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Research paper

Future European biogas: Animal manure, straw and grass potentials for a sustainable European biogas production

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ABSTRACT

Biogas is expected to play an important role in reaching the future energy policy targets of the European Union (EU). The sustainability of biogas substrates has however been recently critically discussed due to the increasing shares of agricultural land used for energy crop production.

The aim of this study was to project and map the biomass and biogas energy potential from a selection of potentially sustainable agricultural residues, which have been documented to improve in biogas yields when co-digested in biogas production, for the EU28 in year 2030. The investigated types of residual biomasses were animal manure, straw by-products from cereal production, and excess grass from rotational and permanent grasslands and meadows. The biogas energy potential from the investigated biomass was projected to range from $1.2 \cdot 10^3$ to $2.3 \cdot 10^3$ PJ y^{-1} in year 2030 in the EU28, depending on the biomass availability. Alone the biogas energy potential projected in the scenario representing low substrate availability corresponds to a doubling of the European biogas production in 2015. The results shows that sustainable alternatives to the use of maize are present in all the member states of the EU28 to an extent that is sufficient to ensure a continuous progressive development of the European biogas sector.

1. Introduction

In the European Union (EU), political targets for climate and energy in 2030 are 40% reductions in greenhouse gas emissions, 27% renewable energy installed capacity for the entire EU energy supply and 27% improvement in the energy efficiency [1,2]. Biogas is expected to play an important role in reaching these energy targets due to the flexibility and storability of biogas as an energy carrier, the very diverse biological sources which can be used for its production, and its already established application in a wide range of applications (heating, transportation and electricity production) [3]. The application of anaerobic digestion (AD) for biogas production remains widespread as a useful bioenergy production route due to the robustness of its main design configurations and pathways [3]. Anaerobic digestion serves multiple purposes. It provides a treatment platform for decreasing large amounts of complex organic materials, converting the majority of such molecules into monomers i.e. methane and carbon dioxide (biogas) utilizable in the energy sector in multiple pathways. Secondly, but equally important, the nutrient rich digestate emanating from the AD process is mainly recycled to farmlands to serve as organic fertilisers replacing increasing amounts of chemical fertilizers and decrease negative environmental impacts (i.e. eutrophication of fresh water systems) which would be the situation if the disposal of such nutrients is not properly managed and controlled [3].

From 2000 to 2015, biogas production in the EU has witnessed more than a sevenfold increase (Table 1) [4]. In 2015, sewage sludge gas and landfill gas represented respectively 17% and 9% of the total production, whereas other biogases from anaerobic digestion (decentralised agricultural plants, centralised co-digestion plants, and municipal solid waste methanisation plants) represented 74% of the total production [5,6].

Since 2010, 50% of the total European production of biogas was produced in Germany. Due to an attractive feed-in tariff system, the German biogas production has expanded significantly. However, this expansion has happened with a substrate supply strongly based on maize, which is worrying due to the potential damage to the environment caused by intensive cultivation of energy crop

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Table 1
The primary production of biogas in the European Union (EU28) from 1990 to 2015 [4].

EU28	1990	1995	2000	2005	2010	2015
PJ	28	48	92	167	357	654

monocultures [7]. The choice of substrates used for biogas production has been recently critically discussed, in particular, with respect to the use of energy crops. Negative environmental and economic issues associated with the use of cultivated energy crops for bioenergy production have been largely reported in the literature [8,9]. Such substrates are therefore increasingly expected to fall out of favour as primary feedstock considered for the biogas AD process and hence alternative sources needed.

The substrate supply for a growing European biogas sector should be carefully considered in order to ensure that the biogas production is sustainable with respect to potential impacts in the environment, nature and climate, and current food and biomaterial production chains.

