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Research paper

Assessment of grassland as biogas feedstock in terms of production costs and greenhouse gas emissions in exemplary federal states of Germany

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ABSTRACT

Grassland production systems offer feedstock for power production based on biogas in Germany. In the future, additional potential grassland will be made available due to further concentration of cattle production in areas that possess comparative advantages for milk and meat production. This study assesses grassland as a feedstock for biogas production in Germany from both an economic and ecological point of view by considering regional production conditions and plant-specific factors. Regional production costs and greenhouse gas emissions for grasslands are calculated within the federal states of Bavaria, Lower Saxony and Schleswig-Holstein, which represent hotspots for German biogas production. A linear model approach is used to optimize the feedstock mix of each biogas plant located in one of these exemplary regions. In a scenario-based analysis, the opportunity costs for energy crops cultivated on arable land are considered to depict a shortage of arable land as an economic advantage of grasslands. Similar to EU biofuel production, the linear model considers the greenhouse gas mitigation potential for power production based on biogas and differing costs of CO_2 emission rights. Greenhouse gas emissions are calculated both with and without iLUC factors to highlight the differences between arable land and grasslands with respect to limited availabilities and the consequences of greenhouse gas emissions. The results show that grasslands could be a reasonable feedstock for biogas production, especially in the northern part of Germany, if iLUC factors are considered and if a greenhouse gas mitigation potential is required that includes high prices for CO_2 emission rights.

1. Introduction

Through 2014, more than 8,700 biogas plants (BGP) were in operation in Germany with an installed electric capacity of around 3.9 MW [1]. Compared to other renewable energy sources, power gained from biogas is subject to particularly high feed-in tariffs. New feed-in tariffs have slowed the expansion of biogas technology since 2013. Subsidizing power production due to high feed-in tariffs was and still is justified by the lower greenhouse gas (GHG) emissions compared with fossil fuels [2]. Biogas production in Germany is mainly based on annual energy crops and manure from livestock production. Within energy crops, silage corn (SC) is the most used feedstock [3]. Grassland also provides a suitable feedstock for biogas production which is identified as a key technology for using grassland in energy production systems [4]. In Germany, grass silage (from permanent grassland and arable land) is estimated to account for 12% of the total feedstock input for biogas production [3]. Nevertheless, grass silage use in a mono digesting system is risky due to both the biological balance and potential mechanical problems within the fermenter [5]. Therefore, co-fermentation of grass silage is usually necessary; this requires additional manure input and other energy crops.

Permanent grassland covers 29% (4,677,100 ha) of the total agricultural land in Germany [6]. These areas, which can be used for energy production, are projected to increase due to the decrease in cattle production in certain areas [7]. The elimination of the European milk quota will likely lower the price of dairy products; as such, dairy production will increase in regions with low production costs and decrease in regions with site-specific disadvantages [8]. Grassland areas in the latter regions can be used for alternative purposes such as biogas production. For example,

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165,000–200,000 ha of grassland in Bavaria is estimated to be available by 2020 [9]. However, the grassland needs to be maintained to satisfy EU policy requirements: Member States shall not decrease the ratio of grassland in relation to total agricultural land by more than 10% relatively to the ratio of reference year 2003 both at national and regional level [10]. Furthermore, it can provide feedstock for regional biogas production [11]. Grass from landscape management can also be a suitable feedstock for biogas production, if the harvesting date is properly chosen [12]. Unlike energy crop production, grass production does not require arable land, which means minimal competition with food production [13]. Further, grasslands are perennial crops that require less tillage and seeding; these factors decrease both the production costs and unit greenhouse gas emissions [14]. Additionally, grassland systems can sequester carbon and further improve the GHG emission balance [15]. Compared to the common energy crops, grassland systems usually require less mineral fertilizer and pesticide input per hectare but more fuel for harvesting [16]. This impacts both production costs and unit GHG emissions.

The aim of the paper is i) to assess grassland use in German biogas production in terms of both production costs and GHG emissions on a site-specific basis. Thus, site-specific variable production costs and the GHG emissions of grassland as a feedstock in German biogas production are calculated and integrated into the authors economic-ecological model approach of German biogas production [17]. Further, the model approach is extended within this study ii) to test whether German biogas production is able to achieve a GHG mitigation potential of 60% based on GHG emissions of the current power mix in Germany in 2014 (0.569 kg CO_2eq kWh^{-1} [18]), which has already been requested for biofuels in the EU [19]. Bringing i) and ii) together, we attempt to verify the following hypotheses:

I. Compared to energy crops from arable land, grassland is a reasonable feedstock for biogas production in some regions of Germany in terms of site-specific production costs.

