Life cycle assessment-based guidance for development of new energy technologies

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2

Chapter 2

Towards Application of Life Cycle Sustainability Analysis

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Abstract

There is an increasing need for expanding the scope of traditional life cycle studies to answer system-wide sustainability questions. This has resulted in a framework for Life Cycle Sustainability Analysis (LCSA). Since the framework was first published in 2009, as one of the outcomes of the CALCAS project, several views and considerations concerning the methodological approach have been published. However, until now practical experience with LCSA is very limited.

This paper reports first efforts and experiences in bringing the LCSA framework into practice by assessing the sustainability of solar fuels. Starting point of the project is the hypotheses that new technologies can only be practically implemented if they fit into a socially, economically and ecologically sustainable context. The analysis therefore aims at identifying performance criteria which a new technology needs to fulfil in order to compete in the existing market.

It is argued that a LCSA study should be initiated with a broad but relevant system description as the first of in total five steps Of this five step approach, the first – system description – is discussed here. The system description identifies and describes the technological description, the intended application of a technology, which share of specific demand for service will be met, which other technologies contribute in meeting this demand, the (relevant indicators for addressing)sustainable impacts of meeting the demand and developments over time. By doing so it provides a solid basis for further steps in the LCSA study.

2.1 Introduction

2.1.1. Towards BioSolar Cells

The Dutch Towards Bio Solar Cells (TBSC) program aims at developing new technologies that make better use of solar energy by artificially increasing the efficiency of the photosynthesis process. These technologies range from developing biodiesel producing algae, modifying the photosynthesis process in plants to improve yields and the development of "artificial leafs" with which fuels can be produced directly from sunlight. The implementation of a new technology can only be successful if -once technological feasible- it is economically viable, environmentally beneficial and socially acceptable. The TBSC program therefore not only aims to develop new technologies, but will simultaneously investigate the initial response of society to find out elements that are critical for acceptance of biosolar technologies. For this, societal debates will be organized and ex ante comparative sustainability assessment of the new technologies are performed to identify sustainable opportunities, constraints and necessary improvements for further development and successful implementation.

2.1.2. A new approach to sustainability assessment

For the ex-ante assessment of biosolar cell technologies to produce solar fuels a novel approach, labelled "*Life Cycle Sustainability Analysis*" (LCSA) will be used. The LCSA framework, used in this paper, was first presented as an outcome of the CAL-CAS project . In the past decades the focus of sustainability analyses has been on the environmental impacts of products or services providing a specific function. An in-creasing need to take a broader view on the possible impact on sustainability of decisions and developments has been recognized (Kloepffer 2008; Finkbeiner et al. 2010; Guinée et al. 2011; Valdivia and Sonnemann G. 2011). A first step towards a broader view introduces the analysis of economic and social impacts of product systems in addition to its environmental impacts. A second step expands from product level assessment towards assessing the consequences of introducing changes in product systems on meso (company, regional) and economy-wide (nation, global) levels. Consequences can be expected, for example, in resource availability for other products or in consumption patterns (Zamagni 2010). It is clear that assessment of new technologies in the TBSC project requires the broadest view on sustainability as is provided by the LCSA approach.

2.1.3. This paper

Since the range of technologies developed in the TBSC project is rather wide, the project of which this paper is a first exploration, focusses on the application of biosolar cell technologies to produce solar fuels. Since the biosolar technologies are still in their early infancy, the primary focus is currently on the production of solar fuels through existing technologies as is proposed by Haije (2011). The aim of this paper is to provide a practical approach for performing an LCSA study focused on solar fuels. First a concise overview of the LCSA framework will be presented, which will be supplemented with insights and experiences from a limited set of recent publications considering LCSA. Insights gained from this overview are then translated in a practical approach for a LCSA concerning biosolar cell technologies to produce solar fuels.

2.2 Current status of life cycle sustainability analysis

2.2.1. Life cycle sustainability analysis (LCSA) framework

One of the main results of the CALCAS project (Zamagni et al. 2009; Guinée et al. 2009) is a high level methodological framework for LCSA (see Figure 2.1). The framework suggests using LCA practice as a steppingstone towards conducting life cycle sustainability assessments and consists of three phases; goal & scope definition, modelling and interpretation.

