Enquiring into the roots of bioenergy - epistemic uncertainties in life cycle assessments

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The research for this Thesis was originally framed around the “sustainability assessment of full chain bioenergy”. However, it is known for some years that the critical impacts of dedicated bioenergy relate to induced land use changes (LUC). Their criticality derives from their potential to dominate environmental impacts from a life-cycle perspective and from the uncertainty that accompanies them. On the other hand, continued land use may be a concern for soil's long-term sustainability (understood as fertility), which has recently received attention in environmental life-cycle assessments (LCA) under the respective life-cycle initiative of the UNEP-SETAC. The Thesis thus focused on these two aspects of sustainability of bioenergy. The overall aim was to disentangle the epistemic uncertainties related to land use impact assessments in order to provide science based decision-support for environmentally sustainable land use management and policy-making, especially relevant for land-demanding or dedicated bioenergy deployment.

Paper I took a Danish willow plantation for cogeneration of heat and power (CHP) through gasification and framed the research around the key land-use reference assumptions. For this, the LCA was structured around three basic land scenarios: marginal abandoned land, marginal extensive grassland and arable land. For each scenario, different LUC models were developed which represent the different impacts induced from the occupation of land for energy cropping. Despite being the most productive, occupying arable land proved to have the largest impacts due to indirect LUC. Gasification willow from marginal abandoned land had also significant impacts from preventing natural regeneration, but it showed a significantly better environmental performance (even under the considered uncertainties) than CHP from natural gas. The implementation of such bioenergy systems on abandoned lands would be thus justified as long as they substitute fossil-fuel based CHP.

In Paper II, the key assumptions related to time horizons in LCA of bioenergy systems were analysed and crucial definitions for them were proposed, as well as generic recommendations regarding them. Similarly, the effect of different modelling approaches in LUC emission accounting was studied by the application of several methods to four biofuel case studies. As a result, dynamic land-use baseline methods were rejected for LUC accounting while top-down LUC models showed to be a more solid alternative to economic LUC models for regulation and footprinting purposes. After considering the studied epistemic uncertainties and based on the key conservative assumptions taken, it was concluded that land-demanding biofuels have larger global warming impacts than the respective fossil fuels they replace unless planted on abandoned lands.

With Papers I-II, the selection of the land-use references and time horizons involved in LCA of biofuels was demonstrated to be crucial for the characterization of the resulting environmental impacts. On top of that, different LCA modelling approaches exist with different virtues and applications, which logically articulate different sets of other key assumptions. Therefore, three land-use reference frameworks were proposed in Paper III to enable value-consistent land use impact assessments. Based on previous findings and recommendations, new methodological modifications to the existing UNEP-SETAC framework were suggested. The proposed modifications were articulated by discriminating among different long-term impacts from land use and by classifying different ecosystem services provided by land as environmental stocks or flows. These modifications reorient the land use impact assessments to impacts during occupation and suggest dealing with permanent impacts separately. In the proposed new methodology, dynamic land-use references are suggested for assessing occupation impacts on abandoned lands (relevant for consequential LCA) while static references are suggested for generic occupation impacts (in any LCA). Static references, understood as the precedent vegetation cover in equilibrium, are also suggested for every transformation impact assessed with any LCA modelling approach.

Last but not least, a hybrid LCA (HLCA) framework was also proposed as an alternative to existing attributional LCA which facilitates both absolute and relative sustainability assessments. Unknown or indirect LUC can be included with top-down LUC models (LUCglobal for world-average greenhouse gas (GHG) emissions or LUCGHProtocol factors for country-average, crop-specific GHG emissions). In order to enable absolute land use impact assessments, the use of substitution is not allowed in the HLCA framework and an area based functional unit (FU) should be chosen. For this, land use impacts can be linked to planetary and regional ecosystem boundaries through normalization references (taken as carrying capacity thresholds). Environmental footprinting of products from land-use systems with co-products can be carried out by choosing product-based FU, but absolute land use impact assessments would involve then value-laden allocation choices. Value-free absolute impact assessments can still be carried out with area-based FU and by adding function-equivalent synthetic products to the other system(s), which allow system (rather than product) comparability.

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