



Electricity Production from Anaerobic Digestion of Animal Slurries in Farm Scale Plants

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Abstract: Currently, in Italy, more than 1200 agricultural biogas plants are running, mainly in the northern regions. At the end of 2012, 1.65% of the Italian electric consumption was produced from agricultural biogas plants. The public incentives framework for electricity production from biogas has been updated by the D.M. of 6 July 2012: the highest value is granted to AD plants with electrical power < 300 kW and mainly fed with by-products. Specific economic bonuses are provided for heat valorization and nitrogen reduction in the digestate. Nevertheless, with regard to agricultural AD plants, remarkable environmental impacts could be due to biomass production as well as to digestate management. On the other hand, benefits could arise from electricity and heat generation from renewable sources and mineral fertilization substitution. The aim of this study is to assess the environmental profile of electricity production from four different AD plant mainly fed with animal slurry and electrical power lower than 300 kW. Using LCA method, the environmental performance of electricity production from biogas has been evaluated using 1 kWh of electricity as functional unit. All processes involved as well as the processes avoided by the biogas production system (e.g. electricity and thermal energy production) were included in the system boundaries and therefore evaluated. The most critical stages (environmental hotspots) were identified and discussed; mitigation strategies of the environmental burdens were evaluated too. Moreover, the outcomes of the environmental assessment were compared with the environmental impact related to the Italian electricity mix. The achieved

results show that the electricity produced from the AD plant has better environmental performances than electricity produced from fossil fuels in particular for impact categories such as global warming and fossil depletion. Moreover, the recovery and the valorization of surplus heat reduce significantly the environmental burdens. Definitely, livestock slurries are a good feedstock for AD plants from an environmental point of view thanks to credits provided by a suitable waste management as well as to the absence of environmental burdens related to their production. The logistic aspects of the biomass supply must be carefully evaluated because the transportation of the feedstock over long distances can offset the environmental benefits due to the replacement of energy generation from fossil fuels.

Keywords: biogas; life cycle assessment; renewable energy.

1. Introduction

The European policy concerning renewable energy has set a goal for supplying 20% of the European energy demand from renewable energy sources by 2020 [4]. An important part of the renewable energy will originate gaseous, liquid and solid biofuels using biomass as a raw material.

The interest on the biogas production for bioenergy generation (electricity and heat) is increasing since it provides a clean and decentralized source of energy from renewable feedstock (Lijo et al., 2014). 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 fertilizer for crop cultivation in substitution of mineral fertilizers (De Vries et al., 2012).

Currently, in Italy, more than 1200 agricultural biogas plants are running, mainly in the northern regions. At the end of 2012, agricultural biogas plants produced about 1.65% of the Italian electric consumption (Bacenetti et al., 2013).

The public-incentives-framework for electricity (EE) production from biogas has been updated by the D.M. of July 6th, 2012: the highest value is granted to AD plants with electrical power < 300 kW and mainly fed with by-products. Specific economic bonuses are provided for heat valorization and nitrogen reduction in the digestate.

Although biogas production arises as a cleaner and environmental safe alternative for energy production, it is important to quantify the environmental impacts associated to this process (Dressler et al., 2012; Lijó et al, 2014a; Lijó et al, 2014b). 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 the literature (Dressler et al., 2012; Hartmann, 2006; 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 (Börjesson and Berglund, 2007; De Vries et al., 2012). 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 digestate management (Poeschl et al., 2012a; b).

The aim of this study is to assess the environmental profile of electricity production from four different AD plants mainly fed with animal slurry and electrical power lower than 300 kW.

2. Materials and Methods

2.1. Methods

Life Cycle Assessment (LCA) is a methodology to assess the potential environmental impacts and resources' consumption associated with a production system (ISO 14040, 2006). LCA methodology was chosen to perform the environmental analysis in this study, following the principles reported in ISO standards (ISO 14040, 2006).

Using the LCA method, the environmental performance of electricity production from biogas has been evaluated using 1 kWh of electricity as functional unit.

As concerns the system boundary, both all the processes involved and the processes avoided by the biogas production system (e.g. electricity and thermal energy production) were included within the system boundary, and therefore evaluated. The most critical stages (environmental hotspots) were identified and discussed; mitigation strategies of the environmental burdens were evaluated as well. Moreover, the outcomes of the environmental assessment were compared with the environmental impact related to the Italian electricity mix. The environmental impact of Italian electric mix was taken from Ecoinvent (Ecoinvent, 2012).

