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The environmental sustainability of biogas production with small sized plant

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Abstract

In the century of the continuous evolution towards new technologies the renewable energy sector play a fundamental role in this direction. Use of these technologies in the small sized farm could help not only the production process but also the economic income of the farm. This paper underlines the availability of three different technologies adaptable to biogas plants for small sized farm. In this study three different technologies have been analyzed in order to present the environmental and economic benefits of these. Based on the use of a bagtank as digester (BT technology), the first technologies is compared with the use of a concrete structure with a storage balloon cover (BC technology), and with the use of a concrete structure as a concrete cover slab (CS technology). Through a streamlined comparative life cycle assessment, the characteristics of the three technologies as far as their environmental performance are analyzed, in order identify the most suitable for small sized biogas plants.

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Keywords: life cycle assessment (LCA); anaerobic digestion; small sized plant; future biofuel industry

1. Introduction

These days, renewable energy is showing a great potential to satisfy in a sustainable way energy demand, in particular for countries and regions with a low availability of fossil fuels and nuclear sites. In this way, growing interest

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in bioenergy is clearly present in recent EU policies, and highlighted in the Directive 2009/28/EC on the promotion with incentives of the production from renewable energy [1]. Among renewable energy sources, biomass plays an important role. There are several processes that transform solid and liquid biomass in secondary energy sources, such as biogas, landfill gas and pyrolysis gas [2]. In 2014, the whole Italian energy demand reached about 1,915,153 GWh, of which about 6.4 % us net through the exploitation of biomass, then also through biogas [3]. In fact, biogas energy comes from biomass, which is the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as biodegradable fraction of industrial and municipal waste. In the last two decades, a lot of interest has been posed to the development of technologies capable to optimize the entire Biogas energy process [4–6] and its applications go from sustainable farming and livestock breeding to district heating [7].

In a Biogas plant, the critical element is the "digester", in which the biodegradable fraction of biomass is fermented through anaerobic digestion and produces biogas that primarily consists of methane (CH_4) and carbon dioxide (CO_2). The percentage of methane depends on the type of organic substances that constitute the biomass, on the technology and on the size of the plant, and generally moves from 50 % up to 80 % [8]. To improve the biogas energy diffusion and to exploit its potential, one of the necessary conditions is the availability of sustainable technologies for biogas plants, particularly from the environmental and economic point of view [9–11].

In the following paragraphs, three different technologies applicable to small-scale biogas plants are described and their environmental performance are analysed using the life cycle assessment (LCA) methodology. An analysis of the economic sustainability of the same technologies can be found in literature [12, 13].

2. Anaerobic Digestion technologies for the production of biogas

As regards the Italian situation, Table 1 shows the number of biogas plants installed from 2011 to 2015 [14–18]. Most of them are in the northern regions. Table 2 shows the classification by size classes of installed power referred to 2011 (more recent data are not available).

Table 1. Italian biogas plants.

Year	2011	2012	2013	2014	2015
Number of plants	521	1264	1391	1491	1555

Table 2. Italian biogas plants by size classes of installed power (2011).

Class of installed power, kW	Number	Percentage
<100	54	10.4 %
101–500	105	20.2 %
501–1,000	289	55.5 %
> 1,000	24	4.6 %
Biogas in the boiler	11	2.1 %
Data not available	38	7.3 %
TOTAL	521	100.0 %

In a biogas plant, the natural process of fermentation and decomposition produces biogas which is subsequently used to obtain electricity and heat. After a phase of upgrading, it can also be used as biomethane. One of the most critical elements for the efficiency of the process in this sense is the "digester", in which the fermentation phase happens and the biodegradable fraction of biomass is fermented through anaerobic digestion [11, 19, 20].

