LIFE CYCLE ASSESSMENT OF AGRICULTURAL BIOGAS PRODUCTION SYSTEMS

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ABSTRACT Climate change is one of the main challenges mankind has to face in the 21st century. Significant contributions to anthropogenic greenhouse gas emissions are caused by agricultural activities. One effective way to reduce agricultural emissions is the implementation of liquid manure to produce biogas. When applying this technique greenhouse gas emissions from manure storage are avoided and renewable energy in terms of heat and electricity is generated in combined heat and power plants. The objective of this study was to assess the environmental impacts of biogas production systems based on the methods of life cycle assessment. A comparison to the traditional use of agricultural manures and conventional energy production was included. A model was designed to evaluate the biogas production systems according their environmental impact using Gabi 4.3 software. Besides global warming potential other impact categories have been used for the evaluation of the effects of the systems in the field of eutrophication and acidification. The results show that environmental benefits can be obtained in regard to the emission of greenhouse gases when comparing electricity production from biogas with the typical German marginal electricity mix.

Keywords: biogas, anaerobic digestion, LCA, life cycle assessment, GHG, greenhouse gases, agricultural energy production, environmental impact

INTRODUCTION Due to (IPCC 2007) agriculture contributed with a share of 13.5% to global anthropogenic greenhouse gas (GHG) emissions in the year 2004. Concerning Germany the Federal Environment Agency (UBA) states that from 2003-2007 the annual emission of CH₄ related with manure management accounted for 260000 tons of overall agricultural GHG emissions (UBA 2009a). Emissions from manure storage can be avoided when using the manure as an input substrate for anaerobic digestion. When the produced biogas is used in a combined heat and power plant (CHP) for generation of electricity and heat, emissions from conventional production systems are avoided by substitution. This study uses the method of Life Cycle Assessment (LCA) to illustrate in which amount biogas production can contribute to a reduction of environmental impacts under German conditions.
MATERIALS AND METHODS

The study is methodologically based on the international standards for life cycle assessment (ISO14040 2006; ISO14044 2006) according to the 2006 version. A model from biogas production at an exemplary biogas plant was build with the software GaBi 4.3 using the EcoInvent-database and data from a research biogas plant of the University of Hohenheim, Germany. Aim of the research was to assess the environmental impacts of biogas production—including generation of heat and electricity—at the biogas plant of the research facility. Chosen as the functional unit (FU) was the production of a quantity of biogas with a calorific value of 1 MJ and usage in a CHP with the final products heat and power. System boundaries encompass the supply of the energy crops, usage of biogas digestate as a fertilizer and also heat and electricity production in a CHP. The time frame is 12 months that split over 2008/2009. Site specific data was used wherever available and added with information from EcoInvent-database mainly in regard to production of energy crops as biogas substrates and transport processes. System expansion was used to deal with (by-)products of the system. In Germany, the marginal mix of conventional power generation based on lignite, anthracite, natural gas and mineral oil each with a share of 1%, 66%, 32% and 1% in 2007, was substituted by the electricity generated from biogas (UBA 2009b). Because of the fact that recent data for the years 2008/2009 is not available yet, the electricity mix mentioned above was used to model the reference system for electricity generation. Statistical data provided by (BMELV 2009) names the most important domestic sales regarding mineral fertilizers in Germany in the business year 2007/08. When considering straight fertilizers these are: calcium ammonium nitrate for N, super phosphate for P₂O₅ and potassium chloride for K₂O. Therefore the assumption in this study is that the plant available part of the nutrients in the biogas digestate replaces these mineral fertilizers and is credited. Supposed to be plant available is a share of 80% for N and 100% for P₂O₅ and K₂O (LTZ 2008; Sensel 2008). The part of digestate which is residue from manure digestion is used for fodder production and hence is excluded from this credit. Production data concerning mineral fertilizers are taken from the EcoInvent 2.0 database (Ecoinvent 2004). Field emissions from biogas digestate are calculated as 30% of NH₄-N as NH₃ based on (Leick 2003; Schäfer 2006) and 1 % of remaining N as N₂O (IPCC 2006), while diffuse CH₄-emissions from the digester are assumed to be 1%. At the research farm where the biogas plant is located a natural gas burner and a mineral oil burner were used for generating heat before the CHP with an electrical power of 186 kW was installed. Because no operating data from the oil burner was available it was assumed in this study that CHP-heat substitutes heat from a gas burner. The electrical power generated is fed to the national electricity grid. The electricity requirement of the biogas plant was calculated with 9.8% of the total electricity produced, heat requirement with 18% of heat produced, both based on measurements at the research facility. An overview of the system under research and the reference systems is given in figure1.
The input substrates used in the digesters are liquid manure, solid manure, maize silage, grass silage and grain with a total annual input of 7155t. Based on on-site measurements the emissions factors for the CHP were calculated (LUBW 2008). These factors and the mass input of the single input-substrates are shown in Table 1.

