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Generating low-carbon heat from biomass: Life cycle assessment of bioenergy scenarios

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ABSTRACT

Bioenergy systems will play a key role in many countries achieving their climate change, emission reduction and renewable energy contribution targets. It is important that implemented bioenergy pathways maximise GHG reductions, particularly since demand and competition for biomass resource is likely to increase in future. This research analyses the actual GHG performance of utilising different biomass resources to generate heat. Life cycle assessment (LCA) is undertaken to evaluate 2092 variants of bioheat options focused on utilising: UK agricultural and food wastes through anaerobic digestion pathways; UK straw agricultural residues and UK grown energy crops through combustion pathways. The results show a very broad range of GHG performances. Many pathways demonstrate GHG savings compared to conventional generation, although some have potential to actually increase GHG emissions, rather than reduce them. Variations in GHG performance do not correlate with feedstocks or technologies, but are most sensitive to the inclusion of specific processing steps and the displacement of certain counterfactuals. This suggests that policies should be developed that target resources with high GHG intensity counterfactuals, and where possible avoid energy intensive processing steps such as pelletisation.

1. Introduction

European Governments have greenhouse gas (GHG) emission and renewable energy targets that are bound by the baseline requirements of the Kyoto Protocol (United Nations, 1998), and the European Commission's Renewable Energy Directive (European Commission, 2009). In addition, the UK is legally bound by the 2008 Climate Change Act (UK Government, 2008), to achieve a mandatory 80% cut in the UK's carbon emissions below 1990 levels by 2050, and a benchmark target to reduce carbon emissions by 35% below 1990 levels by 2020 (DECC, 2009). In the context of these targets, the UK's Renewable Energy Roadmap (DECC, 2013) confirms the high likelihood that bioenergy systems will contribute an increasingly important role in the UK achieving its climate change, emission reduction and renewable energy contribution targets. As bioenergy pathways are being assumed in many national energy strategies globally, critical assessment of biomass resources and bioenergy processes is essential. A key justification for bioenergy systems is their ability to deliver energy with reduced GHG emissions compared to fossil fuel systems (Nguyen et al., 2010). Therefore a fundamental requirement for bioenergy has to be that any biomass resources utilised, and any activities and processes applied to generate bioenergy has to result in genuine reductions in GHG emissions over the whole process life cycles.

The variability of GHG performance of bioenergy pathways has been highlighted by reports such as that by the UK's SUPERGEN Bioenergy Hub (Adams et al., 2013), where it was confirmed that: many bioenergy pathways can deliver energy with GHG savings compared to fossil fuels; although the specific life cycle processes and activities inherent to the bioenergy pathway and the assumed counterfactual (what would have happened to the land/resource if not used for bioenergy) can be highly influential in determining the overall GHG performance of a bioenergy pathway, and some pathways can have GHG emissions greater than fossil fuels.

Evaluating the overall GHG performance of bioenergy pathways can be challenging and is often disputed due to variations in scope of systems, data inputs or choice of methodologies implemented (Haberl et al., 2012). Bioenergy pathways differ in scope and

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boundaries and as a consequence, equal levels of variation should be expected when comparing the GHG performance of bioenergy pathways. It should therefore not be assumed that a broad range of feedstocks, conversion processes and end user demands bound together by the concept "bioenergy" should always deliver consistent GHG reductions compared to alternative fossil fuel pathways. Real reductions in GHG emissions are possible from bioenergy, but caution should be applied to ensure that chosen bioenergy pathways deliver genuine GHG reductions (Adams et al., 2013). A life cycle assessment (LCA) approach is the most frequently applied methodology for evaluating the GHG performance of bioenergy pathways (Bowyer et al., 2012), for example as used by Röder et al., 2015 and Thornley et al., 2015. The principal aim of LCA analysis is to assess the full impact of a pathway – although many of the challenges associated with bioenergy systems may be attributed to the fact that bioenergy is not a single process, but a complex supply chain with extensive physical and socio-economic interfaces that all influence their surroundings. Each potential variation within a bioenergy pathway effectively equates to assessing a slightly different "LCA question" (Thornley et al., 2015).

