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Effect of biogenic carbon inventory on the life cycle assessment of bioenergy: challenges to the neutrality assumption

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ABSTRACT

Biogenic carbon is defined as carbon contained in biomass that is accumulated during plant growth. In spite of the considerable progress towards the inventory of biogenic carbon in the life cycle assessment (LCA) of bioenergy in policy guidelines, many scientific articles tend to give no consideration to biogenic carbon, due to the neutrality assumption, rather than to employ a complete inventory according to the LCA principles. Meanwhile, the assumption of biogenic carbon neutrality has been previously challenged on the basis of changes in soil carbon stock due to land use change and carbon storage capacities of long-rotation trees or wood products. Supporting this argument, we investigate three other inventory aspects which strongly affect final results, namely, differences in framing system boundaries (cradle to grave vs. cradle to gate), forms of carbon emissions (carbon dioxide vs. methane), and valuation of biogenic carbon (relative economic values of biomass products vs. biomass residues). Referring to a generic bioenergy system, our analysis is focused on eight scenarios of various carbon flows encompassing biomass decomposition in fields and its alternative utilization as bioenergy feedstocks. These scenarios are applicable to both biomass products and biomass residues, for which the impacts proportionally depend on the chosen allocation criteria between the two. Further, a framework to quantify the performances of the various possible carbon flows on global warming impacts is formulated. The operation of the framework demonstrates that the assumption of biogenic carbon neutrality introduces a bias to the 'true' values based on a complete inventory. This can make the values of global warming impacts substantially higher or lower than the real scores when different system boundaries, forms of carbon emissions, and biomass valuation are taken into account. The results of this study could contribute to the harmonization of future bioenergy LCA by directing further research to adopt more the concept of utilizing a complete inventory rather than the neutrality assumption.

1. Introduction

Biogenic carbon is defined as carbon contained in biomass that is accumulated during plant growth involving photosynthetic processes. Variations in the inventory of biogenic carbon can be easily ascertained in life cycle assessment (LCA) practices. Downie et al. (2014), for example, has recently discussed various approaches to greenhouse gas (GHG) accounting for biogenic carbon. These different inventory approaches often incite confusion in interpretation due to their divergent final results. In addition, many LCA studies concerning bioenergy tend to give no consideration to biogenic carbon, due to carbon neutrality assumptions, rather than employing a complete inventory. The reason behind the neutrality assumption is that biogenic carbon sequestered during growth is believed to be released back in the same amount and forms, either naturally decomposed or burned, so that there is no net increase in the atmospheric GHGs. One recent example is an article published by Liska et al. (2014) regarding the estimation of CO_2 emissions from crop residue-derived biofuels. The article has stimulated scientific debates and thus has received several reactions, one of

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which is the critique of omitting biogenic carbon from the inventory (Bentsen et al., 2014). In this regard, it is important to identify which approaches are more accurate than others for a certain situation. Theoretically, any deviations when performing an inventory from the LCA principles, i.e., treating all relevant input-outputs as genuine flows including biogenic carbon, would move the final scores away from the true values. Moreover, it would be biased if such deviating results are for example exploited for policy making such as in taxes or incentives applied to bioenergy products.

The objective of this study is to examine the consequences of applying carbon neutrality assumptions (excluding biogenic carbon from an inventory) in the LCA of bioenergy systems whereby the analysis is focused on the global warming impact at different system boundaries (cradle to grave vs. cradle to gate), forms of carbon emissions (CO_2 vs. CH_4), and valuation of biogenic carbon (relative economic values of biomass products vs. biomass residues). In doing so, this study proposes a method to quantify global warming performances of various possible carbon flows in a generic bioenergy system based on a life cycle approach. These carbon flows encompass decomposition of biomass in fields and its alternative utilization as bioenergy feedstocks.

The remainder of the article is structured in the following manner. Section 2 describes the problems of inconsistencies in biogenic carbon inventories in policy guidelines and scientific literature, challenges to the biogenic carbon neutrality assumption, and inventory aspects in terms of system boundaries, forms of carbon emissions, and biomass valuation. Section 3 describes a step-by-step method for assessing global warming impacts of various carbon inventory scenarios. Finally, Section 4 discusses the results and their implications on the assumption of biogenic carbon neutrality.

