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The renewable energy directive and cereal residues

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HIGHLIGHTS

- There is a high uncertainty in the range of possible GHG implications of removing straw.
- GHG emission savings for bioethanol from wheat straw are 21–58% compared to gasoline.
- GHG implications of straw removal can reduce the GHG savings.
- The GHG benefits of straw removal for bioethanol production exceed benefits from incorporation.
- Further research is required to understand SOC losses due to straw removal.

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ABSTRACT

The Renewable Energy Directive (RED) specifies that biomass feedstocks must be sustainable and are not directly implicated with conversion of areas of high carbon stock and biodiversity. There are concerns that first generation biofuels from food-based crops will lead to negative indirect impacts on food prices and place pressure on agricultural land. The RED incentivises the use of non-food and land biomass resources by awarding them with financial credits and assigning them a zero greenhouse gas (GHG) 'cost'. This paper questions whether there are any GHG implications with straw removal from soil that should be accounted for in the life cycle assessment (LCA) of straw-based bioethanol. Emission savings of 21–58% are calculated for straw–bioethanol compared to conventional fossil fuels. The direct GHG implications of straw removal from soil are highly dependent on assumptions on the changes in soil organic carbon (SOC) experienced during straw removal, as well as replacing nutrients removed in straw. The results show that these impacts have the potential to reduce the GHG emission savings to −133%. If straw was alternatively incorporated into the soil, this could sequester between 0.58 and 2.24 tonnes CO_2 eq./ha, whereas substitution of fossil fuels would avoid 0.46 and 1.16 tonnes CO_2 eq./ha, although the full accountable benefit of straw removal is questionable as it is easily reversible. Understanding the full implications of straw removal on GHG emissions relies on further research on residue removal limitations, the impact that losses of SOC has on soil quality, as well as determining whether straw will be acquired from increased removal from soil or displacement from existing markets.

1. Introduction

1.1. The renewable energy directive and second generation biofuels

Climate change targets set under the Kyoto Protocol have led to a push in reducing greenhouse gas (GHG) emissions in the transport sector [1]. In 2009, the European Parliament and the Council of the European Union developed the Renewable Energy Directive (RED [2]) to promote the use of renewable resources in the energy and transport sectors. The UK has committed to produce 15% of all consumed energy from renewable resources by 2020; and at least two-thirds of this as biofuels. Being 98% reliant on fossil fuels [1], the transport sector now represents 20% of total UK GHG emissions [3]. It is one of the only sectors where emissions have increased since 1990 as sheer increases in kilometres travelled overcome any emission savings achieved by adoption of efficient fuels and vehicle efficiency improvements [4]. Biofuels are a short-to-medium-term solution for mitigating GHG emissions from transport [5]. They can be used, in blends with conventional fuels, in modern spark-ignition engines without modification [1], and a distribution network already exists. There is debate, however, over the potential GHG emission savings from an increase in uptake of

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Nomenclature

GHG	greenhouse gas balance
RED	renewable energy directive
ALCA	attributional life cycle assessment
CLCA	consequential life cycle assessment
SOC	soil organic carbon
GHG_{SR}	greenhouse gas emissions associated with straw removal (kg CO_2 eq./tsr)
GHG_{FM}	greenhouse gas emissions associated with fertiliser manufacture to compensate for removed nutrients in straw (kg CO_2 eq./tsr)
GHG_{diesel}	greenhouse gas emissions associated with baling straw (kg CO_2 eq./tsr)
Tsr	tonne straw removed
N_2O	nitrous oxide

biofuels, and concerns over their sustainability identified the need to individually assess each biofuels' GHG mitigation potential [6].

The RED specifies that biofuel production should be sustainable. It introduces broad sustainability criteria to ensure that no adverse land use change occurs from sourcing biofuels from high carbon or biodiverse lands [2]. The RED presents the main methodological framework to assess the GHG emissions from biofuel supply chains. The method mainly follows an attributional life cycle assessment (ALCA) approach, which provides information about the direct GHG emissions that are attributed to the production and use of a product [7]. It is agreed that this methodology is best suited for GHG regulation as the operator has a greater deal of control over the direct emissions resulting from their product [8]. It is believed that consequential LCA, which examines the GHG emissions occurring due to a change in production of a product, is best suited for policy analysis [7–9].

