Science of the Total Environment 463–464 (2013) 541–551

Contents lists available at ScienceDirect

Science of the Total Environment

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

Anaerobic digestion of different feedstocks: Impact on energetic and environmental balances of biogas process

Jacopo Bacenetti [a,*], Marco Negri [a], Marco Fiala [a], Sara González-García [b,c]

[a] Department of Agricultural and Environmental Sciences — Production, Landscape, Agroenergy, University of Milan, 20133 Milan, Italy
[b] CESAM, Department of Environment and Planning — University of Aveiro, 3810-193 Aveiro, Portugal
[c] Department of Chemical Engineering, School of Engineering, University of Santiago de Compostela, 15782 Santiago de Compostela, Spain

HIGHLIGHTS

- Environmental impact of electricity from biogas in Italy
- Energy and GHG emission balances were assessed for 3 biogas plants.
- Alternative scenarios: heat valorization, different reference systems for electricity
- Electricity from biogas saves GHG emissions and fossil fuel use.
- Critical factors are: energy crop production, methane losses, feedstock transport.

ARTICLE INFO

Article history:
Received 6 April 2013
Received in revised form 12 June 2013
Accepted 13 June 2013
Available online 5 July 2013

Editor: Pavlos Kassomenos

Keywords:
Biogas
Greenhouse gas (GHG) emission
Environmental sustainability
Climate Change

ABSTRACT

The possibility of limiting the global warming is strictly linked to the reduction of GHG emissions. Renewable energy both allows reducing emissions and permits to delay fossil fuel depletion. The anaerobic digestion of animal manure and energy crops is a promising way of reducing GHG emissions. In Italy agricultural biogas production was considerably increased; nowadays there are about 520 agricultural biogas plants.
The increasing number of biogas plants, especially of those larger than 500 kW_e (electrical power), involves a high consumption of energy crops, large transport distances of biomass and digestate and difficulties on thermal energy valorization.
In this study the energetic (CED) and environmental (GHG emissions) profiles associated with the production of electricity derived from biogas have been identified. Three biogas plants located in Northern Italy have been analyzed. The study has been carried out considering a cradle-to-grave perspective and thus, special attention has been paid on the feedstock production and biogas production process. The influences on the results taking into account different plant sizes and feeding rate has been assessed in detail.
Energy analysis was performed using the Cumulative Energy Demand method (CED). The climate change was calculated for a 100-year time frame based on GHG emissions indicated as CO_2 equivalents (eq) and defined by the IPCC (2006).
In comparison to the fossil reference system, the electricity production using biogas saves GHG emissions from 0.188 to 1.193 kg CO_2eq per kWh_e. Electricity supply from biogas can also contribute to a considerable reduction of the use of fossil energy carriers (from −3.97 to 10.08 MJ_{fossil} per kWh_e). The electricity production from biogas has a big potential for energy savings and reduction of GHG emissions. Efficient utilization of the cogenerated heat can substantially improve the GHG balance of electricity production from biogas.

1. Introduction

Throughout the years, the attention on the quantification of the environmental impacts derived from agricultural production systems has increased considerably. The agricultural contribution to greenhouse gas (GHG) emissions is undeniable (Intergovernmental Panel on Climate Change [IPCC], 2007). Agricultural activities are responsible for 405 $MtCO_2$eq per year (10% of the total Europe GHG emissions). Nitrous oxide emissions (from fertilizer application and manure management) represent approximately 210 $MtCO_2$eq, while methane emissions (from enteric fermentation, manure management, and rice cultivation) account for about 195 $MtCO_2$eq (De Cara et al., 2005). Furthermore, considering the European objectives regarding the reduction of fossil fuel consumption and GHG emissions, the production of energy from renewable sources is a priority (European Parliament, 2009, 2010).

* Corresponding author. Tel.: +39 250316869; fax: +39 250316845.
E-mail address: jacopo.bacenetti@unimi.it (J. Bacenetti).

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http://dx.doi.org/10.1016/j.scitotenv.2013.06.058

Interest in the different agro-energy processes, including biogas production, is still increasing (González-García et al., 2012). In Europe in 2011, renewable energy sources (RES) produced 676 TWh of electric energy. This figure is equivalent to 20.6% of the gross electricity consumption. Among the RES, hydraulic power represents 46.0%, wind power 26.5%, biomass 19.7%, solar power 6.9%, and geothermal power and ocean energies 0.9% (EurObserv'ER, 2012).

In Italy, energy production from RES was already 9% in 2009; in 2010, it was >10%; and in 2011, it reached 11.6%. In particular, in Italy, 100 TWh per year should be produced by RES to cover the 26% of electric consumption (Ministero Sviluppo Economico, 2012). By the end of 2011, the installed electric power assured the production of 94 TWh per year. In this scenario, the anaerobic digestion (AD) of different feedstock appears to be one of the more promising ways to meet the European objectives (Ministero Sviluppo Economico, 2012).