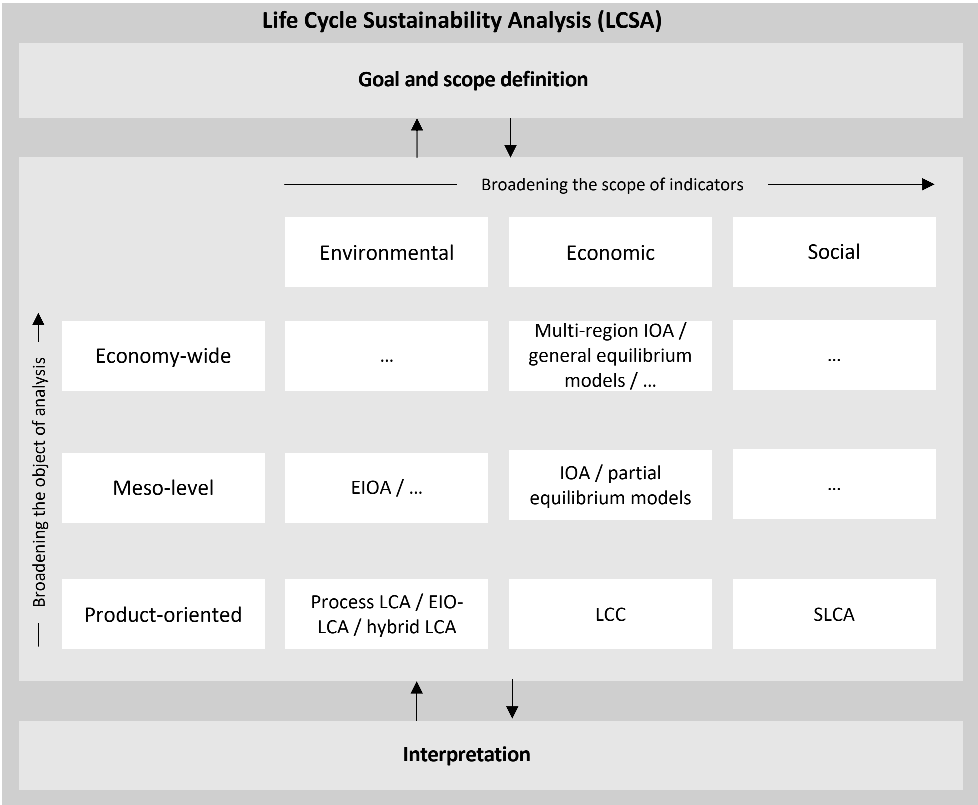

Figure 2.1: Transdisciplinary integration framework for LCSA taken from Guinée et al. (2011).

Goal and scope definition in LCSA

The LCSA framework is not a fixed guide, Guinee describes it as a transdisciplinary framework of different models rather than a model in itself (Guinée et al. 2011). It is intended to guide practitioners in selecting the most appropriate life-cycle based models for a given life-cycle based question (Guinée and Heijungs 2011). In classic LCA studies the goal of a study is formulated in terms of the exact question, target audience and intended application. The scope is defined in terms of temporal, geo-graphic and technological coverage and the level of sophistication of the study in relation to its goal. Finally the object of analysis is described in terms of function, functional unit and reference flows (Guinée et al. 2002). Of course in LCSA studies these issues need to be defined as well, however because of the complexity of LCSA studies, increasing emphasis should be put in particular on framing the right question (Zamagni 2010). A well-defined question will help to choose the right approach and tools for solving this question and thus should be framed in close relation to the relevant (sustainability) criteria shaping decisions at hand (Zamagni 2010). It is important to involve the stakeholders when investigating what the problem is, what the system concerned does, what impacts an intended decision might have, if the system analysed simply replaces other systems on a small scale, or if the technology used is expected play a role on a larger scale (Zamagni et al. 2009; Zamagni 2010).

Modelling

The modelling block in figure 2.1 shows an overview of models, methodologies and tools that can be used for calculating specific sustainability impacts. Selecting and applying the proper model to answer a specific sustainability question however is the main challenge (Guinée et al. 2011) but is guided by three modelling considerations that will be described shortly below.