An optimum control of the degradation process in a biogas plant requires a detailed knowledge of the main chemical and physical parameters [8]:

- Temperature, which plays a crucial role. Biogas plants are generally mesophilic or thermophilic. In the first case, the functionality is more efficient at a temperature between 35 °C and 41 °C, while in the second case at a temperature of about 55 °C;

- Total content of solids (TS) or the total content of solid organic substances (oTS), which is used to measure the volumetric loading of the digester in order to manage the input flows of solids. Digesters operate normally with a TS content of 8–10 %. The total content of solid organic substances is very important for system operations. In fact, too high content may increase the risk of overloading the digester;
- Volatile solids (VS), which are measured as the difference between the solid content and the ash content after combustion. They represent the percentage of the organic matter and influence the methanogenic potential;
- The redox potential of the digester, which is a measure of the oxidability or the reducibility of its contents. The production of biogas is obtained efficiently only in an anaerobic environment, or with a redox potential lower than –330 mV. In general, the use of particular substrates to promote oxidation may cause a variation of pH.
- pH, for which the optimal range for the formation of methane is extremely limited, between 7.0 and 7.7;
- The acid capacity, in mol/l or mg/l, which is a measure of the buffer capacity of the digester and is related to pH.

In this analysis, three different technologies applicable to small size biogas plants (100 kW), bags technology, balloon cover technology and cover slab technology are considered.

2.1. Bags technology (BT)

Bags technology was initially a flexible system for the storage of liquids and manure and subsequently was converted to a biogas production. The plant consists mainly of bags digester for the anaerobic fermentation, a pretreatment tank, a cogenerator and an adjoining room with an adjoining exchanger. The digester is made of a bag in which the fermentative phenomena borne by the organic substance happens [8]. The structure of the bags, made of polyester fabric, is generally capable to store up to 3,000 m^3 of matter. For the case of a small sized plant considered, two bags of 1,800 m^3 each are necessary, with a total area occupation of 1,200 m^2. The digester is equipped with internal mixers allowing agitation of the slurry, which optimizes the anaerobic digestion process. Besides this, each bag is heated through a heat exchanger plate placed externally. Pretreatment tank is a special tank with an agitator that homogenized manure with substrates that are inserted. Also in this first phase, there is a pre-heating of the biomass.

2.2. Balloon Cover technology (BC)

This type of biogas plants are provided with a pre-treatment tank for loading the manure to the digester and a stationary mixer feeder for loading the substrates [8]. The digester consists of a concrete circular structure with a balloon cover with a volume of 2,000 m^3. The digester is equipped with a heating system and mixers that agitates the liquid inside the tank.

2.3. Cover slab technology (CS)

This plant technology is highly industrialized and flexible, because the plant can be operated even if a subsequent parallel logic (two plants side by side) resulting in improved efficiency and reduced area and land losses. Biogas plant with cover slab technology consists in: a pretreatment tank, a volumetric pump with shredder, a compact digester, a final tank for digested material, a co-generator [8]. The pretreatment tank volume is about 50 m^3, and is equipped with a system for mixing and homogenization of the manure with substrates; then there is the control system of the load level. To ensure a better performance especially in winter, the tank is also equipped with a heating system. A volumetric pump and a shredder send the fluid to the digester and circulate fluid inside the pretreatment tank. The digester consists of a compact circular tank with a volume 700 m^3 and is fully insulated and sealed by a cover slab. It is equipped with a heating system that allows to maintain constant at 40 °C internal temperature. Moreover, the presence of the mixers allows to agitate in an optimal manner and automatically the liquid inside the tank. The final tank for digestate collects through a pipe the digestate that comes out of the digester.

3. Comparative life cycle assessment of biogas technologies

The Life Cycle Assessment (LCA) is a technique to assess the environmental impacts associated with all the stages of a product's life from-cradle-to-grave [21], and it is commonly used for several biofuels [22–24]. For the case analyzed, the functional unit, i.e. the measure of the function of the studied system that provides a reference to which the inputs and outputs can be related, is the exploitation of 7,007.5 ton/year of biomass. The functional unit chosen is coherent with the point of view adopted in the analysis: that of a farm that produces such biomass and needs to choose among the three alternatives above presented, based on environmental criteria. The whole biomass matter is composed by 6,602.5 ton/year of animal manure, 275 ton/year of silage maize and 130 ton/year of Molasses. The three plants analyzed employ a 100 kW power engine. For this reason, the yearly electric energy production is 760,000 kWh and the yearly heat production is 500,000 kWh_{term}. In the life cycle analysis, credits are given to each alternative, as avoided impacts, for the net production of electricity and heat and for the production of digestate. The life cycle assessment has been carried out using *SimaPro* 7.3 software [25]. Primary data, i.e. data taken on the field, comes from plants located in northern Italy, while secondary data have been taken from the *Ecoinvent* database [26]. For the impact assessment, the *ReCiPe* method has been adopted [27].