There is increasing awareness of the drawbacks of 1st generation biofuels [10], including the negative impacts they may have on food prices and direct and indirect land use change [6,11]. The current targets for 2020 are to produce 10% of all consumed energy from biofuels, and there are proposals that only half of this can be from food-based resources [12]. The RED has two main methods of incentivising the use of non-food, and non-land resources. Firstly, in Article 3, Part C it states will double the contribution that lignocellulosic-derived biofuels make to biofuel targets. This means that if a Member State produces 5% of renewable fuels from food crops and 2.5% from lignocellulosic material, then that country has met their 10% biofuel contribution target. It is anticipated that their contributions will be quadrupled in future revisions of the RED [12].

The second way the RED supports lignocellulosic biofuels is found in Annex V, Section C, Point 18, where it states that "agricultural residues" are not attributed with upstream GHG emissions. This means that these feedstocks are acquired at a zero GHG 'cost', which has been deemed to be "clearly incorrect" [13]. As the RED does not attribute any upstream emissions from cereal cultivation to straw it implies there are no sustainability impacts associated with using it [14]. This somewhat contradicts the European 'Common Agricultural Policy' which identifies cereal residues as an important contributor towards erosion control due to rainfall and wind [15] as well as being implicated with nutrient recycling, maintaining soil structure and regulating water retention [16,17]. Indiscriminate removal can lead to a decline in soil quality, having both short and long-term adverse impacts on the environment [18]. Currently there are no requirements in GHG reporting methodologies to account for environmental impacts from removing straw from land.

1.2. GHG implications of straw removal

There is an apparent need for a soil quality indicator for use in LCA studies, as soil is a non-renewable resource that plays a central role in agricultural systems [19]. There is ongoing debate to the impacts of straw removal from soil [20], and a few studies have placed these in the context of a LCA study, and as yet no consensus has been drawn [20,21]. Soil can act as either a sink or source of carbon [13]. Soil organic carbon (SOC) is a key indicator of soil quality and degradation [19,22], as it directly affects soil properties such as productivity, nutrient recycling and general soil physical properties [23]. Sequestration of SOC occurs as a result of the long-term storage of atmospheric carbon dioxide (CO_2) as a relatively inert form of carbon with a potential residence time of decades to centuries [16,24]. Oxidation of SOC can occur after tillage operations; for example up to 15 kg of carbon is lost per hectare (ha) during mouldboard ploughing [44]. Residue incorporation and reduced tillage can lead to a build-up of SOC over time, as more stable sources are left undisturbed and soil microbes tend to favour more readily available carbon sources [24]. There has been an increased interest in including changes in SOC in LCA studies, however as of yet, there is no harmonised method [22].

One study examined the impact of straw removal in the context of bioethanol production from wheat straw and found that net GHG emissions savings of 49% could be achieved [25]. This achieves the 35% GHG emission saving targets set by the RED, but not the 60% target applicable after January 2018 by installations that start on or after 1 January 2017. Changes are proposed to reduce the emission saving limits to 60% for plants initiating operation after 2014 [12]. The results of the study by [25] suggested that straw removal was responsible for up to 50% of the emissions of bioethanol production. Therefore, if the GHG implications of straw removal are accounted for in GHG regulation, they could compromise the ability for straw-based bioethanol to achieve future RED emission saving targets.

1.3. The aim of this research

This study addresses the sustainability implications with utilising cereal straw for 2nd generation biofuel production. Straw management is implicated with three main sources of GHG emissions: substitution of nutrients, changes in nitrous oxide (N_2O) emissions from soil, and changes in SOC [25]. The 'nutrient substitution penalty' represents the GHG emissions associated with compensating for nutrient loss after straw removal, so to avoid any losses in grain yield [26]. Incorporation of nitrogen contained in the straw leads to emissions N_2O from soil [27]. These impacts are then placed in context of a recently published lignocellulosic bioethanol LCA study [28] to test whether straw removal compromises the GHG savings of straw-based bioethanol.

2. Methodology

2.1. LCA of lignocellulosic bioethanol production

Assessing the impacts of straw removal on the GHG saving potential of bioethanol requires a RED-compliant study of bioethanol production from straw. The final unit of measurement is 'one GJ bioethanol from wheat straw', and the functional unit is 1 GJ of