A broadened scope of indicators

LCSA incorporates not only environmental impacts but also economic and social impacts to cover all dimensions of sustainability, what is presented as “broadening the scope of indicators”. This is in line with a general accepted view on sustainability assessments that should not only involve environmental impacts or consequences of decisions but also social and economic impacts (Kloepffer 2008; Dobon et al. 2011). A broadened scope calls for a different approach for analysis. In the classic inventory analysis (LCIA), physical flows that connect processes are defined and in the impact assessment specific environmental impacts are calculated from the properties of these flows. Where it is possible to connect a price to a physical flow, most other economic and social impacts are not connected to a system by physical flows but by economic, political, behavioral or cultural relations (Guinée and Heijungs 2011). This makes it impossible to take the conventional scientific reductionist approach used in LCA to model economic and social impacts (Halog and Manik 2011). The proper way of assessing these impacts depends on the specific study at hand. Guidance can be sought in experiences with Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA), where attention needs to be given to the fact that these are assessment tools appropriate for product level assessments.

A broadened object of analysis

Where classic LCA focusses on product level assessments, contemporary sustainability questions go beyond products and services and involve questions concerning technologies, product groups or industries (meso-level) and even state economies or geographical or political entities (economy-wide). This is presented as "broadening the object of analysis". Recent publications on LCSA mainly focus on the product or service level for their assessment (Dobon et al. 2011; Brandão et al. 2010; Gheewala et al. 2011; Achilleos et al. 2011; Schau et al. 2011). Kissinger (2010) stresses that increasing interdependencies of our world economy as a result of globalization also determine the need of assessing sustainability on the same (global) scale. Sustainability in a globalizing world demands that the scale of material flows and impact studies match the scale of human economic activities (Kissinger and Rees 2010). Schau (2011) identifies a possible conflict between the microeconomic aim of reducing cost, mainly concerned on a product level, and the higher level goal of economic growth. Which shows that decisions aimed at improving sustainability on a product level might have adverse effects on a higher level when practiced on a larger scale. Impacts related to choices made at the product level cannot simply be extrapolated to find the impacts on an economy wide level. Modelling of impacts beyond product level can benefit from experiences in economic modelling and environmentally extended input-output assessment (E-IOA).

Deepening

In the CALCAS framework the concept of deepening is introduced to emphasize that broadening the scope of indicators and object of analysis requires a deepened assessment approach. A specific impact cannot longer be attributed to a specific flow alone, but also depends on other impacts or other than physical relations that can be identified in the system studied. Sustainability impacts in LCSA are not only physically related to processes or flows of commodities but are related to a system or process via economic, social, political and cultural relations and mechanisms (Zamagni et al. 2009). The concept of deepening displays the rationale behind LCSA. One should keep in mind that the pursuit of only one-sided benefits of decisions may not achieve sustainability (Moriizumi et al. 2010). Meaning that impacts need to be assessed in relation to other impacts and the overall performance of a system. Finkbeiner (Finkbeiner et al. 2010) stresses that to keep a sustainable balance, trade-offs or interrelations between the three dimensions of sustainability need to be addressed with utmost care. In other words, attention should be assigned to mechanisms like spill-over or rebound effects. Also Halog and Manik (2011) state that covering all possible impacts as separate entities by using models next to each other neglects trans and cross-boundary impacts or interrelationships between and among parts of the study. The added value of performing an integrated sustainability assessment lies in the fact that sustainability as a whole concerns more than the sum of its parts (Halog and Manik 2011).

Interpretation

The final phase of an LCSA study is the interpretation which is comparable to the final phase in LCA. It is the phase in which the results of the analysis and all choices and assumptions made during the course of the analysis are evaluated in terms of soundness and robustness, and overall conclusions are drawn. Results are evaluated and analysed by performing consistency and completeness checks and by performing contribution and perturbations analyses (Guinée et al. 2002). Drawing conclusions on favourable alternatives can be a challenge in LCA studies because an alternative might show a decrease in global warming potential but an increase in ecotoxicity. To base decisions on these varying outcomes in LCA weighing practices are used. It is easy to imagine that LCSA studies provide a wider pallet of changing and interrelated impacts, spreading over different dimensions of sustainability and different disciplines. By that even increasing the complexity of formulating and understanding solid conclusions that form a basis for decision making. Kloepffer (2008), Finkbeiner (2010), Heijungs (2010) and Halog (2011) stress the need for transparent and easy to understand results from an LCSA study. Suggestions are made on introducing multi criteria decision analysis (MCDA) for drawing conclusions (Halog and Manik 2011; Moriizumi et al. 2010).