3.1. Bags technology (BT)

The life cycle inventory for the first technology is presented in Fig. 1, where the inputs and outputs of this process are identified and quantified. In the pretreatment phase there are the material biomass inputs, such as manure, silage maize and molasses. In this first phase, it is used a tractor to transport the silage maize from the trench to the tank, travelling for 1,5 km/day. The pretreatment tank covers approximately an area of 40 m^2. Total electricity consumption of this phase is about 13,140 kWh/year and heat consumption is 186,351 kWh_{term}/year.

The fermentation phase has in input the outputs of pretreatment phase. The digester cover an area of 1,200 m^2. In this case, the electricity consumption is about 65,700 kWh/year and heat consumption is 311,487 kWhterm/year.

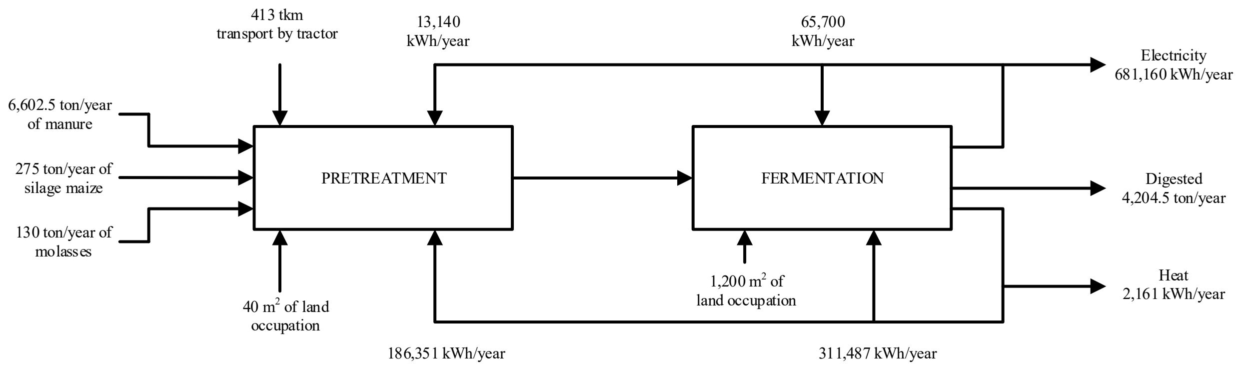

Fig. 1. Input and output flows for the bags technology.

3.2. Balloon Cover technology (BC)

Inputs and outputs of the Balloon technology are presented in Fig. 2. The pretreatment phase consists of two different tanks of loading. Manure and molasses are loaded through a pump in the digester. The silage maize is pretreated in a stationary mixer feeder without a preheating operation. This mixer feeder is stationary and located near the digester. On the bottom of these tanks there is an auger that load the silage into the digester. Both kind of pretreatments have 87,600 kWh/year of total electricity consumption. The pretreatment tank covers approximately an area of 80 m^2.

The fermentation phase follows the pre-treatment phase. In this case, the digester covers an area of 800 m^2. In this case, the electricity consumption is about 65,700 kWh/year and heat consumption is 153,300 kWh_{term}/year.

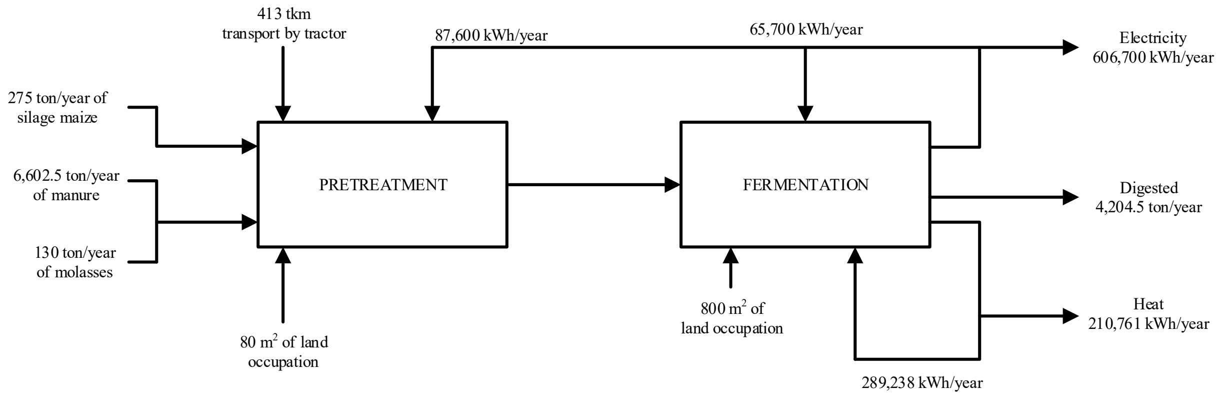

Fig. 2. Input and output flows for the balloon cover technology.

