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Research paper

Climate change impacts of power generation from residual biomass

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ABSTRACT

The European Union relies largely on bioenergy to achieve its climate and energy targets for 2020 and beyond.

We assess, using Attributional Life Cycle Assessment (A-LCA), the climate change mitigation potential of three bioenergy power plants fuelled by residual biomass compared to a fossil system based on the European power generation mix. We study forest residues, cereal straws and cattle slurry.

Our A-LCA methodology includes: i) supply chains and biogenic-CO_2 flows; ii) explicit treatment of time of emissions; iii) instantaneous and time-integrated climate metrics.

Power generation from cereal straws and cattle slurry can provide significant global warming mitigation by 2100 compared to current European electricity mix in all of the conditions considered.

The mitigation potential of forest residues depends on the decay rate considered. Power generation from forest logging residues is an effective mitigation solution compared to the current EU mix only in conditions of decay rates above 5.2% a^{-1}. Even with faster-decomposing feedstocks, bioenergy temporarily causes a STR(i) and STR(c) higher than the fossil system.

The mitigation potential of bioenergy technologies is overestimated when biogenic-CO_2 flows are excluded. Results based solely on supply-chain emissions can only be interpreted as an estimation of the long-term (>100 years) mitigation potential of bioenergy systems interrupted at the end of the lifetime of the plant and whose carbon stock is allowed to accumulate back.

Strategies for bioenergy deployment should take into account possible increases in global warming rate and possible temporary increases in temperature anomaly as well as of cumulative radiative forcing.

1. Introduction

Since 2009 the European Union (EU) has been promoting bioenergy as one of the main renewable, low-carbon sources to achieve its ambitious climate and energy targets for 2020 and beyond [1]. More recently, a new EU energy strategy [2] has called for a profound transformation of Europe's energy system, based on a more secure, sustainable and low-carbon economy, with a commitment to achieve by 2030 at least 27% share of renewables on the EU's energy consumption and 40% greenhouse gas emission reduction relative to emissions in 1990 [3].

Bioenergy is currently the major source of renewable energy in the EU. The demand for biomass in the EU and world-wide is increasing, both in the heating and in the power sector. In 2013, renewable sources generated 26% of EU's electricity, and the target is to reach at least 34% of power generation in 2020 and 45% in 2030. Biomass use for electricity grew by 11% per year during period 2005–2012, and it increased further to reach 18.7% of final

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Abbreviations: AGTP, Absolute Global surface Temperature change Potential; EC, European Commission; EU, European Union; GHG, Greenhouse Gases; GWP, Global Warming Potential; id, idem; (I)LUC, (Indirect) Land Use Change; LCA, Life Cycle Assessment; NMVOC, Non-Methane Volatile Organic Compound; NTCF, Near-Term Climate Forcers; STR(i)/(c), Surface Temperature Response (instantaneous)/(cumulative); SM, Supplementary Material; SOC, Soil Organic Carbon; WMGHG, Well-Mixed Greenhouse Gases; JRC, Joint Research Centre.

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renewable electricity consumption in 2013. Power produced from biomass is expected to exceed 839 PJ by 2020 [4].

Biomass wastes and residues from forestry and agriculture are expected to fuel part of this growth. Utilities throughout the EU are converting existing coal power plants to wood pellets in order to comply with stricter regulations on carbon emissions (e.g. Refs. [5,6]); logging residues are expected to fulfil part of the pellet demand due to legislation discouraging or forbidding the use of high-quality roundwood for energy [7]. Large unexploited potential of cereal straws is available throughout the EU [8] and some Member States already incorporate straw in their energy mix. The installed capacity of biogas plants have increased steeply within the EU in the last years [9,10]; although most of the current plants operate with a mix of substrates dominated by energy crops, recent legislative changes are expected to strongly promote the use of animal slurry and other agricultural residues [11].

The increasing demand for bioenergy must be reconciled with environmental, economic and social sustainability in Europe and globally. Assessing the potential of bioenergy technologies to mitigate climate change is a complex task. Bioenergy systems can influence directly and indirectly local and global climate through a complex interaction of perturbations [12], including: CO_2 and other long and short-lived climate forcers from biomass combustion, alteration of biophysical properties of the land surface, influence on land use and management, and substitution of fossil fuels and other commodities such as food and wood products.

Life Cycle Assessment (LCA) has emerged as the main tool used to inform policy-makers about potential environmental impacts of bioenergy pathways [13]. Plevin et al. [14] have argued that Consequential LCA (C-LCA) is the appropriate modelling framework to support policy design and to compare the potential impacts of different policy measures. Attributional LCA (A-LCA) studies of bioenergy systems in the past have been unable to properly capture the above-mentioned complexities of bioenergy climate impacts and, consequently, have often been misinterpreted, providing decision-makers with incomplete information [15–19].