2.3 Towards applicaton of LCSA

The LCSA framework provides a theoretical approach on how to perform an LCSA study. Next to that it provides the supporting concepts of broadening and deepening in modelling the increased complexity of LCSA. Most recent LCSA studies present a broadened scope of indicators and only Morizumi et al. (2010) report on their approach. Using insights from work reported by Zamagni (2009) and Moriizumi et al. (2010) the remainder of this article seeks to provide a systematic and practical approach for life cycle sustainability assessment of new (biosolar) technologies.

Since the experience with LCSA is still limited and there is variety of questions that can be answered by using the LCSA framework, it cannot be expected that there is one general research approach that fits all LCSA assignments. Here it is suggested that the LCSA level of complexity demands an extensive primary phase in which the object and goal of the study is defined. A thorough system description will provide a solid foundation to frame the right research question and define further research steps, f.e. which impacts to focus on and which models to use to quantify these. In practice, the scope of an LCSA will have to be adapted to the resources available for the study (Zamagni et al. 2009). One should therefore aim for only addressing those issues that are relevant for the specific study instead of aiming for a complete system description.

2.3.1. Describing the system

Figure 2.2 gives a schematic overview of the system concerned in an LCSA study and general themes that need to be addressed. As a reference the system concerned in classic LCA is displayed on the left. Describing the system is an iterative process in itself and will not always be strictly separated from other phases of the LCSA. Insights developed in the process of describing the system will identify additional stakeholders that can be approached to further detail the system. All relevant stakeholders need to be questioned on their concerns, needs, problems, priorities and reasons to act regarding the technology under consideration (Moriizumi et al. 2010).

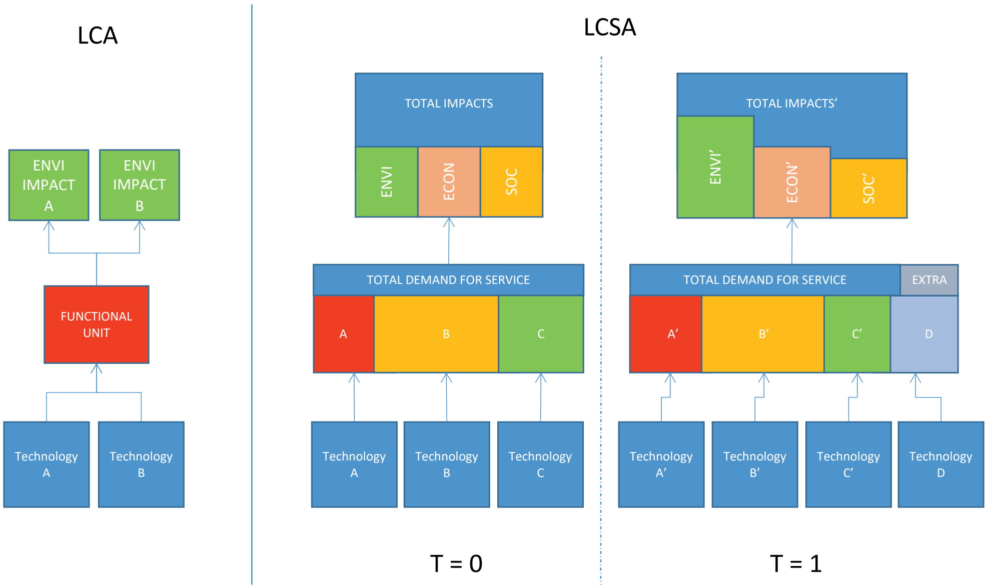

Figure 2.2: LCSA system.

In order to perform a LCSA of a technology one first needs a clear technological description and the application of the technology at hand. The application of a technology contributes to meeting a certain demand for service, for example national or global energy demand. By knowing its application it is possible to identify alternative technologies that also contribute to delivering the same total demand for service. Meeting the total service demand results in environmental, economic and social impacts. If a service demand is provided in a sustainable manner depends on the balance of these impacts in relation to the service provided. Which technologies are deployed and how big their share in meeting the total demand is, depends on the overall impact of the system. In other words if it is technological feasible, economically viable, environmentally beneficial and socially acceptable As an illustration we will give a hypothetical example for total electricity demand. Electricity prices are kept within reasonable limits by using fossil fuel power plants. In addition it is tried to cut CO_2 emissions by investing in more expensive renewable energy options. In the mean while fossil fuel power plants are still under construction because it gives a boost to local economies and renewable energy sources are currently not capable to meet increasing energy demand.