3.3. Cover Slab technology (CS)

Inputs and outputs of the third technology are presented in Fig. 3. In the pretreatment phase, manure, molasses and silage maize are loaded in a heating tank. In this phase, in addition to the heating, there are mixers that homogenize the biomass for a total electricity consumption of 13,140 kWh/year. The heat consumption for pretreatment phase is 155,288 kWh_{term}/year. The pretreatment tank covers approximately an area of 50 m^2. The fermentation phase covers an area of 500 m^2, the final electricity consumption is about 65,700 kWh/year and heat is 222,477 kWh_{term}/year.

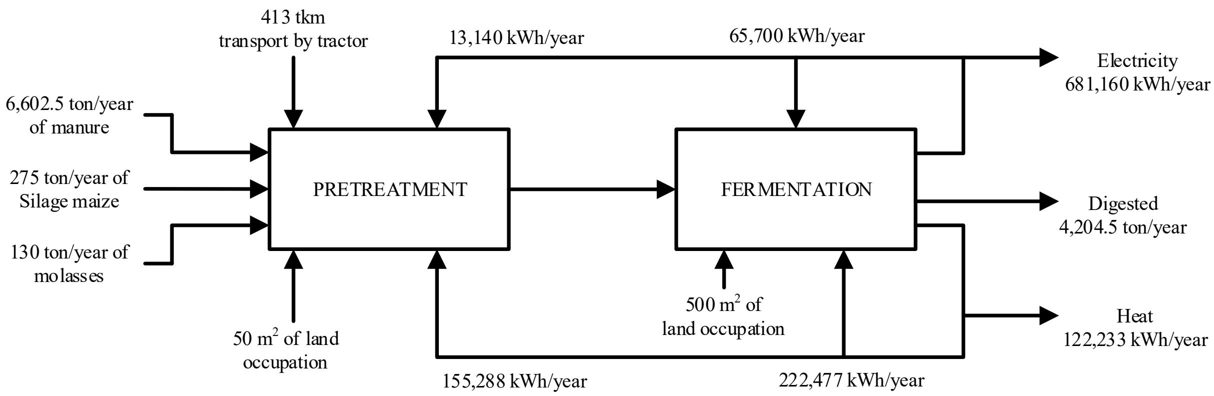

Fig. 3. Input and output flows for the cover slab technology.

4. Life cycle impact assessment

Fig. 4 represents the impacts of the three technologies with reference to the different impact categories. The bars above the zero represent a negative environmental impact, while the bars below the zero represent a positive environmental impact, due to the production of heat and electric energy that would instead be produced in other ways. The analysis of Fig. 4 highlights a complex and interdependent framework. The balloon cover technology has the worst performance in all impact categories. The fossil fuel impact category shows that the most important positive contribution is provided by the cover slab.

