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Life cycle assessment of a biomass CHP plant in UK: The Heathrow energy centre case

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ABSTRACT

Bioenergy has an important role to play in helping the UK meet its carbon target in 2050 and the European Renewable Energy Directive objectives for 2030. There are however uncertainties associated with the use of bioenergy, and whether or how much it contributes to green-house gas emission reductions. In order to help identifying environmental benefits and burdens associated with biomass use for energy production, an attributional life cycle assessment has been carried out of a biomass-fired CHP plant: the Heathrow Airport energy centre. This facility burns woodchips sourced from nearby forests providing 2 MWe of electricity and 8 MWth of thermal energy which delivers heat and cooling to Heathrow Terminal 2 and low temperature hot water to Terminal 5. A hot spot analysis is conducted to identify the process steps with the largest environmental impact, starting from the harvesting of the forest residue to the disposal of the boiler ash. A scenario analysis is performed to compare the impacts of the biomass plant against fossil alternatives and to identify which renewable energy sources, between biomass and MSW, should be prioritised for development and investment. The results show a reduction in GHG emissions from using biomass, with further benefits if the bottom ash is collected and re-used as a soil conditioner for land-farming or forestry. The paper also discusses the treatment of biogenic carbon in the assessment.

1. Introduction

The Climate Change Act, which was passed in the UK in 2008, strengthened the UK's commitment to action to tackle climate change under the Kyoto Protocol (CCC, 2015). This act established a framework to develop an economically credible emissions reduction path and set the 2050 targets and carbon budgets. In 2009, the UK Government announced the first carbon budget (Budget 1, 2008–12) which was followed by three updates (Budget 2, 2013–17; Budget 3, 2018–22; Budget 3, 2023–2027) (DECC, 2015). The most recent budget sets a target of 15% renewable energy by 2020, across the entire energy spectrum of electricity, heat and transport. This implies that around 30% of the electricity supply (up from current 15.5%), 12% of the heat supply (currently 1%) and 10% of the energy supply for transport will have to be from renewable sources (UK Government, 2009). The UK, as a member of the EU, was a party to even more stringent commitments made during COP21: to reduce emissions of greenhouse gases (GHGs) by at least 40% relative to 1990 by 2030, going beyond the previous undertaking of 20% reduction by 2020 (Latvia and the European Commission, 2015).

Although energy consumption is set to increase, renewable sources, including biomass along with wind, hydro and solar, are expected to play an important role in achieving carbon-reduction targets. To maximise the potential of biomass to contribute to delivering the policy goals by developing a secure, competitive and affordable supply of fuel, the UK Government has been promoting a major expansion in the supply and use of biomass, as reported in the UK Biomass Strategy and the UK Bio-energy Strategy (DECC, 2012). Biomass supply in the UK is projected to reach approximately 800 TWh by 2030 (including domestic and imported supplies), representing a potential contribution of 10% to the overall primary energy input (DECC, 2012). Imported biomass will account for part of the supply, so that life cycle cost and environmental assessment of transport is essential. However, there is also significant

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potential to expand UK domestic supply with no detrimental effect on food supplies or land use if a sustainable approach to woodland management is applied (Kretschmer et al., 2011).

The Heathrow Energy Centre Biomass plant (Heathrow, 2015) is one of the largest biomass initiatives of its kind in the UK. Opened in 2013, the 10 MW CHP plant can provide 2 MWe of electricity and 8 MWth of thermal energy to Heathrow Terminals 2 and 5, helping the airport meet its target of cutting carbon emissions by 34% against 1990 levels (Morgani Sindall, 2015). The biomass plant is fuelled with over 25,000 t *per annum* of woodchip, currently supplied by LC Energy from sustainable virgin timber sourced within no more than 100 miles from the airport (LC Energy, 2015). The economic driver for the plant is the output of hot water for heating and chilling at terminals but some electrical power is also generated. Because the available temperature is relatively low, an Organic Rankine Cycle (ORC) system is used for power generation.

Although studies on the thermodynamic and economical assessment of Organic Rankine cycle are wide spread in literature (Fergani et al., 2016; Hassoun and Dincer, 2015; Lecompte et al., 2015; Yang and Yeh, 2015), knowledge on the environmental impact of this technology under a life cycle perspective for energy production is still very limited. Some studies address the greenhouse gas reduction of the Organic Rankine cycle using solid waste in the far east (Imran et al., 2015; Sedpho et al., 2017; Sununta et al., 2017). However, to the authors' knowledge no studies analysed the entire life cycle of an energy plant based on the ORC using biomass. Hence, this paperpresents a life cycle assessment of the Heathrow plant, from harvesting the wood in the forest, to production of heat and power from the plant, including disposal of the waste. The study is attributional, simply assessing the supply system, because the wood fuel already exists but is otherwise unexploited (see Section 2.1) so that a more complex consequential study is not appropriate. GHG emissions from the plant are compared against generation from fossil fuels using a steam turbine for electricity production. Furthermore, energy production from wood biomass through the ORC is compared to other technologies using renewables, including MSW, to provide insight into the relative advantages of different fuels and associated technologies as a basis for guiding financial investment.