System complexity makes it impossible to identify the direction of causal relations be-tween technology, demand for service and impacts. For the sake of modelling it is assumed here that a certain demand for a service is fulfilled by applying certain technologies and that fulfilling this demand with these technologies results in certain impacts. These impacts might result in the improvement of existing technologies or the introduction of new ones. In the real world the introduction of a new technology in a system sets of a dynamic in which both total impacts and the division of the total demand for service over available technologies will change.

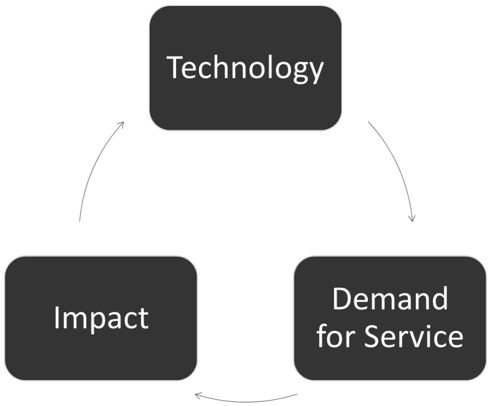

Figure 2.3: Causal relations in modelling LCSA.

Assessing a new technology to identify constraints for development and successful implementation demands for taking developments over time into consideration as well. For developing a technology, its deployment and successful implementation a typical timeframe of 30-40 years can be expected (Hirooka 2006). In this period of time the total demand for service and the (performance of) technologies supplying this service will have changed. A new technology needs to be compared in a future situation. Information on the expected future system especially the demand for service and its supply divided over alternative technologies is required (right side of Figure 2.2). Developing and using scenarios will therefore be one of the steps following the system description.

2.3.2. Proceeding from a system description to a full assessment

Describing the broad system provides a solid basis for approaching next phases that will result in a life cycle sustainability assessment of a technology. It provides insights to frame the right question and relevant stakeholders are identified. By discussing and describing alternative technologies and how these technologies contribute to supply the total service demand also relevant indicators in the three sustainability domains are identified. Information is gathered so far by taking a bottom up approach, by involving stakeholders. From an Industrial Ecologists point of view it is suggested to discuss the system description via a bottom up approach with actors not directly involved to identify possible impacts or points of attention that are probably not ad-dressed but are relevant in a broader view.

After describing the system additional steps need to be taken to finally present quantified sustainability indicators and resulting impacts. These steps consist of defining scenarios on possible developments in technology performance and service demand, finding the right tools to quantify the indicators identified, applying the these tools (including additional data gathering) and interpretation of results presented by the tools applied. All steps for an LCSA to be used to assess biosolar technologies are dis-played in Figure 2.4.

The outcomes of the study need to be used in to discuss what mix of technologies provides the best balance over all sustainable domains. And additionally which performance criteria, depending on sustainable impacts, new biosolar technologies need to fulfil to be added to the list of technologies that will provide the total demand for service.

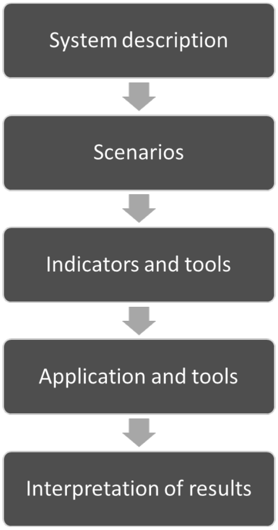

Figure 2.4: Five step approach for LCSA.

2.4 Conclusions and outlook

This paper investigates and proposes a practical approach for performing a life cycle sustainability assessment. It is found that, until now, limited attention is given to the issue of how a LCSA can be approached practically. The paper therefore provides an approach founded in a concise overview of the LCSA framework as presented in the CALCAS project supplemented with insight from recent scientific reporting on LCSA studies. It is argued that a LCSA should be initiated with describing a broad but relevant system description as the first of in total five steps (Figure 2.4). Of this five step approach, the first – system description – has been discussed. The system description identifies and describes the technological description, the intended application of a technology, which share of specific demand for service will be met, which other technologies contribute in meeting this demand, the (relevant indicators for addressing)sustainable impacts of meeting the demand and developments over time. The approach presented in this paper will be brought into practice by applying it in a LCSA study on solar fuels. The practical experience from the latter will provide inputs for fine tuning the approach as presented here.

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