Decentralized recycling of digested wastes in agricultural regions: A multi-dimensional sustainability assessment

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INTRODUCTION

Decentralized anaerobic digestion (AD) of manure and organic residues is a possible strategy to improve carbon and nutrient cycling within agricultural regions, meanwhile generating renewable energy. To date, there has been limited adoption of decentralized AD technology in industrialized countries owing to low profitability for plant operators. There remains a need to demonstrate the wider sustainability of small-scale, decentralized AD in order to justify policy support for such a strategy.

The aim of this study is to identify the benefits in terms of resource efficiency and sustainability of using digested agro-waste (manure, crop residues and food waste, notably) instead of raw animal manure and synthetic fertilizer. To this end, a multi-dimensional sustainability assessment, including an environmental, economic, and social evaluation, is performed for the case of Southern Sweden. Two scenarios are analyzed: 1) Decentralised AD of manure and crop residues + recycling of liquid and solid fraction of digestate after mechanical separation in agriculture (base case: application of undigested manure and synthetic fertilizer + disposal of crop residues); 2) Decentralised AD of manure, crop residues and food waste + recycling of liquid and solid fraction of digestate after mechanical separation in agriculture (base case: application of undigested manure and synthetic fertilizer + disposal of crop residues + incineration of food waste).

MATERIALS AND METHODS

The environmental dimension was investigated through a life cycle assessment (LCA), accounting for trade-offs between fertilizer replacement, transport and soil emissions. The soil organic carbon (SOC) effect is also modelled. Moreover, the study addresses significant shortcomings of some previous LCA studies by expanding system boundaries to account for greenhouse gas (GHG) and nutrient loss effects of avoided manure storage and digestate management in some detail (Styles et al., 2016). Moreover, the LCA study accounts for changes in farm management practices associated with the introduction of a biogas plant.

The economic dimension was assessed by means of a techno-economic analysis of handling liquid and solid digestate at the farm level, resulting in a net present value (NPV) economic indicator.

The social dimension was assessed by means of a stakeholder perception study in Southern Sweden. It concerns a questionnaire that investigates the acceptance of the bio-based fertilizers under study in agriculture among different key agricultural stakeholders.

RESULTS AND DISCUSSION

Figure 1 shows that the GHG credits (avoided emissions) arising from the digestion of the residue types under study outweigh the new GHG emissions from biogas leakage and digestate management. Fertilizer replacement and SOC credits are significant, though considerably smaller than credits arising from the avoidance of fossil fuel combustion and storage of manures.

From an economic perspective, the NPV for the liquid digestate handled was between € -0.48 and € 1.98 t^{-1} yr^{-1}. A 25% increase in nutrient concentrations of N, P and K meant an increased value of the liquid digestate by € 0.85-1.02 t^{-1} yr^{-1}. A higher application rate of the liquid digestate in growing crops (30 vs. 20 t ha^{-1}) improved the profitability for each spreading strategy with about € 0.20-0.60 t^{-1} yr^{-1}. The NPV for solid digestate handled was about € 4.55 t^{-1} yr^{-1}. This higher value compared with liquid digestate can be explained by the high N and P content, autumn spreading with relatively low soil compaction and lower investment costs for the spreader compared with a slurry spreader.

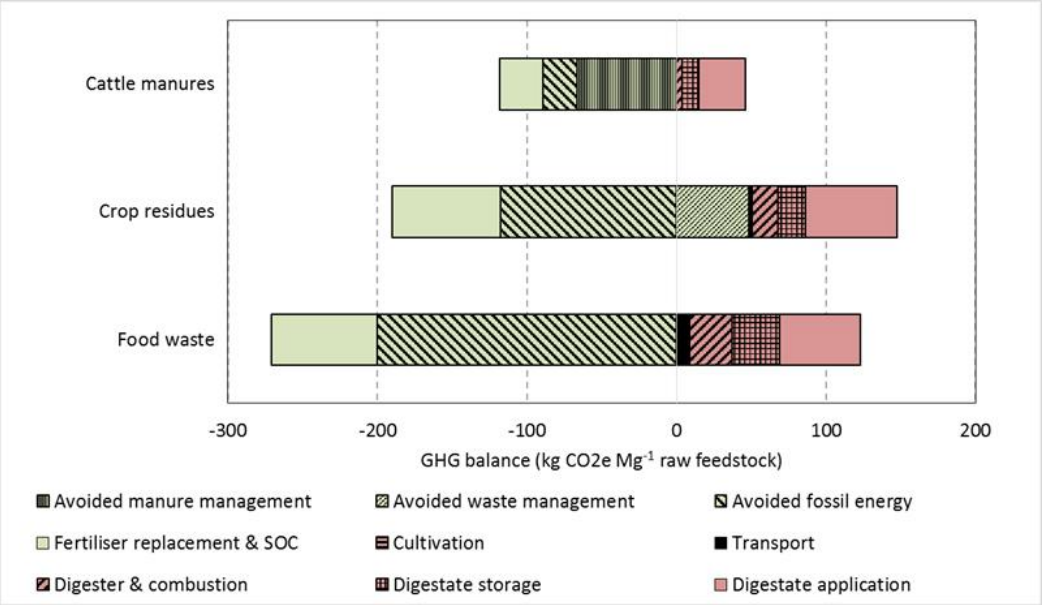

Figure 1. Greenhouse gas (GHG) balance arising from the anaerobic digestion of the three residue types under study; SOC = soil organic carbon.

In terms of social impact, all stakeholders predicted a bright future for digested residues. However, quality assurance and technical innovation to concentrate mineral nutrients in the bio-fertilizers are crucial to enable competition with conventional synthetically manufactured fertilizers (Vaneeckhaute *et al.*, 2018).

CONCLUSIONS

The overall environmental balance of farm-scale anaerobic digestion in Southern Sweden is favorable. Digestate storage and application strategies, fertilizer replacement and soil organic carbon effects, as well as counterfactual effects from the avoided conventional manure management are important factors that should be accounted for in future LCA studies.

The net present value of digestate handling at farm-scale can be positive. The main impacting factors are digestate nutrient content, spreading strategy, application rate and time. Additional governmental support for small-scale AD plants should be provided to leverage the GHG and nutrient cycling benefits.

Stakeholder perception on the use of recycled products in agriculture is positive for the case of Southern Sweden. A key issue for all stakeholders is quality assurance.

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