The method for impact assessment used was CML 2001 as released in 2007. The impact assessment categories described in this paper are global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP).
RESULTS AND DISCUSSION

The results show that GHG emissions can be reduced when using agricultural manures (liquid and solid) as an input substrate for anaerobic digestion with additional usage of biogas in a CHP, the final products being heat and electricity (figure 2). The amount of GHG savings related with biogas production at research plant is 98.9g CO2-eq./MJ biogas. Emission credits as well as burdens contribute to the final result. The highest credit concerning GHG emissions was 97.12g CO2-eq./MJ biogas due to the replacement of traditional fossil fuel power plants (the marginal electricity mix) by biogas power plants. Furthermore a significant GHG reduction can be related to the utilization of CHP heat (31.3g CO2-eq./MJ biogas) and the replacement of mineral fertilizers (2.8g CO2-eq./MJ biogas). The influence of the digestate storage can be quite significant. A research at 61 biogas plants in Germany has analyzed the gas production potential of biogas digestates with results in a range from 0.1 to 21.8% of total methane yield (vTi 2009). Gärtner et al. (2008) assess the CH4-emissions from an uncovered digestate storage tanks in a range from 2.5 to 15%. These values have also been used in the calculation presented here. Due to the uncertainties in literature values it is difficult to specify the exact amount of GHG emissions from an uncovered storage tank and the influence on GWP of biogas production systems. But figure 3 indicates that the reduction potential of the entire process (biogas production including electricity and heat generation) could decrease to about one fifth of the current result if the storage tank would not be covered gas-proof.

Figure 2: Global Warming Potential (GWP), eutrophication potential (EP) and acidification potential (AP) of biogas production at research plant

Regarding other environmental impacts the results differ from GWP. Both EP and AP values have increased with biogas production. In both cases this is mainly caused by the cultivation of energy crops when compared with fallow land. This procedure was chosen as a first conservative approach to analyze the biogas production system. The main
credits correlated with AP and EP were given for the avoided manure storage and marginal power production. Besides crop production, digestate usage and the operation of the CHP causes considerable emissions.

Figure 3: Influence of covering digestate storage tank by CH₄ leakage on GWP of biogas production

An important difference in the total CH₄ emission of the CHP results from the emission factor used. There is a wide spread in literature that ranges from about 0.5 to 3.74 % of CH₄-production of the biogas plant for methane slip (Woess-Gallasch et al. 2007). In the LCA of this study CH₄-emissions from CHP were calculated with 1.58% based on on-side measurements (LUBW 2008). This results in a total annual CH₄ emission of 101t CO₂-eq. at CHP (figure 4). Calculated with literature values instead of measured data the emission ranges from 28.7 to 239t CO₂-eq annually. Obviously there is a nameable uncertainty included in the GHG emission when calculated with literature values instead of measured ones.
Figure 4: Comparing CH₄ emissions of CHP using measured data and literature values

CONCLUSION

The research demonstrates that anaerobic digestion is a practicable solution for the reduction of greenhouse gases related with manure management. Furthermore the generation of electricity from biogas in a combined heat and power plant is advantageous when compared with electricity generation in conventional power plants. To achieve the aim of GHG reduction it is helpful to close the digestate storage tanks of biogas plants gas-proof. Nevertheless further research is needed to determine the exact emission rates from uncovered digestate storage tanks because at present there is a huge spread in literature values. To estimate the total amount GHG savings it is helpful to use data from on-site measurements instead of literature values because uncertainties are reduced thereby.

At present state of the research fallow land was chosen as a reference system for production of energy crops. Because not all energy crops for biogas production are cultivated on fallow land, a next step will be to compare with other reference systems for energy crop cultivation. To fulfill this requirement a reference system for cultivation of energy plants has to be specified, fulfilling the same functions than energy plant cultivation for biogas production. It is highly expected by the authors that EP and AP results then will decrease when compared with the current analysis presented.

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