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Waste wood as bioenergy feedstock. Climate change impacts and related emission uncertainties from waste wood based energy systems in the UK

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ABSTRACT

Considering the urgent need to shift to low carbon energy carriers, waste wood resources could provide an alternative energy feedstock and at the same time reduce emissions from landfill. This research examines the climate change impacts and related emission uncertainties of waste wood based energy. For this, different grades of waste wood and energy application have been investigated using lifecycle assessment. Sensitivity analysis has then been applied for supply chain processes and feedstock properties for the main emission contributing categories: transport, processing, pelletizing, urea resin fraction and related N_2O formation. The results show, depending on the waste wood grade, the conversion option, scale and the related reference case, that emission reductions of up to 91% are possible for non-treated wood waste. Compared to this, energy from treated wood waste with low contamination can achieve up to 83% emission savings, similar to untreated waste wood pellets, but in some cases emissions from waste wood based energy can exceed the ones of the fossil fuel reference - in the worst case by 126%. Emission reductions from highly contaminated feedstocks are largest when replacing electricity from large-scale coal and landfill. The highest emission uncertainties are related to the wood's resin fraction and N_2O formation during combustion and, pelletizing. Comparing wood processing with diesel and electricity powered equipment also generated high variations in the results, while emission variations related to transport are relatively small. Using treated waste wood as a bioenergy feedstock can be a valid option to reduce emissions from energy production but this is only realisable if coal and landfill gas are replaced. To achieve meaningful emission reduction in line with national and international climate change targets, pre-treatment of waste wood would be required to reduce components that form N_2O during the energy conversion.

1. Introduction

The current UK bioenergy sector is dominated by large imports of biomass feedstocks and the UK is the biggest importer of wood pellets globally (FAO, 2016) to produce bioelectricity. Research by others showed that the UK could provide large amounts of bioenergy feedstocks nationally when utilising wastes and residues (Welfle et al., 2014). Waste wood, especially lower grades are one of these untapped resources. Considering the urgent need to shift to low carbon energy carriers, lower grade waste wood could provide an alternative energy feedstock and at the same time reduce emissions from landfill and support waste management in general. It would also be a feedstock with an existing infrastructure, which fits existing technologies and could possibly contribute to UK climate change targets in a timely manner.

While there has been various research on the thermochemical and conversion characteristics of treated waste wood (Edo et al., 2016; Enestam et al., 2013; Gori et al., 2013; Hwang et al., 2014; Yorulmaz and Atimtay, 2009), not much work has been done on the emission reduction potential of treated waste wood. Studies assessing the climate mitigation potential of waste wood usually focus on untreated feedstocks that do not fall under the Waste Incineration Directive (WDI) (Gomez-Barea et al., 2010; McManus, 2010; Sheth and Babu, 2010; Vanneste et al., 2011) and have therefore very similar properties to virgin wood or residues from sawmills. With this climate change impacts related to contaminates and chemicals from wood treatment are often not taken into account when investigating bioenergy feedstocks and the emission reduction potential of lower grade feedstocks. Therefore, this research assesses feedstocks that might be considered for energy generation as part of energy from waste systems but not

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necessarily as bioenergy options to reduce emissions to support climate change targets.

According to latest estimates about 4.3 million tonnes of waste wood are produced in the UK annually (Defra, 2012b). These estimates are vague and over the last ten years they varied between 4.1 and 10.5 million tonnes (Defra, 2008, 2012a, 2012b; Pöyry, 2009; Tolvik, 2011). This is due to waste wood being sometimes difficult to recycle, collect and separate from mixed waste. Moreover, wood processing and wood using sectors such as construction, furniture and joinery are sensitive to economic changes and the amounts of arising waste wood can therefore vary from year to year (Defra, 2008, 2012b; Greenhalf and Brown, 2012; Letsrecycle, 2015; Pöyry, 2009; WRAP, 2011). Statistics on waste wood in the UK are therefore often based on estimates and the fate of the waste wood is not always clear. Estimates from the industry suggest that 1–2 million tonnes of waste wood per year are available for bioenergy applications.

In the UK waste wood is categorised into four different grades; grade A, B, C and D, according to the level of contamination and treatment (WRAP, 2012). The detailed categorisation is provided in Table 1. Grade A and B waste wood is currently used by wood processing industries for panel-, chip- and fibreboards, livestock bedding or garden mulches and its potential as bioenergy feedstock has been investigated in detail by others (Defra, 2012a; Mitchell and Stevens, 2008), while grade C and D waste wood is usually landfilled or incinerated (Defra, 2012a). In case of energy generation, grade A waste wood can be used as any other untreated wood. Compared to this, grades B, C and D require a WDI compliant facilities (WRAP, 2012). Grade B fuel mixes, consisting mainly of grade A products and a maximum of 10% panel products, are compliant with renewable energy support and facilities do not require to be WID compliant (WRAP, 2012). The utilisation of large rations of grade C and D in the fuel mix would not be considered as renewable bioenergy option; nevertheless, these feedstocks were included in the analysis as they can be considered as waste-to-energy option in WDI compliant facilities.