II. Compared to energy crops from arable land, grassland as a biogas feedstock contributes to reduce the specific CO_2eq emissions to less than 60% of the GHG emissions of the current power mix in Germany.

2. Materials and methods

2.1. Yields and specific methane yields of grassland production systems in Germany

Yield data, which are estimated based on farmers' evaluations, are published by the respective Statistical Offices of the federal states at a district level. Therefore, plant heights of several fields are measured at various times to gain a representative sample. The data are then converted to yield per ha [20]. The strong effect of cultivation intensity which also affects the species composition in grassland production systems [21], is characterized by the number of cuts per year and leads to strong variations in biomass yield potential [22]. Grassland is mainly used within the farm and is not sold to customers. Consequently, gaining an accurate weight determination which could be used for yield estimations is not important for many farmers [23]. Due to missing data from several federal states and districts, it was impossible to apply the model across Germany. Therefore, we have chosen three federal states, Schleswig-Holstein, Lower Saxony and Bavaria. They are characterized as biogas hot-spots and by high quality of grassland yield data collection. Schleswig-Holstein and Lower Saxony conduct many field studies and work with well-trained reporting farmers to estimate crop and grassland yields. In Bavaria, approximately 1,050 official well-trained experts from government service collect yearly yield data and provide reliable data sets [24,25].

The common way of using grassland as biogas feedstock is silage [26]. The specific methane yield of grass silage from permanent grassland is characterized by a wide range, depending, among numerous other things, on management intensity and plant community [4,27]. Nevertheless, the model approach is not able to differentiate the variety of permanent grassland and thus needs a specific input value. Therefore, we assumed the standard methane yield for grass silage of Döhler [28] which is specified with 320 m^3CH_4 t oDM^{-1}.[1] According to Messner et al. [29] and Mähnert et al. [30] this seems to be an appropriate generalization for our model approach. Döhler [28] assumes an organic matter proportion of 90% of dry mass (DM) and a dry mass proportion of 35% fresh mass (FM) resulting in a methane yield of 101 m^3 CH_4 t FM^{-1}.

2.2. Input data and allocation of grassland production systems

According to Messner and Elsässer [31] and Tilvikiene et al. [32], 3 and 4 cuts are the most preferable cutting regimes for biogas substrate production and have low methane yield differences. Therefore, we assume a production system with 3 cuts per year (Fig. 1).

2.2.1. Amounts and costs of mineral fertilizer

Fertilization is based on nutrient removal which is calculated according to regional FM yields. As such, removed nutrients are allocated to the respective grassland areas. Nutrient shifts due to different feedstock within the digestate are not considered. Phosphate (P) and potassium (K) remain in the digestate without losses [33]. Therefore, a closed nutrient cycle is assumed for P and K. Nitrogen (N) fertilization is modeled different due to its unique properties. The removal of N is linearly interpolated based on DM yields [34]. The difference represents the N amount to be added to the system. The nitrogen needed is supplied by digestate, which accounts for 75% of the plant available nitrogen [35]. Furthermore, the supply via the digestate is limited to 170 kg N ha^{-1} due to the governmental restrictions. Mineral fertilizer, which is priced at 1 € kg^{-1} N (average value 2010–2014) [36], is only used to fill the gap in overall N removal.

2.2.2. Variable production costs and diesel consumption of grassland production systems

The mechanization of grassland and energy crop production systems is divided into two parts. Overall costs for cultivation until harvesting (e.g., reseeding) are considered (Table 1). The harvesting process is assumed to be performed by a service provider; therefore, the working time is estimated and assessed with hourly charges of the agricultural contractor, including an hourly wage of 20 € h^{-1} for the driver (Table 1). The diesel consumption of the machinery is linearly interpolated [37]. Assumptions for production costs are also integrated (Table 1). Detailed values for variable production costs and diesel consumption for the remaining energy crops (i.e., sugar beet (SB), winter wheat as whole plant silage (WPWW) and grain) are integrated within the general model approach [17].

2.2.3. Greenhouse gas emissions from grassland cultivation

Greenhouse gas emissions are expressed as kg CO_2eq over a 100-year time horizon [41]. In our study, 1 kg CO_2 equals 1 kg

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[1] The biogas yield and methane yield were expressed in m^3 t^{-1} using the ideal gas law (norm conditions: 273.15 K and 1 bar).