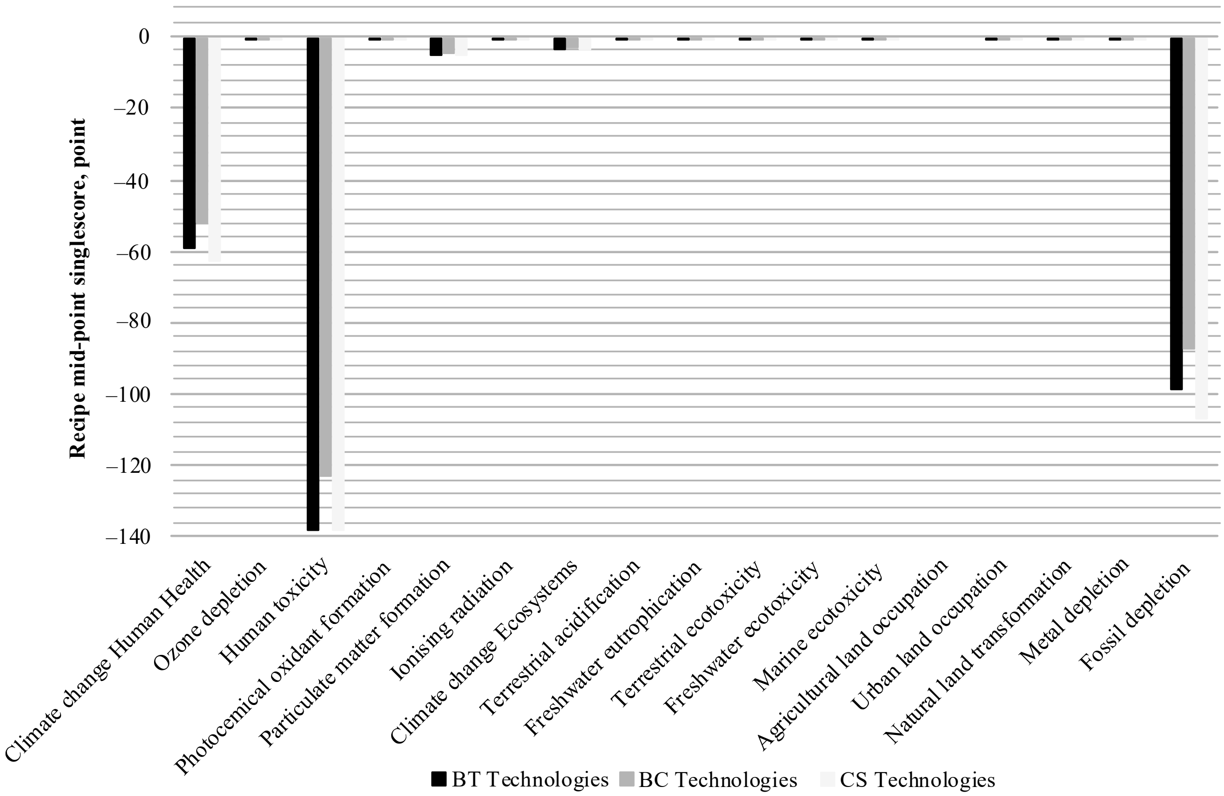

Fig. 4. Impacts of the three technologies.

Fig. 5 shows the single score comparison among the three technologies, which sum the impacts of all categories in a single score. The main difference between bags and cover slab technology is related to the fossil fuels category.

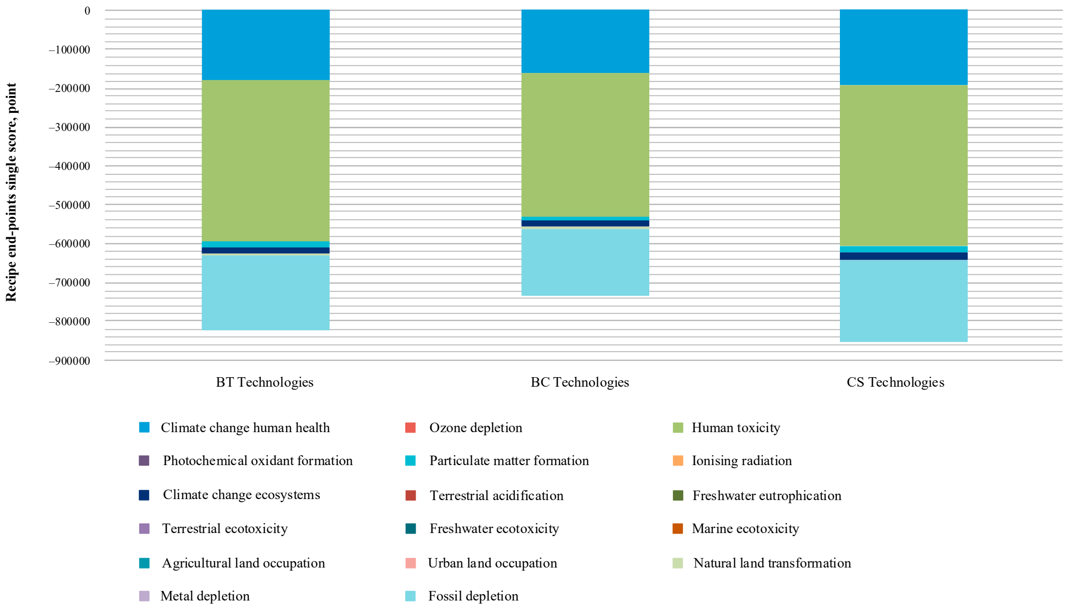

Fig. 5. Single score comparison among the three technologies.

