Applied Energy 102 (2013) 131–139

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Greenhouse gas emissions from first generation ethanol derived from wheat and sugar beet in Germany – Analysis and comparison of advanced by-product utilization pathways

Jana Weinberg *, Martin Kaltschmitt

Technische Universität Hamburg – Harburg, Institut für Umwelttechnik und Energiewirtschaft, Eißendorfer Straße 40, D-21073 Hamburg, Germany

HIGHLIGHTS

- ▸ Ethanol production from sugar beet and wheat is investigated.
- ▸ Instead of feed production from residues by-products are used for energy production.
- ▸ Ethanol from sugar beet with biogas co-production shows lowest GHG emissions.
- ▸ For wheat pathways bran and gluten separation generates lowest GHG emissions.
- ▸ An allocation method is recommended involving co-produced fertilizer.

ARTICLE INFO

Article history:
Received 19 January 2012
Received in revised form 30 May 2012
Accepted 15 June 2012
Available online 15 July 2012

Keywords:
LCA
Ethanol
By-products
Greenhouse gases

ABSTRACT

In state of the art ethanol production, by-products like vinasse from sugar beet or distiller's dried grains with solubles (DDGSs) from wheat grains are usually used as animal feed. The drying process consumes a significant amount of energy that could be reduced by producing other valuable materials or energy carriers from these by-products. Besides resulting higher overall conversion rates and improved process efficiencies, by-products, which can be extracted or are automatically created during the various conversion steps, should be used to reduce environmental impacts as well. In this analysis, advanced pathways for the recovery and use of by-products from bio-chemical ethanol production like gluten separation from wheat starch, biogas production from stillage or vinasse and combustion of bran for electricity generation are analyzed with regard to their contribution to the greenhouse effect. Therefore, different methodological approaches are applied and compared. The analysis shows among others that ethanol from sugar beet generates less greenhouse gases (GHGs) compared to the ethanol production from wheat. The biogas production from residues and especially the use of bran for heat and electricity generation shows significant GHG reduction compared to the state of the art application. However, the methodological approach for the treatment of by-products highly influences the results. For the reproducibility of the results an energy equivalent allocation method involving the specific application of the respective co-product is recommended.

1. Introduction

So far fossil sources of energy like coal, crude oil and natural gas are easily accessible and refining or conversion technologies are well known. Although, the ongoing depletion of crude oil resources and a desired greater autonomy from oil exporting countries makes the move towards alternatives to fossil fuels inevitable.

In the year 2009 the German greenhouse gas (GHG) emissions from the mobility sector amounted to 20.5% of all emitted greenhouse gases while more than 95% of them are resulting from road traffic [1]. Due to the effects on global climate due to these GHG emissions, the European Union (EU) has adopted the Renewable Energy Directive (RED) claiming a share of 10% renewable energy within the mobility sector until 2020 [2]. The type of renewable energy to be used is not specified by this legislation. Therefore, several governments promote e.g. electro-mobility. But for the near future, one of the most important instruments for GHG reduction in traffic is the increased utilization of biofuels. This type of renewable energy should contribute to the goal of the European Union to decrease GHG emissions by 6% in the year 2020 compared to the 2010 level [3]. To reach this goal the emissions of

* Corresponding author. Tel.: +49 40 42878 3528; fax: +49 40 42878 2315.
E-mail address: jana.weinberg@tuhh.de (J. Weinberg).

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http://dx.doi.org/10.1016/j.apenergy.2012.06.047

biofuels must have a potential to save at least 35% GHG emissions compared to fossil fuel. Future targets are even more ambitious by increasing this value to 50% for existing and 60% for new plants [2].

One important biofuel that is used in Germany as well as in Europe is ethanol added up to 10% into gasoline. Most German ethanol for mobility purposes is generated from wheat grains. This fuel reaches the GHG reduction goals today, but for future application the target is not fulfilled according to current status [2]. Since second generation biofuels like ethanol from straw or wooden materials are only available in test or pilot scale so far it is questionable if these fuels might be ready until they are needed.

For first generation ethanol production from grains, plants with significant process improvements like bran separation are already under operation (e.g. ethanol plant in Wanze, Belgium [4]). Another possibility that might reduce GHG emissions by reducing energy consumption is the generation of biogas from stillage (e.g. ethanol plant Schwedt, Germany [5]).

