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Corn stover collection prior to biogas production – Evaluation of greenhouse gas emissions

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ABSTRACT

Sustainability in terms of greenhouse gas (GHG) emission saving for biogas production and utilisation is defined by Renewable Energy Directive (RED) and amending documents. The method for determination of GHG emissions defines that, when crop residues are evaluated, only those emissions originating from collection should be considered in the balance. As a result of such approach, lower emissions could be assigned to life cycle of crop residues, due to neglected effects of nutrients removal via residues and digestate management practice. Objective of this study was to evaluate GHG emissions of corn stover collection, intended for biogas production. The evaluation was performed strictly following the method defined in RED, but also by additional scenarios, to consider effects of nutrients removal and digestate management. GHG emissions of corn stover collection were in the range of 14,000 gCO_{2eq}/tDM to 150,000 gCO_{2eq}/tDM depending on the scenario. Lowest emissions are associated with scenario completely in line with the method stated in RED and highest when digestate is used on other fields than those from where corn stover was collected and if removed nitrogen, potassium and phosphorus nutrients are compensated by mineral fertilisers. Further investigations should be oriented to give improved data about nitrogen removal via crop residues, its transformation during anaerobic digestion and emission factors for digestate application. These data could considerably improve evaluation of biogas production from crop residues in terms of GHG emissions.

1. Introduction

Corn stover, crop residue of corn grain production, is the most abundant agricultural biomass in many Danube region countries in central and south-eastern Europe (Martinov et al., 2016). It is potential source for generating renewable energy such as biogas. It is still mostly unused due to its lignocellulosic nature which is unsuitable for fermentation (Lizasoain et al., 2017). There are some pre-treatment technologies, *e.g.* enzymatic treatment (Schroyen et al., 2014), steam explosion (Lizasoain et al., 2017; Shafiei et al., 2013) and other physical treatments (Theuretzbacher et al., 2015), mostly in the stage of early commercial maturity. They are used for breaking of lignocellulosic structure in corn stover and similar crop residues, prior to biogas production. By expansion of these technologies it is reasonable to expect that corn stover utilisation as a biogas substrate will significantly increase in the future.

Production and use of biofuels for transport, such as biomethane, bioliquids and biomass for electricity, heating and cooling should fulfil sustainability criteria defined by Renewable Energy Directive (RED) and its amending documents (European Commission, 2009, 2017a, 2017b). For biofuels, a greenhouse gas (GHG) emission saving is the most challenging criterion due to fact that the saving in comparison to a fossil fuel comparator has to reach at least 60%. In 2021, this value will be 70%. For biomass used for electricity generation, heating and cooling, GHG emission saving will have to be minimum 80% in comparison to the fossil fuel comparator. Values of the fossil fuel comparators for biofuels and biomass used for electricity are 94 and 183 gCO_{2eq}/MJ, respectively. The RED is providing, in Annex V, a method which should be used for determination of the actual GHG emission savings for biofuels. It can also be used in an adapted form for determination of the same value in case of biogas utilisation for electricity, heating or

Abbreviations: BB, Big bales; DM, Dry matter; EONR, Economically Optimum Nitrogen Rate; GHG, Greenhouse gases; ILUC, Indirect Land Use Change; IPCC, Intergovernmental panel for climate change; LCA, Life Cycle Assessment; LCI, Life Cycle Inventory; LCIA, Life Cycle Impact Assessment; PE-HD, Polyethylene High Density; PE-LD, Polyethylene Low Density; RB, Round bales; RED, Renewable Energy Directive; SOC, Soil Organic Carbon.

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cogeneration. The aim of this method is to assess the emissions within different life cycle phases of the end product, *e.g.* biomethane or electricity, and to compare them with the mentioned fossil fuel comparator. These phases are: cultivation or extraction of raw material (collection of crop residues), production, transport and distribution and use.

By implementation of the ILUC (Indirect Land Use Change) Directive 1513/2015 (European Commission, 2015), amended RED incentivise the production of the second generation biofuels made from, among other, non-food cellulosic materials, such as corn stover, by limiting the share of conventional, first generation, biofuels to 7%. Also, the amendments set a reference target value of minimum 0.5% for advanced biofuels which member states should have adopted by April 2017 and state that contribution of these biofuels counts double to the national targets. Another measure for promotion of agricultural crop residues, defined by RED, is that the GHG emissions are zero up to the process of their collection. That should contribute to much easier fulfilment of the GHG emission saving criterion for all energy utilisation pathways of crop residues. It practically means that, according to the RED method, emissions associated with the extraction phase or cultivation of raw materials are only those made as a consequence of agricultural operations engaged in the crop residue collection. The European Standard EN 16214-4: 2013 (European Committee for standardization, 2013) has been developed to assist in the implementation of the RED method and confirms its compliance with the principles of Life Cycle Assessment (LCA). Giuntoli et al. (2015) have determined GHG emission savings for several energy utilisation pathways of biogas, and these values are reported as a default GHG emission saving values stated in RED amending documents (European Commission, 2017a, 2017b).