Among the steps defined within the life cycle impact assessment phase of the standardized LCA methodology, only classification and characterization stages were undertaken (ISO 14040, 2006). The characterization factors reported by the ILCD method were used. The following impact potentials were evaluated according to the selected method: climate change (CC), ozone depletion (OD), particulate matter (PM); photochemical oxidant formation (POF); acidification (TA), freshwater eutrophication (FE), terrestrial eutrophication (TE) marine eutrophication (ME), and mineral, fossil and renewable resource Depletion (MFRD). The software SimaPro 7.3 was used for the computational implementation of the inventories (Goedkoop et al., 2010). Due to the uncertainties about the definition of characterization factors for many active ingredients, the toxicity-related impact categories were not evaluated (Sleeswikk et al.; 2008).

2.2. Materials

The environmental burdens of four different agricultural anaerobic digestion plants were evaluated. All the plants are located in Northern Italy and are fed mainly with animal slurry and manure; Table 1 shows the main characteristics of the 4 AD plants. Two plants (A and B) digest only animal slurries, while the two others plants (C and D) codigest animal slurry and maize silage. Table 2 reports the characteristics of the different feedstock digested in the plants.

In all the AD plants, digestate is stored in open tanks. Therefore, methane emissions and ammonia emissions take place. They are assumed at 8.9 kg/MWh for methane and 0.23 kg/MWh for ammonia (Whiting and Azapagic, 2014). As regard to the heat cogenerated by the CHP engine, besides the thermal self-consumption, only plant A uses a share of this energy. In more details, for 2 h/day it is

used for hot water production while, from October 15th to March 15th, it is used (12 h/day) to heat farm buildings (farmer house, offices, etc.). The surplus heat valorized offsets the production of the same thermal energy by a natural gas boiler.

Table 1. Main characteristics of the biogas plants.

	Unit	Biogas plant			
		A	B C		D
District		Cremona	Lodi	Pavia	Cremona
Electrical power	kW	100	250	300	300
Starting year	-	2013	2010	2013	2013
Feeding rate^[1]	t/day	CS 40 t/day	PS 180 t/day	CS 35 t/day MS 13 t/day	PS 45 t/day MS 14 t/day
Electric self consumption	%	7.0	7.6	9.2	8.4
Transport Distance	km	0.1	3.5	1.5 for CS 0.8 for MS	1.3 for PS 0.7 for MS

^[1] CS = cow slurry; PS = pig slurry; MS = maize silage

Table 2. Feedstock characteristics.

	Total solid	Specific biogas production	Methane
Feedstock	% _{WB}	m ³ /t _{DM}	% vol
Cow slurry	8.0%	325	56%
Pig slurry	3.5%	450	56%
Maize silage	33.0%	600	52%

3. Results and Discussion

The environmental load for the electricity generated in the biogas plants is reported in Table 3. Those plants fed with animal slurries (A and B) show better environmental performances than plants (C and D) that codigest also maize silage.

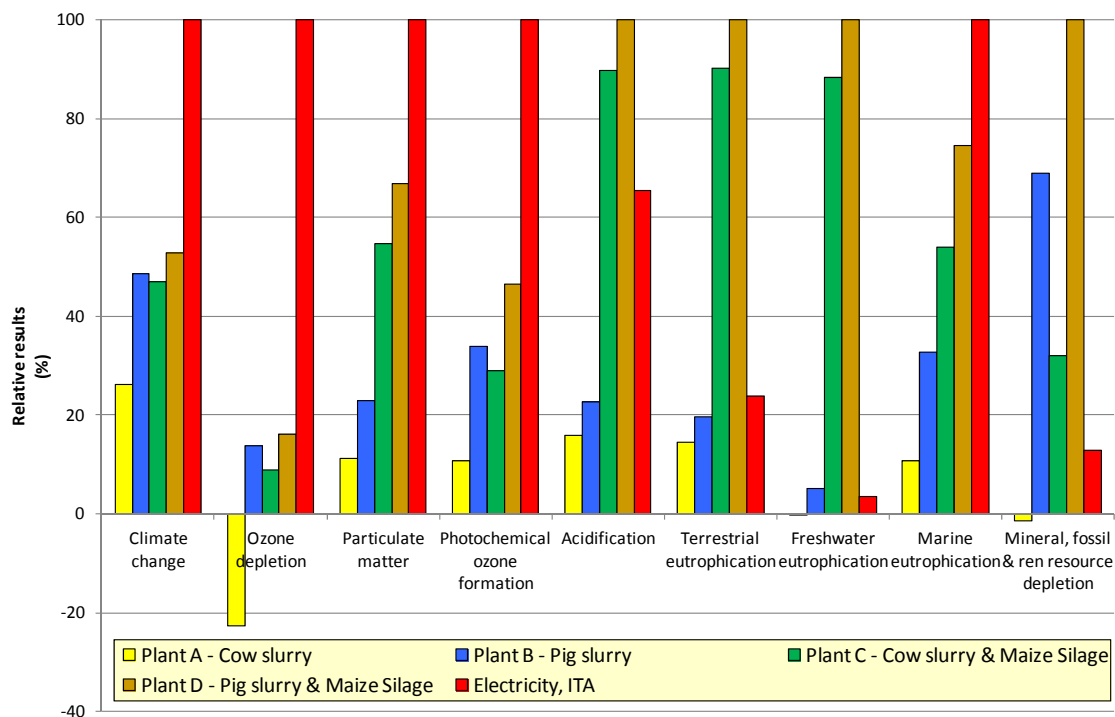
Among the different biogas plants, the plant A produces electricity with the lowest environmental impact: thanks to the heat-valorization credits, for 3 (OD, FE and MFRD) of the 9 assessed impact categories, environmental benefits are achieved. Although totally fed with pig slurry, plant B has, for CC and MFRD, a high environmental load due to the transport of a big feedstock mass. For all the assessed impact categories, plant B shows higher environmental loads than plant B.

