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# Energy- and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations

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**A b s t r a c t**
With increasing use of biomass for energy, questions arise about the validity of bioenergy as a means to reduce greenhouse gas emissions and dependence on fossil fuels. Life Cycle Assessment (LCA) is a methodology able to reveal these environmental and energy performances, but results may differ even for apparently similar bioenergy systems. Differences are due to several reasons: type and management of raw materials, conversion technologies, end-use technologies, system boundaries and reference energy system with which the bioenergy chain is compared. Based on review of published papers and elaboration of software data concerning greenhouse gas and energy balances of bioenergy, other renewable and conventional fossil systems, this paper discusses key issues in bioenergy system LCA. These issues have a strong influence on the final results but are often overlooked or mishandled in most of the studies available in literature. The article addresses the following aspects: recognition of the biomass carbon cycle, including carbon stock changes in biomass and soil over time; inclusion of nitrous oxide and methane emissions from agricultural activities; selection of the appropriate fossil reference system; homogeneity of the input parameters in Life Cycle Inventories; influence of the allocation procedure when multiple products are involved; future trends in bioenergy (i.e. second-generation biofuels and biorefineries).
Because many key issues are site-specific, and many factors affect the outcome, it is not possible to give exact values for the amount of greenhouse gas emissions and fossil energy consumption saved by a certain bioenergy product, because too many uncertainties are involved. For these reasons, the results are here provided as a means of wide ranges. Despite this wide range of results, it has been possible to draw some important conclusions and devise recommendations concerning the existing bioenergy systems, and some emerging implications about the future deployment and trends of bioenergy products are pointed out.