In Italy, during the past 10 years, agricultural biogas production was considerably increased, and nowadays, more than 520 agricultural biogas plants are running mainly in northern regions (Piccinini, 2012). In 2011, biogas produced 3405 GWh of electricity (EurObserv'ER, 2012). Strong public incentives are granted for electricity produced from biogas. From 2013 with the (D.M. 6 July 2012) (Ministero Sviluppo Economico, 2012) the public incentives framework for electricity production from biogas has been updated giving more importance to heat valorization and byproducts utilization. Nevertheless, for the biogas plants put into operation before 31 December 2012 and with electrical power lower than 1 MWe, 280 €/MWh$_e$ are granted for the electricity fed into the grid without any consideration regarding heat valorization and byproduct utilization for feeding. Thus, despite the possibility of using biogas for thermal generation or upgrading it to biomethane, due to the incentives, biogas is usually utilized to feed combined heat and power generation plant (CHP) engines and therefore converted into electricity and heat.

Regarding the feeding of digesters, although the AD of animal manure is one of the best techniques for an energetic valorization of these by-products (Angelidaki and Ellegaard, 2003; Edelmann et al., 2005; Maranon et al., 2011; Pantaleo et al., 2013), most biogas plants are fed with energy crops. The cereal silages are the main feedstock for biogas production, both in Italy and in other European countries (Comino et al., 2009; Moriizumi et al., 2012; Patterson et al., 2011; Hartmann, 2006; Dressler et al., 2012). However, biogas plants can use manure in co-digestion with energy crops. The co-digestion of different feedstock results in benefits that come from the AD of manure (energy generation, organic matter stabilization, and reduction of methane emissions during storage) with the increment of the CHP electrical power and the reduction of digester volumes (Bystricky et al., 2010).

Although the AD of agricultural feedstock can be performed with different types of biogas plants (Fabbri et al., 2011), the most widespread technology is characterized by mesophilic conditions and single-stage digestion in continuous stirred-tank reactors [CSTR] (Fantozzi and Buratti, 2009a, 2009b).

Biogas production involves important environmental issues, especially global warming, acidification, and eutrophication potentials (Dressler et al., 2012; Meyer-Aurich et al., 2012). Many studies have been conducted concerning the environmental sustainability and performance of biogas production systems (Edelmann et al., 2005; Appels et al., 2011; Tricase and Lombardi, 2012; Pertl et al., 2010; Dressler et al., 2012; Pöschl et al., 2012) as well as biogas conversion into electricity (Hartmann, 2006; Benetto et al., 2010). In particular, special attention has been paid on GHG emissions (Clemens et al., 2006; Rehl and Muller, 2013; Dressler et al., 2012) and energy balance (Börjesson and Berglund, 2007; Benetto et al., 2010; Kimming et al., 2011; Dressler et al., 2012) related to these bioenergy systems. Most of these studies have performed these assessments following the life cycle assessment (LCA) methodology, a standardized and holistic method that allows for identifying the environmental consequences of the life cycle of a product, process, or activity by evaluating the potential environmental impacts throughout its whole life cycle production chain (ISO 14040, 2006).

The increasing number of biogas plants, especially those larger than 500 kW electrical power, involves a high consumption of energy crops, large transportation distances from both the input side (biomass feedstock) and the output side (digestate), and difficulties with thermal energy valorization (Chevalier and Meunier, 2005). The issues listed above may play different roles depending on the size of the biogas plant and the type of biomass used (Pöschl et al., 2010, 2012).

This study aims at assessing the sustainability of the electricity production from biogas considering different types of feedstock and biogas plant sizes. Thus, a full overview of feedstock production as well as of biogas conversion into electricity in Italy must be presented. The sustainability has been assessed in terms of the two concerns established by European Union (European parliament and council, 2003): energy demand and GHG emissions throughout their life cycles.

2. Materials and methods

LCA is a methodological framework for quantifying and assessing the environmental impacts attributable to a product's life-cycle—that is, from raw material acquisition—through the production and use phases to waste management at the end of life, which is known as a "from-cradle-to-grave" analysis (ISO 14040, 2006). LCA is an objective process for evaluating the environmental burdens associated with a product by identifying natural resource consumption and emissions to environmental compartments and for identifying and implementing opportunities to attain environmental improvements. The present study concerns the assessment of electricity production from biogas.

2.1. Goal and scope

As mentioned, the goal of this study is the assessment of the energy and the GHG emission balances of the production of electricity from biogas in northern Italy under different real scenarios based on different feedstocks and biogas plant sizes.

Therefore, following LCA guidelines, three biogas-to-energy processes have been analyzed and carefully assessed in order to quantify the environmental effects and to identify the environmental key process (ISO 14040, 2006). Considering that feedstock production or recovery involves important environmental issues (González-García et al., 2013) particular attention was paid to the agricultural subsystem. The production of an energy crop (maize) in different districts of northern Italy as well as the recovery of pig slurry was evaluated in detail.

The AD of two different feedstocks (pig slurry and maize silage) in three biogas plants located in the Po Valley area and characterized by different amounts of electrical power were assessed in order to identify the system with the highest energetic benefit and environmental friendliness.

2.2. Functional unit

Biogas production systems have two main functions: i) the digestion of organic material into biogas and ii) the subsequent use as fuel for electricity and/or heat generation. In this study, two different functional units have been chosen for calculations. For the feedstock production and harvesting/collection phase, the functional unit was defined as 1 t of fresh matter. Also, 1 kWh of electricity (kWh$_e$) produced in a CHP using biogas was the functional unit (FU) for the entire electricity production system. The selection of these FUs is in agreement with other biogas LCA studies (Dressler et al., 2012; Pöschl et al., 2012; Bacenetti et al., 2012a, 2012b).