The EU has developed a series of non-legally binding bioenergy sustainability criteria (European Commission, 2010), that in part set guidelines for the levels of GHG savings that should be achieved through the generation of bioenergy from a given biomass resource in comparison to that from conventional fossil fuel energy. There is also a proposed framework for these guideline sustainability criteria to be made progressively more stringent (Panoutsou et al., 2010). Although there are growing concerns about that the scope of methodologies applied for benchmarking the sustainability credentials of different biomass resources, supply chains and bioenergy conversion pathways (Upham and Tomei, 2010). For example the criteria predominantly focuses on the production of biofuels, rather than solid biomass fuels; there is no accounting for changes in land carbon stock unless there is a change in land use; and measuring the GHG impact of biomass for energy relating to indirect land use change (ILUC) is highly uncertain and difficult to model (Ahlgren and Di Lucia, 2014). Therefore the sustainability credentials and potential GHG impact of utilising increasing levels of biomass resources, has become a vital area of discussion with growing interest from Governments and energy and environmental stakeholders.

The UK Department of Energy & Climate Change (DECC) developed the 'Bioenergy Emissions and Counterfactual' (BEAC) model to provide a scientific tool for investigating the GHG impact of different biomass supply chains, and to evaluate the resulting GHG intensity of generated bioenergy (DECC, 2014a; MacKay and Stephenson, 2014). This research was undertaken in response to the growing consensus that the GHG balance of bioenergy systems can be highly variable and with the UK increasingly targeting bioenergy, there is great reliance on the notion that the UK's bioenergy sector will deliver GHG savings in comparison to fossil fuel generation. DECC's BEAC research focused on evaluating the GHG performance of biomass resources sourced from North America that would potentially be transported to the UK to generate electricity (MacKay and Stephenson, 2014).

This paper presents research where a series of UK biomass resource scenarios were developed with the primary aim of analysing the GHG performance of generating heat bioenergy from UK biomass resources. The research reflects work carried out by the authors working closely with DECC to apply their BEAC analysis methodology to evaluate the GHG performance of generating heat through various bioenergy pathways using key categories of UK biomass resources. An LCA approach is used to evaluate the GHG performance of 2092 variants of bioheat scenarios utilising UK biomass: agricultural wastes (animal slurries); food wastes; agricultural residues (straws); and purpose grown energy crops – categories of biomass resource identified as representing great potential for the future UK bioenergy sector (Welfle, 2014; Welfle et al., 2014a, 2014b). The generation of heat bioenergy is the focus of the research, as previous work has undertaken similar analysis evaluating the GHG performance of biomass supply chains for power bioenergy pathways (MacKay and Stephenson, 2014). Also, the demands of the UK biopower sector to 2020 are projected to exceed the UK's domestic supply and increasingly become reliant on imported resources (Welfle, 2014).

2. Methodology

The applied methodology was developed with the aim of analysing the GHG performance of different UK biomass resources to generate heat bioenergy, and to investigate the different influences that lead to variability in GHG performance across different bioenergy scenarios.

2.1. Methodology framework: goal and scope definition

A series of unique biomass sourcing and bioenergy generation scenarios were developed with DECC to reflect different potential pathways for generating heat bioenergy from UK biomass. These were modelled through developing a spreadsheet analysis tool. Each of these 'bioenergy scenarios' were designed with varying life cycle pathways with different activities and processes inherent to each scenario. A further series of 'counterfactual scenarios' were also developed to allow the analysis of potential GHG impacts or savings that may be achieved through utilising the land/resources for bioenergy generation, rather than the life cycle pathway of the counterfactual.

Through evaluating the GHG impact and energy demand for each life cycle step within both the counterfactual and bioenergy scenarios, the overall GHG emission balance for each bioenergy pathway can be calculated. Fig. 1 provides an overview of the methodology framework and the calculation steps applied for determining the overall GHG balance of different biomass resource scenarios.

Fig. 2 presents a high level schematic of the calculation pathways, themes and analysis boundaries applicable to the research's bioenergy and counterfactual scenarios. Table 1 summarises the specific processes and activities analysed across the different scenarios. The specific processes and activities evaluated for each category of biomass resources were included following discussions with stakeholders and review of widespread peer-reviewed literature.

Overall GHG performance calculations were undertaken reflecting all combinations of lifecycle activities and processes applicable to each category of biomass resource. The applied calculation assumptions when modelling each life cycle process and activity are listed along with all applicable references within this paper's Supplementary Material.

This analysis methodology represents an attributional form of life cycle assessment (ALCA), where the results generated for each bioenergy pathways are reflective of the specific characteristics of the different bioenergy and counterfactual scenarios. This includes consideration of changes in biogenic carbon across the scenarios to allow a complete accounting of the carbon inventory in accordance to the principles of LCA. Processes with potential GHG impacts outside the different scenario's analysis boundaries are not analysed and are therefore outside the scope of the research.

The key analysis outputs for each of the UK resource bioenergy pathways are: heat bioenergy potential of the different pathways (MWh); the potential GHG performance of generated bioenergy (kg