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Environmental assessment of farm-scaled anaerobic co-digestion for bioenergy production

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ABSTRACT

The aim of this study was to assess the environmental profile of a bioenergy system based on a co-digestion plant using maize silage and pig slurry as substrates. All the processes involved in the production of bioenergy as well as the avoided processes accrued from the biogas production system were evaluated. The results evidenced the environmental importance of the cultivation step and the environmental credits associated to the avoided processes.

In addition, this plant was compared with two different plants that digest both substrates separately. The results revealed the environmental benefits of the utilisation of pig slurry due to the absence of environmental burdens associated with its production as well as credits provided when avoiding its conventional management. The results also presented the environmental drawbacks of the utilisation of maize silage due to the environmental burdens related with its production. Accordingly, the anaerobic mono-digestion of maize silage achieved the worst results. The co-digestion of both substrates was ranked in an intermediate position.

Additionally, three possible digestate management options were assessed. The results showed the beneficial effect of digestate application as an organic fertiliser, principally on account of environmental credits due to avoided mineral fertilisation. However, digestate application involves important acidifying and eutrophicating emissions.

1. Introduction

A sustainable society requires the affordable access to energy sources for key services such as lighting, housing, mobility and communication (IPCC, 2011). The European Union is facing unprecedented energy challenges resulting from its dependency on imported fossil fuels and their influence on climate change (Commission of the European Communities, 2006). The availability of different bioenergy production systems should be a main pillar towards the creation of a new energy scheme (Cherubini and Strømman, 2011). The European policy concerning renewable energy has set a goal for supplying 20% of the European energy demand from renewable energy sources by 2020 (EU, 2009).

Biogas, produced from the anaerobic digestion of organic matter, is an option of increasing interest with an expected production of 25% of the bioenergy in the future (Holm-Nielsen and Oleskowiez-Popiel, 2008). Energy production from biogas has increased all over Europe in recent years (EurObserv'ER, 2010). European countries where the agricultural biogas is most developed are Germany, Italy, Denmark, Austria and Sweden (Holm-Nielsen et al., 2009). Biogas production from animal manure has been proved to reduce greenhouse gas (GHG) emissions, especially ammonia and methane derived from manure storage facilities (Holm-Nielsen and Oleskowiez-Popiel, 2008). In addition, it avoids the pollution of surface and ground water resources (Holm-Nielsen and Oleskowiez-Popiel, 2008). Beyond the benefits aforementioned, the anaerobic digestion of biomass produces renewable energy and organic fertiliser, which implies reduction in the demand of mineral fertilisers (Berglund, 2006; Carrosio, 2013).

Public policies have played an important role in stimulating and shaping the spread of biogas plants. For example, in Italy important incentives are given for electricity production from biogas such as green certificates and feed-in tariffs (Carrosio, 2013). As a result, there are more than one thousand farm-scale biogas plants in this country (Fabbri et al., 2013), mainly located in the Po Valley region (Northern Italy). This area is characterised by a high concentration

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of large livestock farms and intensive cultivation of cereals (Carrosio, 2013). Around 18% of Italian biogas plants process livestock manure, 20% cereal crops and 62% use both types of feedstock (Carrosio, 2013). There is a reason behind this distribution: the anaerobic digestion of manure renders lower biogas yield than other substrates such as energy crops (Holm-Nielsen et al., 2007). To counteract this drawback, higher biogas yield can be achieved through its co-digestion with other substrates such as cereal crops (De Vries et al., 2012b). Thus, feedstock choice is an important factor to determine the power capacity of the plant (Carrosio, 2013).

Life Cycle Assessment (LCA) is an internationally accepted method to gain insight into the environmental aspects of a product or system (ISO 14040, 2006). A number of LCA studies can be found in the literature analysing the environmental performance of biogas based systems. In these studies, large variations in energy performance and environmental impacts were found among the different biogas systems, which can be attributed to the variability of feedstock, different cultivation systems of energy crops (Bauer et al., 2010; Dressler et al., 2012), final use of energy or management schemes for the digestate (Börjesson and Berglund, 2007; De Vries et al., 2012b; Dressler et al., 2012; Poeschl et al., 2012). Hence, it is not possible to draw any general conclusion on the environmental impact of bioenergy production without clearly defining the system boundaries considered (Berglund, 2006).

