy-makers wanting to judge whether a new biofuel produces a reduction in overall GHG emissions might want to use ALCA to compare the new biofuel to traditional fossil fuels. They must, however, be aware that there could be indirect market effects with large consequences for the result if the new biofuel should begin to substitute large portions of fossil fuels.

Indirect land use change (ILUC) is one example of indirect effects. Searchinger et al. (2008) showed that bioethanol in the US gives large GHG emission reductions in an ALCA perspective, but that the results might change dramatically if one considers how increased production of corn in the US will affect the use of agricultural land globally. In their example, increased production of corn in the US means higher import of soy to the US. This again means soy production must be expanded elsewhere and most likely on land with high carbon stocks needing to be transformed into agricultural land. While this particular study has been widely debated and criticized, ILUC remains an important challenge to LCAs of bio-based products.

5. LCA of waste handling

LCA is widely applied in relation to end-of-life strategies and waste handling options for products. Many of these studies begin when products (or materials) reach an end-of-life stage, i.e., the production stages of the products or materials are outside the system boundaries. Such study design is useful in order to compare and choose between waste handling options, and is commonly referred to as the zero-burden assumption. This term was first employed to state that there was no need to include upstream activities when studying the handling of wastes at the end-of-life stage. This is because the upstream stages would be equal for all systems to compare (Finnveden 1999, Ekvall et al 2007). The zero-burden assumption has been exported to other areas, for example to the calculation rules in the EU RED (EU 2008). There seems to be little consideration of the inherent paradox included in defining a waste as a raw material input for an energy product. This paradox becomes a real problem when materials previously wasted start to gain a substantial economic value.

There are good reasons to open a discussion on the appropriate allocation of burdens to different material flows, and even better reasons if the World undergoes a transition to a circular economy where wastes, unlike today, should be seen as deviations in the system. The same discussion applies when the original flow that is a given a higher economic value is a side-stream rather than a waste. All changes in processes that involve a change in the relative value of flows in a product system will require a discussion on the attribution of impacts to the different flows.

An LCA of waste handling of a biological material might conclude that one should incinerate the material to produce energy products or degrade the material to produce biogas. There is, however, a danger that such a conclusion misses how rest products can or cannot be utilised in other product systems. Co-firing of waste wood together with other bioresources to generate heat and power will give good results for contribution to climate change specifically for handling of waste wood. However, when wood waste is incinerated, the resulting ash cannot be returned to forests. This will eventually lead to nutrient depletion in the forest.

A similar problem might arise when waste substrates are mixed for biogas production, where the resulting biological rest material may or may not be suitable as a fertiliser.

6. Time is a factor

Although LCA is based on a general framework to be applied for all products based on all materials, it is widely recognised that specific products or materials need specific treatment in the method. When LCA is used to generate environmental product declarations (EPDs), the assessment must conform to so-called product category rules (PCR) which spells out the assumptions and specific calculation rules for the given product or material. A typical difference between biotic and abiotic materials is that the first type of materials normally decays much more rapidly than the latter. Naturally (sic!), there is a higher urgency to handle organic wastes than most inorganic wastes and the question of how to treat the waste cannot be delayed until the proper method is found. Instead, it must be done instantly. Therefore, the function of waste handling becomes more important than the function potentially fulfilled by recycling the material.

Time is also an important factor in relation to the carbon cycle. The carbon atoms in biogenic materials are no different than the carbon atoms in fossil materials. There is, however, a large difference in the average time from a carbon atom is released to the atmosphere until the same carbon atom can be stored in nature. This has spurred a debate on carbon debt, a term coined to illustrate the time lag from a GHG emission to the storage of the same amount of carbon (see for instance Fargione et al 2008 and Holtsmark 2012). This has led to research within the LCA community on how employment of different plant species and trees to energy purposes contribute to global warming (Bright et al. 2012). The overall utilisation of the plant or the tree becomes important, and it raises questions on how to allocate between main products, by-products and waste flows.

7. How to connect impacts to their origin?

Allocation is an important methodological issue in LCA. Whenever a process provides more than one useful product, the LCA practitioner must find a way to partition environmental impacts between the products. This is especially relevant when resources previously understood as waste resources enter a circular economy and are used as input to a new product system.

For instance, the use of the palm oil by-product PFAD (Palm Fatty Acid Distillate) as raw material for biodiesel production has spurred debate in Norway and other European countries. PFAD has been classified a waste and in many LCA studies it has been considered cut-off from environmental issues related to palm oil production, including devastation of tropical rain forests. With the increasing debate about the role of PFAD in driving deforestation, its status as a waste has been reconsidered in Norway (Klima- og miljødepartementet 2016).

As a consequence, it may be necessary to include the environmental impacts from cultivation of palm in the life cycle of PFAD. In LCA terms, this could be done by considering the use of PFAD as recycling, and by applying allocation to partition the environmental impacts from palm cultivation between palm oil and PFAD. It is quite possible that other biomass materials will see similar developments (see e.g. Oldfield et al. 2018, Pradel et al. 2016), both in terms of policy discussions and in terms of how LCA is applied when wastes are valorised.

The process of applying allocation is not entirely straightforward, however. The LCA practitioner must identify a fair and relevant basis for partitioning the impact, which could be reflected by the mass of different products, by their energy or nutritional content, by their economic value, or by other characteristics.

8. Policy implications

LCA is, despite the potential hurdles discussed here, the only method available to quantify, and thus manage, environmental impacts from product life cycles. What should policy makers be aware of when LCA is used as a knowledge basis for policy-making?

1) Results from an LCA are dependent on the type of LCA used. An ALCA tries to reply different questions than a CLCA and uses different system boundaries and data. This does not mean that either type is better than the other, but that they should be deliberately applied for different purposes.
2) CLCA should be used to form policies and investigate different possible futures.
3) ALCA should be used to document the environmental impacts as the policies are made into reality.
4) Results from an LCA are dependent on the assumptions. This is especially important when resources previously wasted are turned into useful products.
5) An LCA cannot decide how different types of environmental impacts should be weighed against one another. This type of prioritization is normally a question for the policy domain and LCA can merely provide information on different impacts.

For more information please visit the project website: http://www.susvaluewaste.no/

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