Recent debate has brought forward methodological improvements to A-LCA analysis to help tackle some of these limitations. Soimakallio et al. [20] make a compelling case that the use of a baseline or counterfactual, i.e. “the hypothetical situation without the studied product system”, is appropriate in A-LCA and necessary to properly evaluate the impacts of land-based products, such as bioenergy. This is crucial, since the climate change mitigation potential of bioenergy has often been calculated in terms of GHG savings against fossil alternative systems but ignoring the actual land use development without bioenergy production, as highlighted by recent studies [16,21–24].

Further, A-LCA is often applied as a static approach. Emissions and sequestrations at different times are either flattened, as if happening at once at time zero, or annualized over a subjective period of time and discounted fully after such period [25,26]. This can create, at best, ambiguity in the interpretation of the results and, at worst, misrepresent the impact of a technology on the climate [27].

The choice of Global Warming Potential (GWP) as the operative metric under the UNFCCC and Kyoto protocol has made it the metric of reference for the climate change impact category in LCA studies. Nonetheless, the GWP metric is not free from criticism due to its unclear physical meaning and for the possible misinterpretations of short-lived forcers [25,28,29]. Kirschbaum [30] has summarized that impacts of climate change can be linked either to its magnitude (i.e. temperature anomaly above pre-industrial era), to its rate or to its cumulative effect. The use of time-explicit metrics based on the Absolute Global surface Temperature change Potential (AGTP), both in its end-point as well as time-integrated formulation [31,32], can provide valuable insights to impact assessment [25,31].

The aim of this work is to apply all these methodological innovations to an attributional life cycle assessment of the climate impacts of electricity production from three bioenergy systems: 1) Power plant fuelled with pellets from forest logging residues with an electrical capacity of 80 MW; 2) Power plant fuelled with cereal straw bales with an electrical capacity of 15 MW; 3) Anaerobic digestion plant fuelled by cattle slurry with an electrical capacity of 300 kW.

We reckon that our analysis provides valuable information to policymakers on the feedstocks, systems, configurations and management practices that carry potential environmental risks and that should thus not be promoted or, at least, monitored with care.

2. Materials and methods

2.1. Goal and scope definition

The LCA follows an attributional modelling principle. We designed three systems representing three different production scales (see Fig. 1): a) large-scale power plant with a gross electrical capacity of 80 MW fuelled with wood pellets from forest logging residues (FRel); b) medium-scale power plant of 15 MW fuelled with cereal straw bales (STel); c) small-scale internal combustion engine of 300 kW fuelled with biogas produced from anaerobic digestion of cattle slurry, employing an open or gas-tight tank for digestate storage (Biogas OD/CD).

The goal of the analysis is to assess the potential of these bioenergy power plants to mitigate the planet's temperature anomaly compared to alternative systems relying also on fossil sources. The reference alternative system, hereafter called simply reference system, is designed to represent the current EU-27 power generation mix. We refrain from the use of the term “counterfactual” as this may seem to imply a deterministic alternative to the bioenergy use, while we want to emphasize that the conclusions of our study are specific to the systems assumed, including the reference(s). We do not assume perfect substitution; the reference system is used solely to put the climate impacts into context. For this reason we evaluate the sensitivity of the results to multiple assumptions characterizing the bioenergy and the reference system (see Section 2.4).

To facilitate the interpretation of results and connection with existing LCA literature, we divide both the bioenergy and the reference systems into two separate subsystems: supply-chain and biogenic emissions. “Supply-chain” inventories account for all inputs and emissions associated to the energy sector; i.e. collection, transport, processing and end-use. Within this inventory we apply the common approach of zero-rating for biogenic-CO_2 emissions at the point of combustion. In the “biogenic” inventory we account for all biogenic-CO_2 flows. This includes CO_2 emissions from the combustion of biomass (bioenergy) and CO_2 emissions from aerobic decomposition of the uncollected biomass (reference) (Figs. S1 and S2).

The analysis is also divided into two stages. In a first stage we focus solely on the GHG emissions from the supply chains of the three bioenergy systems (Fig. S3). This approach reflects the common assumptions used in A-LCA of bioenergy systems: the analysis is static in time, the climate metric used is GWP at a fixed time horizon of 100 years, the alternative land-use is ignored and so are the dynamics of emission profiles as well as of the climate response. This method also mirrors the sustainability criterion of GHG emissions saving threshold implemented in European legislation [1]. The detailed results from this analysis are presented in the Supporting Material (SM).

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