During analysis of wheat straw based bioethanol, Whittaker et al. (2014) have done critical overview of the RED method and claimed that it is not in line with the European Common Agricultural Policy because of the impact that the removal of crop residues has on the soil fertility preservation and erosion protection. The removal of crop residues can be manifested through additional GHG emissions due to application of mineral fertilizers used to compensate nutrients removed from soil via residues (Cherubini et al., 2009; Cherubini and Ulgiati, 2010; Whittaker et al., 2014). In case of biogas production and utilisation, impact of crop residues removal is directly influenced by the management of a digestate – a co-product of biogas production. One case would be that this organic fertilizer is distributed on the same agricultural field where crop residues were taken. Second would be that it is used on another fields. In combination with rules for application of RED method, several problems arise that could assign lower overall GHG emissions to analysed system.

In the first case, closed loop system is achieved, and except nitrogen lost during application of digestate (volatilisation of ammonia and direct emissions of nitrous oxide), all nutrients are returned to the field. Problem arises due to lost nitrogen since additionally fertilisers used for its compensation would be assigned to a following crop. For substrates, like corn silage, this is not the case which is thoroughly explained in (Giuntoli et al., 2015). In the second case, when digestate is used on other fields, digestate represents co-product and some GHG emissions need to be assigned to it due to allocation envisaged by RED method. This is logical approach, but again remains the question of additionally applied fertilizer. How to include those emissions which would be the consequence of application of fertilisers intended for nutrients compensation. RED method, due to the rule that GHG emissions are zero up to the process of crop residue collection, does not enable inclusion of such emissions. Adams et al. (2015) emphasized deficiencies of RED method associated to allocation of GHG emissions between biogas and digestate for common substrates, *i.e.* manure and corn silage, but obviously problem is even more complex if crop residues are used as a substrate. Solution could be to assign to the analysed system GHG emissions arising from removal of the corn stover from field combined with applied digestate management pathway. These emissions would be assigned to phase collection. Of course, it is not clear if these additional emissions could have major impact on sustainability of corn stover use as a biogas substrate. The value of these additional emissions is unknown and it is not fully clear which ones should be included.

Evaluation of the collection phase of corn stover, which is intended to be used for biogas, in terms of the GHG emissions without accounting possible long-term sustainability impact that its removal has on the soil, is deficiency of the RED method. Appropriate inclusion of these emissions needs to be based on scientific backgrounds for the impacts of corn stover removal. Objective of this study is to determine the GHG emissions associated with the collection of corn stover prior to biogas production in accordance to the RED method but also by taking into account GHG emissions which are consequence of nutrients removal. In this way will be provided backgrounds for better understanding possible improvements of the RED method which could more precisely assess the GHG emissions savings related to utilisation of corn stover and other crop residues.

2. Material and methods

2.1. Material

2.1.1. Procedures of corn stover collection

Stover collection can be organized in such a way that incorporates several, two or only a single pass over the field. The appropriate stover collection technique should be selected depending on grain harvest efficiency, an increase of the grain-loss rate and contamination by soil, *i.e.* soiling, expressed as ash content (about 5% of ash presents mineral matter of unsoiled corn stover). Based on a detailed survey of the relevant literature (Perlack and Turhollow, 2002; Shinners et al., 2007a, 2007b, 2009, 2012), it is concluded that the two-pass procedure is the most appropriate one to collect stover for biogas production, since it is more efficient from energy aspect than collection in several passes and does not influence harvest efficiency and grain-loss rate as by single pass collection. In comparison to the multi-pass, the two-pass approach is also preferable in terms of soiling. Nevertheless, this harvest procedure results in higher rate (up to 90%) of harvested cobs and husks.

For two-pass procedure, the special header with chopper–windrower is needed, *e.g. Cornrower* developed in USA and presented in (Shinners et al., 2012; Straeter, 2011), and recently developed and offered by one European manufacturer. Formed windrow–swath is a good pad for material dropping out of harvester, cobs, husks and snapped leaves. It is assumed that the use of such device would raise the usual harvester's fuel consumption of 28 L/ha (Cooperative Union of Vojvodina, 2014) by app. 33% (Straeter, 2011). However, since the corn stover shredding can be seen as a part of the corn grain growing cycle, only fuel consumption for windrow forming is included in the stover collection analysis. It is assumed that this amounted about 20% of the additional consumption, or 2 L/ha. The process "Combine harvesting, CH" from the *Ecoinvent* was used as a basis to model the windrow forming phase.

The baling of windrowed material in the form of big (rectangular) bales (BB) or round bales (RB) is the second harvest pass. Both types of balers are considered since they are commonly used. Baling (pick-up) efficiency differs for different corn stover parts, but