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Review of life cycle assessment for biogas production in Europe

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ABSTRACT

Resource strategy concerns and the need for mitigation of environmental impacts associated with energy generation from fossil fuels have increased the deployment of renewable energy carriers such as biogas. Biogas has beneficial environmental aspects such as waste treatment, production of energy from waste and general substrates and a better way to spread the fermented residues through improved nutrient and flow abilities. The objective of this study was to assess the status of biogas production and its effects on the environment due to greenhouse gases (GHG) and other environmental impacts. In this work, 15 life cycle assessment (LCA) studies of biogas systems from around Europe were reviewed. Biogas scenarios in all the studies had lower GHG intensities than their reference systems.

The study shows that the type of feedstock, *e.g.*, maize, grass or animal manure is a determining factor for the environmental impacts of biogas systems. Improving biogas plant technology and management by collecting the biogas during the storage of digested residues or installing a gas flare will improve the greenhouse gas balance of biogas systems. In comparison with traditional manure storage, anaerobic digestion of animal manure avoids methane (CH_4) and nitrous oxide (N_2O) emissions and adds to the substitution of artificial mineral fertilizer. Apart from the impacts resulting from the production of energy crops, acidification (AC) and eutrophication (EP) from biogas systems could be reduced by using combined heat and power units (CHPU) with catalytic converters and high efficiency.

Contents

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1. Introduction

Worldwide, fossil fuels are by far the most prominent energy carriers providing about 80% of total energy consumption [1]. Obviously, this is in conflict with the necessity to curb the utilization of fossil energy resources due to their immense environmental impacts, particularly the emission of greenhouse gases (GHG) and pollutants [2]. With limited availability of easily accessible fossil fuels and growing demand at the same time, the exploitation of so-called unconventional fossil resources is becoming economically viable, which is associated with even higher risks for sensitive ecosystems and less favorable energy input-to-output ratios. It appears that a sustainable energy system is impossible to achieve based on fossil resources. Therefore, alternative energy resources need to be developed at a growth rate that clearly transcends that of global energy demand.

In 2009, biomass contributed 13.1% of global energy demand [1]. The total global primary energy supplied from biomass reached approximately 55 EJ in 2012 [4]. Heating accounted for the vast majority of the use of biomass (46 EJ), including heat produced from modern use of biomass (biofuels) and traditional uses in the form of wood and peat [4]. By the end of 2012, global bio-power capacity was approaching 83 GW. The United States had a substantial lead with 62 TW h yr^{-1}, followed by Germany with 37 TW h yr^{-1}, Brazil with 36 TW h yr^{-1} and China with 27 TW h yr^{-1} [4]. In Europe, biomass currently accounts for 2/3 of renewable energy and will play a key role in achieving the target approved by the renewable energy directive of 20% of final energy consumption based on renewable sources by 2020 [5]. In Germany, biomass accounted for approx. 8.2% of the primary energy demand in the year 2013 [6]. By 2050, Germany aspires to cover 80% of its electricity consumption from RES [3].

Examples of biofuels produced from biomass include bioethanol, biodiesel and biogas. Currently, Germany is the world leader in the deployment of biogas technology and plays the leading role in the European biogas market [7]. The number of biogas plants in Germany increased from 1050 in 2000 to 7850 in 2013. With respect to overall biogas production, Germany is followed by the United Kingdom, France, Italy and the Netherlands [8]. Biogas is utilized in combined heat and power (CHP) units to produce electricity and heat. In 2013, primary production of biogas in Europe (including landfill and sewage gas) was an estimated 13.4 million tons of oil equivalents (Mtoe) [9].

In order to assess the environmental impacts that are associated with producing and utilizing biogas as an energy carrier, the method of Life Cycle Assessment (LCA) can be applied [10]. A lot of LCA studies in Europe and worldwide focused on biogas production systems. This should provide a solid knowledge base for both policymakers and engineers to improve the efficiency of such systems and reduce their environmental impacts [11,12]. At the same time, comparing different LCA studies can be challenging due to differences in scope and a lack of documentation. The goals of this review were as follows:

- Summarize the current knowledge of the methodology of LCA-studies of agricultural biogas systems,
- Systematically compare different LCA-studies of agricultural biogas systems to get a rigorous review,
- Make a synthesis of the results and conclude on the status of environmental impacts associated with biogas production in Europe in order to identify measures for reducing GHG and other emissions from biogas systems.

2. Application of LCA to biogas systems

For this paper, 15 LCA-studies of biogas systems from around Europe were reviewed.

The studies were selected according to the following requirements:

- An environmental analysis of the biogas life cycle must be the main or at least one of the main objectives of the study;
- Mass input into biogas plants should contain energy crops, animal waste, or organic waste;
- In order to reflect the actual state of the art and recent developments, only studies starting from the year 2001 were included;
- Only original studies where methods and/or results originate from the authors and not from literature and/or Ph.D. and Master Theses;
- Only studies in Europe due to the similar natural conditions in these countries;
- From each country, a maximum of two papers, except for Germany which has much more biogas plants than all other European countries;
- The study must include at least the impact category global warming potential (GWP);
- Studies must be based on the LCA methods described in the ISO 14040 and 14044 [13,14];
- No duplications; economic or social impacts were not considered.

As a standardized method, the process of performing a LCA is divided into four steps, as summarized in the following with respect to biogas systems.

2.1. Goal and scope definition

The general goal of LCA for biogas energy systems is to determine the environmental impacts of producing and utilizing biogas as an energy source, *i.e.*, energy and material requirements as well as emissions to the (biotic and abiotic) environment.

Different biogas LCA studies have one or more of the following specific goals:

- Assess the environmental impact from biogas production and derive measures to reduce them;
- Compare different feedstock for biogas production and identify optimal mixtures with respect to environmental and economic aspects;