The objective of this study was to assess the environmental performance of a co-digestion plant operating with pig slurry and maize silage. The analysis included the assessment and quantification of inputs, energy flows and emissions during the entire life cycle of the biogas production and use. Moreover, the main factors with the largest impacts on the environmental performance and energy produced were identified and analysed in detail. The main outcomes of the anaerobic co-digestion process were compared with anaerobic mono-digestion in order to understand the opportunities offered by the simultaneous digestion of two or more different feedstocks.

2. Materials and methods

An LCA study largely depends on the assumptions made regarding data quality, system boundaries and allocation method. Awareness of the implications of these methodological aspects is therefore important in properly interpreting the results (Berglund, 2006).

2.1. Methodology

LCA has been the methodology selected for the environmental analysis performed in this study. LCA is a standardised method which guarantees the reproducibility of the results obtained (ISO 14040, 2006; ISO 14044, 2006).

For this purpose, detailed data regarding the consumption of natural resources and the emissions to air, water and soil linked to the life cycle of the product was collected, from raw material acquisition through the phases of production and use to waste management (ISO 14040, 2006).

2.2. Goal and scope definition

As aforementioned, the goal of this study was to evaluate the environmental profile of a biogas based bioenergy system from a cradle-to-gate perspective. To do so, a real Italian biogas plant which co-digests pig slurry and maize silage was assessed in detail. Specific objectives included the identification of the most critical stages (environmental *hotspots*) in order to identify opportunities to attain environmental benefits as well as to compare the environmental performance of this biogas plant with two plants in which pig slurry and maize silage are digested separately (Lijó et al., 2014).

The Po Valley is the most important Italian agricultural area and it also comprises the most industrialised regions of Northern Italy (Piedmont, Lombardy, Emilia Romagna and Veneto). The plant under study is located in the district of Vercelli (Piedmont region). It has an electrical power of 999 kWe and codigests maize silage (55% in mass) and pig slurry (45% in mass). The life cycle environmental impacts were determined by building a Life Cycle Inventory (LCI), that is, the identification and quantification of all relevant inputs and outputs flows of the bioenergy system.

2.3. Functional unit

According to the ISO standards, the functional unit (FU) is defined as the main function of the system expressed in quantitative terms and provides the reference to which all the inputs and outputs of the product system are calculated (ISO 14040, 2006). The main function of this bioenergy system is the production of biogas and its further conversion into electricity and heat. Therefore, the FU chosen was the average biogas production per day: 11,436 m^3 of biogas.

2.4. Description of systems under assessment

The system boundaries define which processes are included in the analysis. The system was subdivided in different subsystems (abbreviated as SS) for better understanding. The system boundaries include maize biomass production (SS1), feedstock supply (SS2), bioenergy production (SS3) and digestate management (SS4) as well as avoided processes such as conventional management of pig slurry, electricity production and mineral fertilisation. The study comprises the production of inputs used in these processes, such as chemicals, diesel fuel, electricity and infrastructure. All processes considered within the bioenergy system under study are outlined in Fig. 1.

As shown in Fig. 1, the production of pig slurry was excluded from the system boundaries because it was considered as a waste from pig breeding farms. Therefore, its production is independent of its utilisation as a fuel for anaerobic digestion (De Vries et al., 2012a).

2.4.1. SS1: Maize biomass production

This subsystem includes all agricultural activities involved within the cultivation of maize, from field preparation to the harvesting operations. Maize is extensively cultivated in the Po Valley region for both energy and food/feed purposes (Fabbri et al., 2013; González-García et al., 2013). Nevertheless, mainly due to the Italian subsidy framework for electricity generation from renewable sources, most biogas plants built in Italy before 2013 are fed with cereal silage and, in particular, with maize silage since it is the most productive energy crop. Specifically, strong public incentives were granted for electricity produced from biogas plants operating before 31 December 2012 and with an electrical power lower than 1 MW (280 € MW h^{-1} of electricity fed into the grid). From 1 January 2013, the incentives (236 € MW h^{-1} of electricity fed into the grid) are granted to plants with an electrical power lower than 300 kW, fed mainly with by-products (minimum 70% of the biomass fed to the digesters) (Negri et al., 2014). As a result, around 10% of total maize cultivation in this area is dedicated to biogas production (Casati, 2013). Thus, in this study it was assumed that the maize requirement for food and feed is completely satisfied. Nitrogen and phosphorus emissions derived from the application of fertilisers (digestate and urea) were also