Beside grain, sugar beet as a raw material for ethanol generation is discussed more intensively in Germany because of high yields per hectare and the already existing infrastructure. Additionally the process design is similar to an ethanol generation from starchy biomass [6]. However, sugar beet is not often used yet because of higher logistic costs and low storability. Nevertheless, realized as an annex plant to an existing sugar refinery this might be a promising option.

Against this background the objective of this paper is to analyze GHG emissions for various concepts of an advanced utilization of by-products compared to the emissions of the state of the art ethanol generation. Dealing with uneven by-products is always challenging in life cycle assessments (LCAs), like shown e.g. by Nguyen and Hermansen [7]. To present the possible variation in results different methodological approaches for the assessment of the by-products are investigated and evaluated with regard to their applicability (e.g. for decision making processes).

2. Methodology

The methodological approach for the calculation of environmental parameters in a LCA is carried out according to the given standards ISO 14040 [8] and 14044 [9]. It consists of four steps explained in more detail below.

2.1. Goal and scope definition

The goal of this analysis is to determine the overall greenhouse gas emissions for first generation ethanol derived from sugar beet and wheat with a special focus on the use of by-products and their methodological assessment including different alternatives of by-product handling like allocation and credits.

The system boundaries for the investigated ethanol pathways include the conversion of the biomass to ethanol in the conversion facility. The analysis implies the overall energy and material demand for ethanol production with all specific pre-chains for energy, biomass and other material provision as well as the overall material demand for building infrastructure. The geographical reference area for the cultivation as well as the conversion is Germany and the time frame is the year 2011. Direct and indirect land use is neglected, because it is assumed that existing plants can be retrofitted. The functional unit is the energy content of the produced ethanol at the production site, in MJ (based on the lower heating value) (LHV).

First the results will be drawn for the case that no by-products are counted in order to show the source of the overall emissions. Then the by-products are assessed by different kinds of allocation and are compared to the existing RED-methodology in order to show divergences. Additionally a system expansion (i.e. credits are given for the displacement of substitutable goods) is carried out and the results are compared to the outcomes from allocation.

2.1.1. Allocation variants and RED-methodology

Within the allocation variants, the GHG emissions are allocated to the different products according to the following three criteria (i.e. mass, energy and energy equivalents).

- Mass based allocation: the emissions are allocated based on the dry matter content of the various by-products.
- Energy based allocation: emissions are allocated based on the energy leaving the system boundary (i.e. ethanol, supplemental electricity). Dried feed pellets or digestate are not regarded (e.g. based on their heating value) because these products are not used for energy supply.
- Allocation based on energy equivalents: the different by-products are considered by converting them into energy equivalents with regard to their specific application. Food and feed are counted for based on the nutrition value because this is the form of energy that is used and assimilated. The nutrients in the digestate are rated by the cumulative energy demand for the production of mineral fertilizer that can be replaced. Evidently electricity is regarded as energy.

Additionally it is assumed that energy carriers provided within the ethanol provision process are used for the process internal energy supply with highest priority. To account for this, first it is checked if the heat demand of the ethanol plant can be satisfied by the combustion of the energy carrier provided from the by-product. If more heat can be generated than necessary, it is assumed that a combined heat and power plant is installed to cover the process heat demand and to generate additional electricity. This electricity is used to operate the ethanol plant. Only supplemental electricity leaves the system boundaries and is counted for by allocation (Fig. 1).

The results from allocation are compared to the results that can be calculated according to the RED-methodology. Therefore the specifications are explained hereinafter: In the RED allocation based on energy content (referred to the lower heating value) is carried out for energy carriers as well as for electricity gained from residues in combined heat and power (CHP) production. For electricity generated in a CHP plant from non-residue by-products a credit is given for the single electricity production from the same energy carrier.

2.1.2. System expansion variant

Within the system expansion variant for the handling of by-products, credits are granted. Therefore, avoided emissions from the regular way of production of the substituted products are subtracted from the overall emissions of the process.

2.2. Inventory analysis

For the ethanol production pathways different possibilities for the by-product utilization are analyzed including the energy and material flows as well as the emissions that are generated during each step of the life cycle. The necessary data are discussed in chapter 3.

2.3. Impact analysis

Within the impact analysis, the data collected within the previous step are related to the impact category “contribution to the anthropogenic greenhouse effect”. Therefore, all emissions with