2. Methodology: life cycle assessment

Life Cycle Assessment is one of the most developed and widely used environmental assessment tools for comparing alternative technologies when the location of the activity is already defined (Clift et al., 2000; Clift, 2013). LCA quantifies the amount of materials and energy used and the emissions and waste over the complete supply chain (i.e. life cycles) of goods and services (Baumann and Tillman, 2004). Moreover, it helps in determining the "hot spots" in the system, i.e. those activities that have the most significant environmental impact and should be improved in the first instance, thus enabling identification of more environmentally sustainable options (Clift, 2006).

In LCA, a multifunctional process is defined as an activity that fulfils more than one function, such as a combined heat and power plant which produce electricity and heat at the same time (Ekvall and Finnveden, 2001). It is then necessary to find a rational basis for allocating the environmental burdens between the functions. The problem of allocation in LCA has been the topic of much debate (e.g. Clift et al., 2000; Heijungs and Guinée, 2007). The ISO standards recommend that the allocation should be avoided by "expanding the product system to include the additional functions related to the co-products" (ISO, 2006a, 2006b). This can be performed by broadening the system boundaries to include the avoided burdens of conventional productions (i.e substitution by system expansion) (Tillman et al., 1994; Eriksson et al., 2007; ILCD, 2010). The same approach is recommended by the UK product labelling standard provided that it can be proved that the recovered material or energy is actually put to the use claimed (BSI, 2011). This approach is applied in this study.

Following the methodological approach of Clift et al. (2000) for Integrated Waste Management (IWM), a pragmatic distinction is made between Foreground and Background, considering the former as 'the set of processes whose selection or mode of operation is affected directly by decisions based on the study' and the latter as 'all other processes which interact with the Foreground, usually by supplying or receiving material or energy'. The burdens evaluated here are considered under three categories (Clift et al., 2000): direct burdens, associated with the use phase of the process/service; indirect burdens, due to upstream and downstream processes (e.g. energy provision for electricity or diesel for transportation); and avoided burdens associated with products or services supplied by the process (e.g. energy produced by the system).

Currently more than thirty software packages exist to perform LCA analysis, with differing scope and capacity: some are specific for certain applications, while others have been directly developed by industrial organisations (Manfredi and Pant, 2012). In this study GaBi 6 has been used (Thinkstep, 2015).

Table 1 shows the impact categories analysed here, they are further described in the supplementary information.

2.1. *Forest residues*

This study focuses on forest residues as fuel. The wood chips used at Heathrow are sourced from normal harvesting and maintenance operations in forests within 100 miles from the airport. Biomass forest residue is defined here as the residue gathered during harvesting; it includes annual whole tree thinning, small roundwood, branches and stem tips (Whittaker et al., 2011).

Forest residues are not produced specifically for use as an energy resource. Rather, they are a waste from the production of more valuable forest products, so that harvesting of biowaste for energy recovery does not affect its generation. However, there are other possible environmental implications (Cherubini et al., 2009). The reference scenario for the environmental assessment is current common practice: extraction is not cost-effective so that residues are thinned and left in the forest to decompose along with other debris (Whittaker et al., 2011). This can have a significant role in sequestering carbon in soil, dead wood and leaf litter, and also in restoring soil nutrients, whilst also improving the habitat and hence the biodiversity of the forest (DEFRA, 2008; Cherubini et al., 2009; Whittaker et al., 2011). Harvesting the residues has a direct effect in reducing these beneficial effects but the environmental consequences are difficult to quantify. Changes in carbon flux are particularly complicated because the potential to sequester carbon in the soil is dependent on former and current agronomic practices, climate and soil characteristics and is therefore site-specific. Furthermore, the timescale for decomposition of forest residues is many orders of magnitude greater than the timescale over which they are used as fuel. Therefore as recommended by Whittaker et al. (2011), the assessment does not include the background effects on forests of extracting the residues.

At the level of consequential effects, creation of a market for forestry wood waste can make the production of the main forest products more attractive, leading to an expansion of forest land to displace other land uses. This may have negative or