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Tonini, Davide; Alvarado-Morales, Merlin; Astrup, Thomas Fruergaard

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GHG emission factors of biofuels: A case study for Denmark

Davide Tonini*, Merlin Alvarado-Morales, Thomas Fruergaard Astrup

DTU Environment

*Corresponding author email: 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). Yet, biofuels produced from residual biomass promise important environmental savings. However, since these residues are today used 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 capture the actual environmental impacts.

This study quantified the GHG emission factors for production of: i) electricity, ii) biomethane and iii) bioethanol from a number of substrates including industrial/agricultural/urban residues and terrestrial/aquatic energy crops. Four conversion pathways were considered: combustion, fermentation-to-ethanol, fermentation-to-biogas, and thermal gasification. Consequential life-cycle assessment was used to quantify the GHG emission factors. The modelling was facilitated with the LCA-model *EASETECH*. The functional unit was 1 unit-energy produced (i.e., 1 kWh electricity or 1 MJ transport-biofuel). Benefits from the use of (eventual) co-products (e.g. heat) were included.

Overall, bioenergy production from residues always showed significant GHG savings compared with conventional fossil fuels. This holds true as long as these residues are not (currently) used as animal feed. This is the case of industrial residues (e.g. beet molasses/pulp, whey, brewer's grain) for which diversion (from the feed sector) to energy production did not induce GHG savings compared with conventional fossil means of production. Because of their high yields, low fertilizer input and favorable soil carbon balance, perennial energy crops such as willow and *Miscanthus* also showed significant GHG savings compared with fossil fuels. This was also the case for algae, while annual crops, such as wheat and maize, showed GHG emission factors comparable with coal/gasoline (or higher) because of the potential indirect land-use change (iLUC) impacts associated with their establishment.