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# How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues

Mirjam Röder [a,*], Carly Whittaker [b], Patricia Thornley [a]

[a] Tyndall Centre for Climate Change Research, The University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom

[b] Agroecology Department, Rothamsted Research, Harpenden, Herts AL5 2JQ, United Kingdom

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ABSTRACT

Climate change and energy policies often encourage bioenergy as a sustainable greenhouse gas (GHG) reduction option. Recent research has raised concerns about the climate change impacts of bioenergy as heterogeneous pathways of producing and converting biomass, indirect impacts, uncertainties within the bioenergy supply chains and evaluation methods generate large variation in emission profiles. This research examines the combustion of wood pellets from forest residues to generate electricity and considers uncertainties related to GHG emissions arising at different points within the supply chain. Different supply chain pathways were investigated by using life cycle assessment (LCA) to analyse the emissions and sensitivity analysis was used to identify the most significant factors influencing the overall GHG balance. The calculations showed in the best case results in GHG reductions of 83% compared to coal-fired electricity generation. When parameters such as different drying fuels, storage emission, dry matter losses and feedstock market changes were included the bioenergy emission profiles showed strong variation with up to 73% higher GHG emissions compared to coal. The impact of methane emissions during storage has shown to be particularly significant regarding uncertainty and increases in emissions. Investigation and management of losses and emissions during storage is therefore key to ensuring significant GHG reductions from biomass.



## 1. Introduction

To reach climate change targets the total greenhouse gas (GHG) emissions of the EU and the UK are required to reduce by 20% [1] and 37% [2] respectively by 2020 compared to the 1990 level. Existing European and UK policies consider bioenergy as a valid GHG reduction option in reaching these targets [3–5]. By 2020 about 10% of the EU's primary energy requirements could be supplied by biomass [6]. It is therefore

* *Corresponding author*. Tyndall Centre for Climate Change Research, Oxford Road, Manchester M13 9PL, United Kingdom. Tel.: +44 (0) 161 275 4344.

E-mail addresses: mirjam.roeder@manchester.ac.uk (M. Röder), carly.whittaker@rothamsted.ac.uk (C. Whittaker), P.Thornley@manchester.ac.uk (P. Thornley).

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imperative that bioenergy systems deliver real emission reductions [5,7,8]. Recent research has presented different outcomes regarding the benefits and climate change impacts of bioenergy, due to the broad variability in feedstocks, different application and conversion methods, uncertainties in supply chain processes, variability in models and methods of evaluation and system assumptions [7].

Bioenergy from forest residues is often considered as carbon neutral and emissions from production stages of the main product are often ignored in policy-related calculations as the feedstock is considered a by-product [5,9–12]. Forest and sawmill residues are claimed to have a large global availability and under certain conditions can achieve large GHG emissions savings [13–15]. They are commonly processed as pellets to deliver benefits of low moisture content, high energy density, low storage requirements, relatively clean and easy handling and manageability across various scales. Over the last 5–10 years the global pellet market has grown steadily and is projected to continue its growth [14,16]. Due to the increasing demand within the EU, imports of pellets from North America have increased rapidly [14,17]. This has been mainly driven by policies promoting bioenergy as an option to significantly decrease GHG emissions and maintain energy security. However, recent research has questioned the emission savings actually achieved. When land use, carbon stock changes or temporal aspects are taken into account lower levels of GHG savings are sometimes reported [11,12,15,18–23], while more traditional life cycle assessments (LCA) of wood pellets find savings of 60–90% compared to fossil fuel systems [13,15,24–29].

The work presented here examines the significance of key sources of GHG uncertainty in wood pellet supply chains from forest and sawmill residues. The research is specific to large-scale electricity generation the UK; however will be relevant to other consumers of wood pellets sourcing from the South-East USA (SE U.S.). The analysis has been done through life cycle assessment (LCA) to identify supply chain emissions and sensitivity analysis was used to assess the impact of uncertainty on the final GHG emission results. The aim was to evaluate emissions and impacts of imported wood pellets and to identify critical steps where improved characterisation will support management of the biomass supply chains to maximize the emission reduction potential and avoid unintentional outcomes from energy and climate change policies.

## 2. Methods

### 2.1. *Life cycle assessment*

#### 2.1.1. *Goal*

The goal of this study was to investigate emission uncertainties of selected forest residue supply chains to evaluate possible impacts and identify supply chain steps that require close attention to ensure real GHG reductions. For this purpose, an attributional LCA was appropriate, with a comprehensive supply chain scope that includes all steps from forest establishment through to the generation of electricity. The fossil fuel based reference source was coal-fired electricity generation, since this reflects current UK trends to convert coal-fired power plants to high levels of biomass pellet co-firing and large-scale, dedicated biomass firing. The analysis followed the principles of LCA according to ISO Standard 14040:2006 and 14044:2006 [30,31].

#### 2.1.2. *Scope*

*2.1.2.1. Supply chain description and functional unit*. The supply chains were selected and defined according to existing pathways of large-scale electricity production in the UK from biomass. The functional unit (FU) of the LCA was 1 kWh of generated electricity in the UK. The supply chains were agreed with industrial stakeholders and academic research partners. The term forest residue covers several different products and parts of trees in forest and timber production, including sawmill residues [13,15,32]. Several of these materials can be used to produce wood pellets. Currently sawdust (sawmill residues) is the main raw material for producing wood pellets [14]. However, residues like tree branches, tree tops, bark and early thinnings are increasingly used [13,32]. Hence, the supply chain emissions of wood pellets can differ with variations in raw material, management practices, processing steps and logistics (transport and storage). Since it was the aim of this work to explore the significance of uncertainties at different stages to the overall GHG balance, two different supply chains were chosen which are common pathways for the production of industrial wood pellets:

1. **Forest residues** composed of: 80% thinnings and 20% forest residues (branches, tops and bark)
2. **Sawmill residues** composed of: 91% sawdust, 9% sawmill residues (shavings, bark, chips)

Combinations of both feedstock types maybe used commercially which were found to give results lying between the above cases and so only these 2 are presented. The proportions were selected according to existing literature and stakeholder information [13,15].

*2.1.2.2. System boundaries*. The pellets are produced from forest and sawmill residues in the South-East USA (SE U.S.), which is one of the major forest production locations in North America and a main supply region of industrial wood pellets for the UK market [13,15,22,26,33].

The forest considered is a mixed loblolly pine (Pinus taeda) and shortleaf pine (Pinus echinata) stand, which makes up about 25% of the forest area and 59% of the net volume of growing stock in SE U.S. [34,35]. The forests are under private corporate management focussing on long-term supply of high quality timber in accordance with sustainability and policy regulations [13,20,36].

The forest is established by land preparation and planting of new seedlings [34,35,37] with a growing period of 45 years, yield class 9 and then harvested by clear cut [19,35]. While yield and rotation can be significant parameters when evaluating carbon stocks, carbon debt and payback time [15,19–22,36,38,39], they did not significantly affect the parameters explored in this assessment as described in Section 3 and so variants of these have been neglected in the analysis. It is assumed that forest management follows a medium-intensive cultivation [22], which includes fertiliser and