2. In-depth description of the problems

2.1. Biogenic carbon inventory in policy guidelines and scientific literature

There is still debate regarding the manner to treat biogenic carbon in bioenergy systems in a policy context. At the global level, the Intergovernmental Panel on Climate Change (IPCC) adopts a carbon stock method rather than an input–output flow approach in accounting for biogenic carbon (Levasseur et al., 2013). A similar approach is also employed by the United Nations Framework Convention on Climate Change (UNFCCC) in order to report country's emissions resulting from land use and energy as separate sectors (Haberl et al., 2012). Encompassed within these frameworks, if trees are cleared from forest and, later in the life cycle, the biomass is combusted as bioenergy, the carbon that is lost from combustion can alternatively be expressed as a land use change (LUC), an instantaneous decomposition in the fields. If this is done, the CO_2 emissions from biomass combustion shall no longer be considered in order to avoid double counting, i.e., the emissions from biomass combustion are considered as zero. This latter argument is often utilized inaccurately as a basis to assume biogenic carbon neutrality. In contrast, Haberl et al. (2012) clearly stated that the above accounting practices do not justify biogenic carbon neutrality but, instead, provide an option that emissions generated from biomass combustion can optionally be inventoried as LUC. If done properly, either ways (claims as combustion or land-use emissions) would lead to the same results. More precisely, the authors stated that "the assumption that all biomass is carbon-neutral results from a misapplication of the original guidance provided for the national-level carbon accounting under the UNFCCC". We think that such an observation could be derived easily since Haberl and coworkers observed the entire bioenergy system from the life cycle perspective. This approach is based on the recognition that a complete inventory will provide a more accurate estimate of carbon balances. The current article adopts this view to establish criteria to examine the assumption of biogenic carbon neutrality in bioenergy systems.

The carbon accounting based on the carbon stock method would essentially result in the correct results if applied consistently, i.e., carbon emissions are all expressed either as land use or as energy use. Considering this, not-inventorying the emissions from biomass-use as bioenergy do not imply that the biomass is automatically 'carbon neutral'. The following is an example of possible inconsistency when applying the carbon stock method. The coverage of the UNFCCC accounting system for global warming is applicable to all countries worldwide. Meanwhile, Kyoto Protocol caps emissions from land use and from energy sectors differently for Annex 1 and non-Annex 1 parties, primarily consist of developed and developing countries, respectively (Haberl et al., 2012; UNFCCC, 2014). The first authors further stated that the protocol potentially caused errors as a consequence of the non-homogenous implementation of the accounting rules in different countries. In this regard, incomplete information regarding the inventory during an initial phase (LUC) could result in double counting or GHG emissions never being accounted for at all.

In spite of some progress towards the inventory of biogenic carbon in the life cycle assessment (LCA) of bioenergy, variations can still be ascertained between policy guidelines. As discussed in Johnson (2009), a life-cycle based method such as the British PAS 2050 initially did not consider biogenic carbon uptakes and emissions. Subsequently, its revised version clearly states that all biogenic carbon flows must be considered (BSI, 2011). The same applies for the GHG protocol developed by World Resources Institute and World Business Council for Sustainable Development (WRI-WBCSD, 2011). Similarly, the International Reference Life Cycle Data System (EC-JRC-IES, 2010) that was developed by the European Commission recommended the use of LCA principles with a complete input–output flow approach. Meanwhile, EU (2009) expressed carbon neutrality in a slightly different manner, where the capture of CO_2 in the cultivation of biomass is excluded, and emissions from biofuel use are set to be zero.

Divergence in ways to develop biogenic carbon inventories is more extensively found in the scientific literature of bioenergy LCA. Based on a survey that exceeded 100 publications, most solid bioenergy studies disregarded biogenic carbon emissions in the combustion of biomass (Johnson, 2009). More specifically, out of the 25 researchers working on the GHG emissions of wood fuel, only one group did not assume biomass to be carbon neutral. Similarly, nearly half of the liquid biofuel studies did not include biogenic carbon in their inventory (Wiloso et al., 2012). In this survey, 13 out of 27 LCA studies of second generation bioethanol based on energy crops and biomass residues did not consider carbon sequestration through photosynthesis. This indicates that the attitude towards adopting the concept of biogenic carbon neutrality varies between LCA studies on different forms of energy, i.e., 96% for solid bioenergy and 48% for second-generation liquid biofuel. This is quite a surprising observation that many scientific articles tend to give no consideration to biogenic carbon considering the neutrality assumption, which admittance varies depending on the forms of bioenergy (solid vs. liquid). In accordance with the trend in the policy guidelines, perhaps, additional scientific publications in the future would adopt more the concept of utilizing complete inventory rather than assuming carbon neutrality. This paper intends to contribute to the harmonization of the LCA of bioenergy in favor of the above perspective.