METHODOLOGY FOR LCA OF BIOREFINERIES – A LITERATURE REVIEW

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ABSTRACT

The number of LCAs of biorefinery systems has increased in recent years, however there is a large variety in how the LCA methodology is used. The aim of this paper was to analyse existing life cycle assessment case studies of biorefinery systems concerning basic key issues related to the LCA methodology, and how these have been handled in the case studies. This is intended to contribute to improved insight of the difficulties when performing LCA of biorefinery systems, which could facilitate future studies.

INTRODUCTION

The current trend in biomass conversion technologies is towards so called biorefineries, where a spectrum of different products allows for a more energy and cost efficient utilization of the biomass. Another trend is the attention given in research, policymaking and media to the environmental impact of biomass systems, especially climate impacts. Over the years, many life cycle assessment (LCA) studies of bioenergy systems have been performed. Still, LCA of bioenergy faces some methodological issues, it has for example during the last years been under heavy debate how to include indirect land use changes in the calculations.

LCA of biorefinery systems make the calculations even more intricate; there are a number of basic LCA key issues that will be relevant to consider. First of all, biorefinery produces several high-value outputs, rather than one main product and by-products. This means that the choice of functional unit will be very important. Further, the environmental impact somehow has to be divided over the high-value products. Also, a biorefinery-LCA with several output products will require much more assumptions and data input, which increases the uncertainty. It will therefore be extra important to define appropriate systems boundaries.

In a project funded by the Swedish Knowledge Centre for Renewable Transportation Fuels (f3), some LCA researchers in Sweden have come together to discuss these issues. The project group consists of representatives from the Swedish University of Agricultural Sciences, Lund University, KTH Royal Institute of Technology, IVL Swedish Environmental Research Institute, SP Technical Research Institute of Sweden and Chalmers University of Technology. The project group will identify and discuss the key issues of BR-LCA and work out recommendations on how they can be handled. The project is to be finalised in September 2013. The present paper will be a part of the outcome of this project.

The aim of this paper is to analyse existing life cycle assessment case studies of biorefinery systems concerning basic key issues related to the LCA methodology, and how these have been handled in the case studies. This is intended to contribute to improved insight of the difficulties when performing LCA of biorefinery systems, which could facilitate future studies.

MATERIALS AND METHODS

In this study, 12 scientific papers published between 2009 and 2013 have been reviewed (Table 1). The articles were found by a screening in which both the publically available Google Scholar and Lund University Library database were used. Screenings for papers were performed in August 2012 and February 2013. The studies were chosen to provide examples of case studies of biorefinery systems and they do not to represent the entire collection of papers in the field. One selection criterion for the papers included in the literature review was that they should present an LCA-based environmental assessment of a system in which more than one valuable product is produced from biomass. The term biorefinery is not specified in all of the included studies, which may have an explanation in the lack of a clear and universal definition of biorefineries. A biorefinery can be anything from a simple ethanol factory to a complex, integrated system in which a number of actors cooperate and a variety of products are produced.

Table 1. Studies used in the analysis

No	**Study**
1	Cherubini & Jungmeier (2010)
2	Cherubini & Ulgiati (2010)
3	(Ekman & Börjesson (2011)
4	Gonzalez-Garcia et al. (2011)
5	Kimming et al. (2011)
6	Lim & Lee (2011)
7	Earles et al. (2011)
8	Souza et al. (2012)
9	Piemonte (2012)
10	Pourbafrani et al. (2013)
11	Tonini & Astrup (2012)
12	Uihlein & Schebek (2009)

RESULTS

The stated **aim** in the majority of studies included in the literature review is to assess, identify, quantify, characterize, investigate or evaluate the environmental impact of a biorefinery system in comparison with a reference system. This either refers to a fossil-based production system (study number 1, 2, 3, 5, 10, 11 and 12) or conventional biofuels (study number 6 and 8). A few studies also aim at identifying hot spots and suggest improvements to lower the environmental impacts of the biorefineries (study number 4, 6, 7, 11 and 12). In none of the studies an intended audience is specified.

The majority of the reviewed LCAs do not specify if **consequential or attributional** modeling is performed. None of the studies referred to the ISO 14040-14044 standards. Study number 5, 6 and 11 define themselves as consequential LCAs. Only study number 3 defines itself as accounting LCA.

The **functional units** (FU) in the reviewed studies are mainly of three types. The first type is one selected product, for example, 1 tonne dissolving cellulose (study number 4), 1 kg propionic acid (study number 3) or 1 kg fuel (study number 9). The second category includes FUs that contain a combination of products produced such as 1000 kg ethanol, 368 kg acetic acid and 55300 square feet oriented strand board panels (study number 7) or MWh of different energy carriers supplied to a system/year (study number 5 and 10). The third category of FU refers to the input of feedstock expressed either as 1 tonne of biomass or waste (study number 11 and 12), 477 ktonnes of biomass (the total annual input) (study number 1) or 1 ha of sugarcane (study number 8) or 1 ha palm oil plantation in 100 years (study number 6). FUs in the third category showed to be most common alternative. The latter FU was in some cases motivated as the only reasonable alternative since one single main product could not be identified. In one case, a sensitivity analysis was performed in which the functional unit was altered (study number 10).

The reviewed studies had different **system boundaries**, cradle-to-gate is one of the most common stated. Also geographical specifications were different and proved to have some impact especially regarding the choice of input data such as type of energy used as input or to be replaced/compared to. This is valid for all studies since they all refer to different geographic regions.

Average **data** is used as input in most of the studies. Only studies number 5 and 11 are the only ones that take more detailed consideration of long or short-term marginal data. Especially the study number 11 makes a detailed sensitivity analysis related to what time perspective that is assumed.

The most common method to **handle multiple output products** is by system expansion. Three studies (3, 4 and 9) use economic allocation in the base case with the motivation that this is suitable to apply also for products with diverse characteristics. Some studies (3 and 10) test the application of other allocation methods, energy or mass based, in a sensitivity analysis. The studies that apply economic allocation based on market prices are those describing systems that either are in operation (study number 4) or that produce products identical to existing alternatives on the market today (study number 3).

DISCUSSION

When doing this review of literature, it could be concluded that the number of LCAs of biorefinery systems has increased in recent years since this approach to biofuels production has gained importance. However, the literature review revealed a large variety in the methodology used in the assessments, and that the methodological choices where not always given much attention even though they have major impact on the end results.

Besides the basic methodological LCA key issues there are also a number of biorefinery or biomass specific key issues, which are more related to the methodology of the impact assessment e.g. land use, biodiversity, accounting method for biogenic carbon both in input biomass and end products. Some of these issues will be treated in the coming project, described in the introduction.

CONCLUSIONS

The complexities involved when performing LCA of biorefinery systems has lead to inconsistency in existing case studies, making comparability among studies difficult. The problem is further enlarged by the lack of proper documentation of assumptions regarding data and methodological choices in many case studies. We see a need for further research on these topics.

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