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Tonini, Davide; Astrup, Thomas Fruergaard

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Bioenergy from crops and biomass residues: a consequential life-cycle assessment including land-use changes

Davide Tonini, Thomas Astrup
Department of Environmental Engineering, Technical University of Denmark (DTU), 2800 Kgs. Lyngby, Denmark. Mail: dait@env.dtu.dk

Biofuels are promising means to reduce fossil fuel depletion and mitigate greenhouse-gas (GHG) emissions. However, recent studies questioned the environmental benefits earlier attributed to biofuels, when these involve land-use changes (direct/indirect, i.e., dLUC/iLUC) (1-5). Yet, second generation biofuels produced from residual biomass promise important environmental savings. However, since these residues are today in-use for specific purposes (e.g., feeding), a detailed modelling of the consequences (e.g., on the feed-market) induced by their diversion to energy should be performed to represent the actual environmental impacts.

This study quantified the GHG emissions associated with a number of scenarios involving bioenergy production (as combined-heat-and-power, heating, and transport biofuel) from energy crops, industrial/agricultural residues, algae, and the organic fraction of municipal solid waste. Four conversion pathways were considered: combustion, fermentation-to-ethanol, fermentation-to-biogas, and thermal gasification. A total of 80 bioenergy scenarios were assessed. Consequential life-cycle assessment (CLCA) was used to quantify the environmental impacts. CLCA aimed at identifying all the consequences associated with the establishment of bioenergy systems compared with the reference (current use of fossil and biomass resource). The modelling was facilitated with the LCA-model *EASETECH*. The functional unit was 1 unit-energy produced (i.e., 1 kWh electricity, 1 MJ heat or 1 MJ transport-biofuel, depending on the energy-service provided by the individual scenarios). The benefits derived from the use of the co-products were included.

Results revealed that iLUC GHG emissions were the major contributor to the total GHG impact (up to ca. 50%). For energy crops, the impact from iLUC was in the range 1.5-3.5 kg $CO_{2\text{-eq.}}$ kg^{-1} crop. Overall, bioenergy production from municipal solid waste and agricultural/industrial residues should be prioritized over cultivation of energy crops. This holds true as long as these residues are not today used as animal feed. Results also demonstrated that algae represent an interesting alternative to terrestrial energy crops.

This study provides GHG emission factors for a wide number of bioenergy scenarios. The aim is to inform decision/policy makers on the environmental consequences of producing biofuels from different sources, and for a variety of energy-services. Further, a new LCA-model (*EASETECH*) for bioenergy assessment is presented.

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