In 2010, the Biomass Energy Europe project (BEE) published a report comparing more than 70 assessment papers on biomass for energy production [10]. Forty-two of these papers address the potential of agricultural and organic residues on global to national scale, with the energy potentials on EU level also highlighted. The BEE found that in many of the studies, the specific type of agricultural residue was not well defined (i.e. types of animal manure) and only few of the assessments were joined with spatial data in order to map the distribution [10]. In 2012, the Biomass Futures project published the “Atlas of EU Biomass potentials”. The authors concluded that the largest potential could be obtained from agricultural residues defined as manure, straw and cutting/prunings from permanent crops. In total, this potential was estimated to correspond to $4.4 \cdot 10^3$ PJ in 2030 [11]. Animal manure is recognized to be a very favourable substrate for biogas production, as it combines energy production, nutrient recycling and decreases emissions of CH_4 and N_2O compared to conventional manure management [3,12]. Due to high concentrations of water in animal manure is it seldom economically feasible to run biogas plants solely on animal manure. Green vegetation i.e. Poaceae has been documented to improve biogas yields by 18–40% when co-digested with animal manure, while increases of 10–80% were observed with crop residues i.e. wheat straw, rice straw, maize stalks depending on pre-treatment conditions and contents of dry matter [13]. Thus, the availability and distribution of such residues for codigestion is an interesting aspect for maintaining and expanding the biogas sector in Europe.

Residues from agricultural production can be argued to incorporate well with the EU directive on promotion of the use of energy from renewable sources sustainability criteria [14]. For the use of solid and gaseous biomass in electricity, heating and cooling a set of non-binding recommendations for ensuring sustainability has been set, these are:

I. The biomass use should ensure greenhouse gas savings of at least 35% compared to fossil fuels (increasing to 50% in 2017, and 60% in 2018 for new plants).

II. Resources cultivated on areas converted from land with high carbon stocks and land with high biodiversity should not be used.

The second recommendation from the European Commission recognises that negative land use changes should not take place with the aim of producing biomass for energy production, thus potentially biodiversity loss and species extinction. None of the recommendations, however, takes into account that biomass production on farmland (both directly and indirectly) could contribute to crossing the planetary boundaries as discussed and outlined by Steffen et al. [15] due to e.g. extensive fertilization, fresh water use and soil erosion.

In contrast to the existing literature on the topic, this study solely focus on the biomass and biogas energy potential from a selection of specific agricultural residues which have been documented to improve in biogas yields when co-digested in biogas production. The assessed substrates in this study are residual grass from permanent and rotational grasslands, straw from cereal production, and manure from cattle, swine and poultry.

2. Data and methods

2.1. Biomass types in focus

The task of evaluating whether a bioenergy production process or the biomass feedstock used is sustainable is not trivial, especially when considering the above-mentioned concerns related to the sustainability of biomass production. The biomass resources assessed in this study can neither be claimed to be sustainable in all aspects, as the final impacts of utilising them will depend on the local conditions for cultivation, harvest, transport, storage and the eventual applied conversion technologies. However, an overall condition for the assessed biomass resources has been that they are low environmentally impacting biomass, residues from agricultural production, and are potentially sustainable when handled efficiently and with respect to nature and the environment.

Crops cultivated on farmland with the sole purpose of being utilized for energy production have been excluded in this study, prioritizing that the farmland is used for food, raw material (bio-based) and fodder production.

2.2. Assessing the quantity of animal manure and the biogas energy potential

For estimating the manure potential in the EU28 in year 2030, the average number of cattle and pigs (number of animal heads) and poultry (number of slaughtered animals) registered by Eurostat from year 2011–2015 were applied as base values [16–18]. Forecasts for the agricultural production of meat, milk and dairy in Europe and Central Asia [19] were applied for estimating the livestock numbers in 2030. The annual growth rate for the production of beef and dairy cattle are forecasted to be respectively 0.32% and 0.33% while the annual growth rate for the production of pork and poultry is forecasted to be respectively 0.47% and 1.24%. The estimated pig and cattle manure quantities were distinguished based on the age of the animals and the purpose of breeding (i.e. for dairy or meat production). For estimating the produced amounts of poultry manure, a distinction of the poultry groups was necessary: chicken, broiler, duck, turkey and goose. The amounts of produced animal manure (faeces and urine combined) were estimated using the American Society of Agricultural Engineers (ASAE) standards [20]. The quantities of manure are estimated in total solids (TS) representing the dry matter of faeces and urine combined. For animals bred for meat, manure production was estimated based on excreted manure per “finished animals”. The manure production from other animals was estimated based on the values of manure excreted per day per animal. However, only the manure when the animals are housed can be collected and used for energy conversion purposes. The housing period will depend on the local production methods, thus they are expected to vary depending on the specific farming practices. Conventional farming methods usually imply that the animals are housed during most of their lifetime. An important exception, however, is cattle farming. Pasture grazing is a traditional method of feeding cattle. The application of grazing as a method of feeding, however, varies over Europe depending on i.e.

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