Compared to the plants that digest slurries, plants (C and D) fed also with maize silage show a considerably higher impact for AC, TE, FE and ME: the fertilizer applications during maize cultivation involve emissions of ammonia in the air as well as nitrogen leaching and phosphate losses (run-off and leaching). Plant C, fed with pig slurry and maize silage, has the worst results for all the nine impact categories.

Table 3. Environmental impact of electricity from AD plants.

Impact category	Unit	Plant A	Plant B	Plant C	Plant D	EE mix ITA
Climate change	kg CO ₂ eq	1,70E-01	3,16E-01	3,06E-01	3,43E-01	6,51E-01
Ozone depletivo	kg CFC-11 eq	-1,31E-08	7,95E-09	5,08E-09	9,26E-09	5,76E-08
Particulate matter	kg PM2.5 eq	2,55E-05	5,19E-05	1,24E-04	1,51E-04	2,26E-04
Photochemical ozone formation	kg NMVOC eq	1,80E-04	5,70E-04	4,86E-04	7,83E-04	1,68E-03
Acidification	molc H+ eq	8,66E-04	1,24E-03	4,88E-03	5,44E-03	3,56E-03
Terrestrial eutrophication	molc N eq	3,48E-03	4,71E-03	2,17E-02	2,40E-02	5,72E-03
Freshwater eutrophication	kg P eq	-5,85E-08	9,59E-07	1,64E-05	1,86E-05	6,52E-07
Marine eutrophication	kg N eq	5,46E-05	1,67E-04	2,76E-04	3,81E-04	5,11E-04
Mineral, fossil&ren resource depl.	kg Sb eq	-3,63E-08	1,77E-06	8,22E-07	2,56E-06	3,31E-07

Figure 1 shows the environmental load for the electricity produced by the different biogas plants and the comparison with the Italian electric mix. For 5 impact categories (CC, OD, PM, POF and ME), the Italian electricity has a higher environmental impact than electric energy from AD plants; however, for AC, TE, FE it has a lower impact than EE from the AD plants (C and D) fed with maize silage. AC, TE and FE, impact categories related to the emission of nitrogen compounds, are higher than for the Italian electricity mix for biogas plants fed with maize silage (C and D); this is due to organic and mineral fertilizations needed for maize cultivation. During digestate application, ammonia emissions takes place while, following nitrogen application, nitrate leaching occurs. The worst performances of plant D compared to plant C are due to: i) higher maize silage utilization; ii) the transport of a largest amount of animal slurry (52.5 t · km/day in plant C and 58.5 t · km/day in plant D)

**Figure 1.** Comparison among the environmental impact of electricity produced in the four different biogas plants and in the Italian electric mix.

4. Conclusions

The electricity produced from the AD plants fed with animal slurry has better environmental performances than electricity produced from fossil fuels, whereas for AD plants fed with maize silage this is true only for those impact categories not related to ammonia and dinitrogen monoxide emissions and to nitrate and phosphate leaching. The use of maize silage as feedstock involves a high environmental impact for acidification and eutrophication impact categories.

Moreover, recovery and valorization of surplus heat (Plant A) significantly reduce the environmental burdens. Livestock slurries are a good feedstock for AD plants from an environmental point of view, thanks to credits provided by a suitable waste management as well as to the absence of environmental burdens related to their production. Logistic aspects of the biomass supply must be carefully evaluated because transporting the feedstock over long distances can offset the environmental benefits due to the replacement of energy generation from fossil fuels.

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