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Assuring the sustainable production of biogas from anaerobic mono-digestion

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ABSTRACT

This study aims to analyse the potential environmental benefits and impacts associated to the anaerobic mono-digestion of two different substrates (pig slurry and maize silage). The Life Cycle Assessment methodology was applied in two full-scale Italian biogas plants (Plant A - pig slurry and Plant B - maize silage) in order to calculate the environmental profile of both systems with the aim of identifying the most suitable alternative from an environmental point of view. The study also includes credits due to avoided processes such as electricity production from the grid and mineral fertilisation as well as the conventional management of pig slurry regarding Plant A.

The main outcomes show the importance of the feedstock composition on the environmental performance of these systems. While the assessment of Plant A ended up in environmental benefits in all impact categories as a consequence of credits related to replaced processes, its capacity for bioenergy production was limited. On the contrary, the use of maize silage as substrate provided a larger production capacity but it was also associated to negative environmental impacts. In this system, the cultivation of maize showed up as the largest responsible of the environmental impacts, specifically due to diesel fuel consumption in agricultural activities as well as on-site emissions linked to the application of fertilisers.

A sensitivity analysis proved that the environmental profile of these bioenergy systems could be improved through surplus heat use as well as technological improvements such as the replacement of the traditional dehumidification unit by a chiller.

1. Introduction

Climate change is the most imminent environmental issue the world is facing today (Appels et al., 2011). There is a general consensus that global warming is mainly caused by greenhouse gases (GHG) of anthropogenic origin (Appels et al., 2011). GHG emissions associated to energy are the most important (~80% of the total), being electricity and heat production the largest emitting sector, followed by transport (European Environmental Agency, 2008). The production and use of renewable energy may help mitigate climate change and also reduce dependence on fossil sources (Cherubini and Strømman, 2011). In line with this, the European energy policy has the target of increasing the share of renewable energy to 20% by 2020 (European Parliament, 2009).

The interest on the biogas production for bioenergy generation is increasing since it provides a clean and decentralized source of energy from renewable feedstock. Biogas is a biofuel which can be obtained from the anaerobic digestion (AD) of a wide range of organic feedstocks, mainly organic waste from agriculture, livestock, industries and households (Igliński et al., 2012; Bacenetti et al., 2014). The largest source of organic waste available in Europe for biogas production is animal manure (Holm-Nielsen et al., 2009). Several agricultural, environmental and socio-economic benefits ranging from the improvement of the fertiliser quality, reduction of odour and pathogens and its valorisation as biogas are associated to the anaerobic digestion process (Holm-Nielsen et al., 2009). In parallel to animal manure, special attention is being paid on the use of energy crops as potential feedstock due to their high content of volatile solids, which renders high biogas yields (Jury et al., 2010). In terms of physical and chemical characteristics, energy crops are more homogeneous than organic wastes (Panoutsou, 2007). Therefore, dedicated crops such as

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Abbreviations

AD	anaerobic digestion
LCI	life cycle inventory
FU	functional unit
SS1	subsystem 1
SS2	subsystem 2
SS3	subsystem 3
SS4	subsystem 4
CHP	combined heat and power
CSTR	continuous stirred tank reactor
VS	volatile solids
CC	climate change
OD	ozone depletion
TA	terrestrial acidification
FE	freshwater eutrophication
ME	marine eutrophication
POF	photochemical oxidant formation
ALO	agricultural land occupation
FD	fossil depletion
AEP	avoided electricity production
ACM	avoided conventional management
BC	base case
AS	alternative scenarios
AS1	alternative scenario 1
AS2	alternative scenario 2
AS3	alternative scenario 3

maize, wheat, triticale and sugar beet are being largely cultivated for energy purposes.

Moreover, biogas production involves the production of a valuable co-product such as digestate, a stream rich in nutrients which could be used as an organic fertiliser for crop cultivation in substitution of mineral fertilisers (Holm-Nielsen et al., 2009). The use of digestate would also allow returning nutrients back to the soil (Abubaker et al., 2012).

As a result, many agricultural biogas plants have been built in Europe in order to produce electric and thermal energy, especially in Germany, Denmark, Austria, Sweden and Italy (Bacenetti et al., 2013; Holm-Nielsen et al., 2009). Focussing on Italy, strong public incentives have been granted for electricity produced from biogas (Ministerio dello Sviluppo Economico, 2012). Accordingly, there are around 1000 biogas plants in the Italian agricultural sector. Most of them are in the northern regions such as Lombardy, Emilia Romagna and Veneto, where the largest number of livestock farms are located (Bacenetti et al., 2014).

Although biogas production arises as a clean and environmental safe alternative for energy production, it is important to quantify the environmental impacts associated to this process. Life Cycle Assessment (LCA) is an internationally accepted method to gain insight into the environmental consequences of a product or system (ISO 14040, 2006). This methodology has been widely used to assess the environmental profile of bioenergy production systems and numerous studies can be found in literature (Jury et al., 2010; Lansche and Müller, 2012). In these studies, bioenergy systems provide good opportunities to achieve environmental benefits when fossil fuels are replaced or when they are compared with conventional waste management schemes (Börjesson and Berglund, 2007). However, it is interesting to highlight that the environmental performance of a bioenergy system from biogas is considerably affected by the feedstock considered, the final use of the biogas and the management of the digestate (Poeschl et al., 2012a,b).

Therefore, the aim of this study was to assess the environmental performance and energy requirement of two different biogas production systems based on the consideration of pig slurry and maize silage as feedstock.

2. Materials and methods

2.1. Methodology

LCA is a methodological framework useful to determine the environmental impacts of a system, product or activity (ISO 14040, 2006). LCA features a high developed methodology, which includes the emissions of pollutants and material and energy consumptions from raw material acquisition, through the production and use phases to waste management.

2.2. Goal and scope definition

As mentioned, the goal of this study was to evaluate from a cradle-to-gate approach the environmental profiles of two different bioenergy systems (biogas to electricity). To do so, two real Italian biogas plants which feature anaerobic mono-digestion were assessed in detail following the ISO standards (ISO 14040, 2006).

Table 1 encompasses technical data related to the plants under study including feedstock and electrical power capacity (kW_e). Plant A is located in the district of Lodi and performs the anaerobic mono-digestion of pig slurry. Northern Italy is one of the most important European regions for livestock production (in particular milk cows and pigs) (Eurostat; Holm-Nielsen et al., 2009). Consequently, the interest on biogas plants with manure as feedstock is based on the wide availability of pig slurry. Plant B is located in the district of Pavia and uses maize silage as feedstock. This plant was selected because maize is the most commonly energy crop used for biogas production in Europe due to its high yield of dry matter per hectare and high potential of methane production (De Vries et al., 2012b; Dressler et al., 2012).

The life cycle environmental impacts of both plants were determined by building a Life Cycle Inventory (LCI), that is, the identification and quantification of all relevant inputs and outputs flows of each system. Specific objectives included the identification of the most critical stages (environmental *hotspots*) in both bioenergy systems in order to identify opportunities to attain environmental benefits.

2.3. Functional unit

According to ISO standards, the functional unit (FU) is defined as the main function of the system expressed in quantitative terms (ISO 14040, 2006). The main function of these bioenergy systems is the anaerobic digestion of feedstock for biogas production in order to cogenerate electricity and heat. Therefore, the FU chosen was 1 t of feedstock mixture fed to the digester.

2.4. Description of systems under assessment

Fig. 1 outlines the main processes considered within each bioenergy system. All processes involved in both bioenergy systems