The following research presents the result of a lifecycle assessment (LCA) of energy generation from different waste wood grades at different scale and applications, with existing technologies, infrastructures and regulations in the UK. While the type of combustion system has an impact on the operational and environmental performance, the focus was on the most common systems used in the UK.

The objective was to evaluate the climate change impacts and related emission uncertainties of waste wood based energy in the UK and discuss its potential, barriers and opportunities as a valid bioenergy feedstock.

2. Methods

2.1. Lifecycle assessment

As methodology attributional lifecycle assessment (LCA) has been applied according to ISO Standard 14040:2006 and 14044:2006 (BSI, 2006a, 2006b). The goal of this LCA was to investigate climate change impacts and emission uncertainties of different options to generate energy from different grades of waste wood. This allowed identifying the supply chain processes and feedstock properties making major emission contributions. The impact category presented in this paper is global warming potential (GWP). The calculations were done with the LCA software SimaPro 8.3 using the Ecoinvent database and the ILCD 2011 Midpoint + V1.09 method (PRé, 2016). Additional calculations and the system modelling identifying feedstock demands and analysing key factors were done in Excel and in BEAT2 V2.1 (Defra, 2010). BEAT2 V2.1 is a tool providing information on environmental impacts of UK bioenergy systems. The results account for greenhouse gases expressed as CO_2eq with a 100-year time horizon with emission factors used in the selected methods in SimaPro and BEAT2 V2.1. Biogenic carbon has not been included in the assessment due to lacking data about the lifetime and origin of the waste wood and in accordance with current accounting frameworks in the UK and the EU.

The reference scenarios include a variety of different fuels (including landfill gas and waste incineration with energy recovery) that reflect the current UK energy system at commensurate scales. The details for the different waste wood systems and their reference scenarios are presented in Table 2. The supply chains selected include mature and existing technologies in accordance with specifications and regulations for handling, processing and recycling waste in the United Kingdom (Defra, 2008, 2011; EA, 2013; WRAP, 2012). Less mature technologies such as gasification and pyrolysis may be possible in future but the research aims to investigate existing technologies, which are readily available to support the UK's climate change targets in a timely manner, and the alternatives are not yet adequately proven.

The scope of analysis is energy from waste wood supply chains within the UK, including all transportation, handling and processing steps of the supply chain starting with the collection and delivery of the waste wood to the waste or processing yard, handling, processing of the waste wood, transport of the feedstock to the bioenergy facility and energy conversion in different configurations as presented in Fig. 1 and Table 2. The functional unit (FU) was 1 MWh of generated energy in form of electricity, heat and combined heat and power (CHP). The final unit of measurement was kg CO_2 equivalent (eq) MWh^{-1}. As this research investigated waste products, the energy demand and emissions included in the calculation start with the end of life of the original product, hence the collection of the product for disposal or recycling. Any upstream inputs and emissions related to the production of the original product were excluded from the analysis. The investigated options included different grades of waste wood, which are used in different applications with different supply chain processes in accordance with existing legislation for waste handling and processing (Defra, 2011; WRAP, 2012).

The following waste wood grades, from industrial and post-consumer use, are considered as feedstocks in this research were:

- Grade A as clean waste wood not falling under the WID regulations and suitable for domestic application and compliant with renewable energy support schemes. Feedstock is considered as pellets and chips for domestic and commercial applications;

Table 1
Waste wood grades in the UK (WRAP, 2012).

Grade A:	clean untreated waste wood (hardwood and softwood) in form of, e.g., process off-cuts, packaging, pallets or cable drums
Grade B:	mixed grade (hardwood and softwood), up to 60% grade A wood mixed with wood containing contaminants like paint and screws at a low proportion. Can contain up to 5–10% panel products but no lower grade material; WID compliant if operator cannot demonstrate that no grade C is included
Grade C:	fuel grade, treated wood, e.g., coated, painted and impregnated products, high content panel products, chipboards, MDF, plywood, fibreboard; WID compliant
Grade D:	low grade and hazardous waste wood, chipboard, processed and treated wood containing contaminants such as melamine, arsenic, chromium and creosote, e.g., railway sleepers, transmission poles; hazardous waste incinerator

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