Life cycle evaluation of production and utilisation pathways of coupled anaerobic digestion (AD) and gasification/pyrolysis systems using the anaerobic biorefinery concept.

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Abstract

Life Cycle Analysis modelling has been applied to an operational Anaerobic Digestion (AD) plant, (utilising Cattle Slurry/Grass Silage), currently producing biogas for electricity and heat production, with digestate going to land-spreading. The aim of the research was to evaluate the environmental costs and benefits of coupling the existing plant with Gasification or Pyrolysis systems for the utilisation of digestate from the plant, producing either predominantly Syngas (Gasification) or Oils/Tars (Pyrolysis). Utilisation pathways evaluated as part of the research include the following: Gasification: Syngas to Methanation to Synthetic Natural Gas (SNG); and Pyrolysis: Syngas and bio-oil to dual-fuel electricity production. While the focus of the evaluation will be the potential GHG-eq emissions reductions achievable from the different processing and utilisation pathways, the full range of impact areas are included in the analysis. The analysis will include reflection on the challenges of applying LCA to complex biorefinery/bioenergy systems to inform future methodological developments and guidance.

Keywords: Life-cycle analysis, biogas, biochar, bio-oil, syngas, gasification, pyrolysis

1. Introduction

The generation of biogas or biomethane from the anaerobic digestion (AD) of a range of feedstocks is playing an increasingly important role in Northern Ireland, where greenhouse gas emissions (GHG) from agriculture account for 25% of the regions total GHG emissions. LCA was applied to an operational AD plant, producing biogas from agricultural and food waste feedstocks, currently generating renewable electricity for supply to the grid, with digestate from the process currently applied to land. A range of scenarios were modelled, based on the AD Biorefinery concept, which evaluated the environmental costs and benefits of utilising the digestate from the AD process as a feedstock for gasification or pyrolysis, producing syngas, bio-oils and biochar. The overall aim of the research was to evaluate the environmental sustainability of a range utilisation pathways for bioenergy deployment, with a focus on (but not confined to) GHG emissions, with a view to identifying optimal biorefinery configurations and utilisation pathways to inform policy and bioenergy deployment. A further aim of the research was to reflect on the challenges of applying LCA to complex biorefinery/bioenergy systems to inform future methodological developments and guidance. Utilisation pathways included gasification and methanation of digestate to produce synthetic natural gas (bio-SNG), and digestate pyrolysis to produce bio-oils. The focus of this paper will be the use of LCA for the comparative evaluation of the following scenarios:

Current grid production for electricity;

Renewable Baseline: AD/Biogas producing electricity and heat (Artificial fertiliser); and

Biorefinery process: AD-Pyrolysis system (AD-PY) producing electricity and heat (Biofertiliser)

While the focus of the paper will be the process of evaluating these scenarios and the results obtained, comparison with the results of the evaluation of other utilisation pathways will also be included.

2. Methodology

2.1. Goal and scope

Functional Unit (FU) and method

The application of LCA to bioenergy systems presents particularly challenges for the choice of functional unit (FU) and is most often informed by the aims of the research. Since the focus of the evaluation is mitigations of GHG's, the functional unit has been defined as 1 MWh of electricity. The ReCiPe midpoint method and impact areas were chosen to allow the analysis to evaluate single impact categories which might be of interest to policy makers and other researchers System boundaries.The system boundaries for the scenarios are shown in Figures 1.

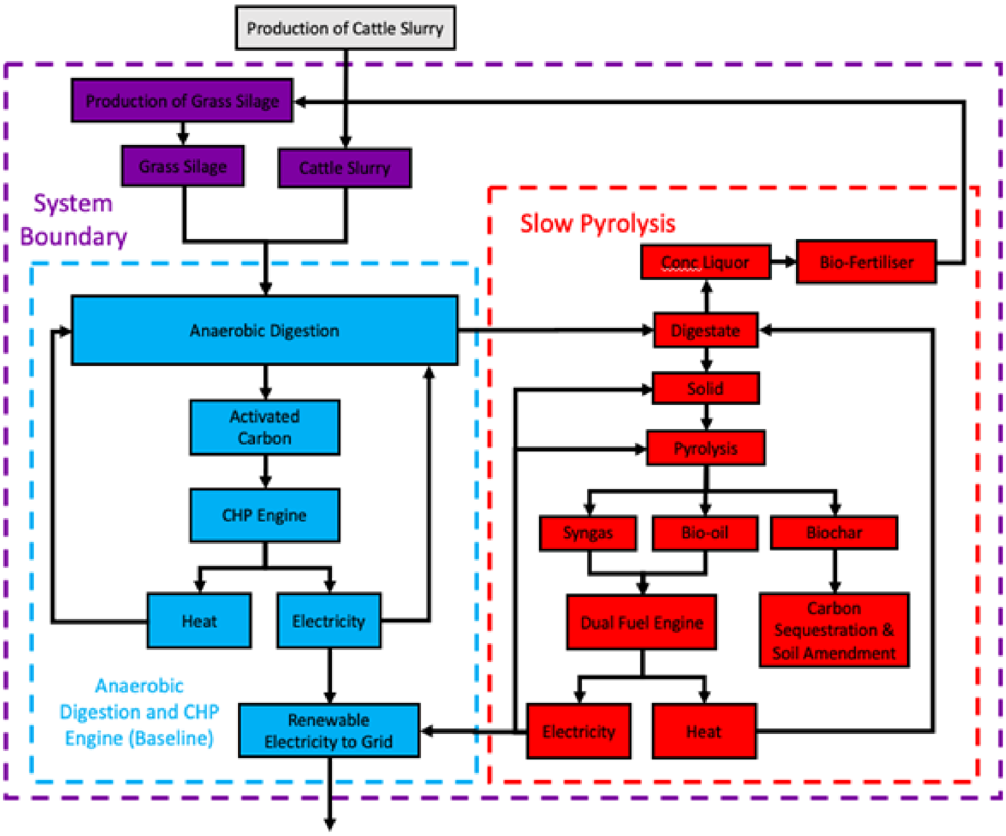

Figure 1. System boundaries

3. Results

The results include overall GHG-eq emissions from each scenario, the full range of LCA impact categories and the following sensivity analyses:

1. Variations in product yield fractions from pyrolysis;
2. Variations in dry solids content of digestate

4. Conclusions

The results of the LCA evaluation of the AD-PY scenario demonstrated reductions in GHG-eq emissions from the expansion of the electricity generation capacity of the plant from the combustion of syngas and bio-oil in the dual-fuel engine. Further GHG-eq emissions reductions were demonstrated from the displacement of artificial fertiliser with bio-fertiliser from the digestate liquid fraction. Recommendations for future research include evaluation of the potential benefits from recycling of biochar to AD.

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