4.1. Sensitivity analysis

To evaluate the sensitivity and the level of uncertainty of results obtained in this study, a Monte Carlo analysis was performed. Further, with the adoption of Monte Carlo analysis, inventory input parameters are randomly changed and transformed into stochastic variable with a log-normal distribution. This analysis also provides the probability that, for each environmental impact category, one of the two scenarios will prevail over the other, i.e. will have a lower environmental impact. In this case, Monte Carlo analysis has been adopted to the comparison of scenario BT technologies (BT) with scenario CS technologies (CS) where the uncertainly that coming from Fig. 5 may affect the final results. The standard deviations of the inventory parameters come from the Ecoinvent database. Coming from comparison results obtained in Fig. 6, the probability that CS presents an higher environmental impact then BT is lower than 45 % for all of the environmental impact categories.

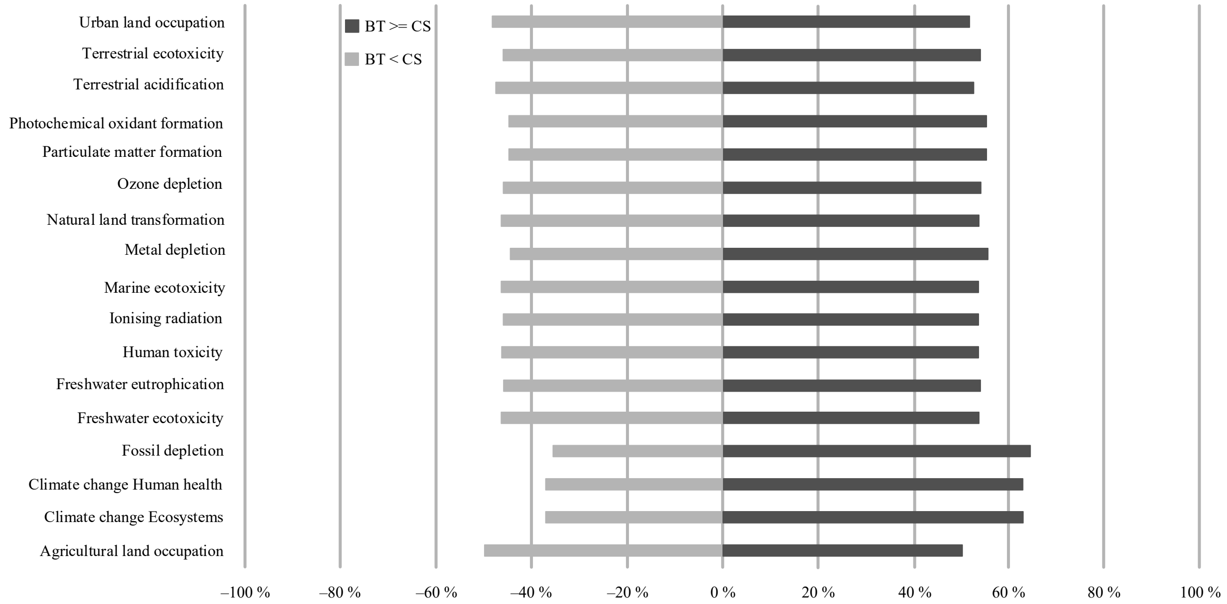

Fig. 6. Percentage variation of two scenarios by impact categories.

5. Conclusions and discussion

In this paper, three different technologies for manure anaerobic digestion in small sized plants have been compared with regard to their environmental impact. The first technology is based on the use of a bag tank as digester, the second is based on the use of a concrete structure with a storage balloon cover and the third one on the use of a concrete structure with a concrete cover slab. The comparison has been carried out through a life cycle assessment analysis, which is a methodology to assess the environmental impacts associated with all the stages of a product's life from-cradle-to-grave. The balloon cover technology has the worst performance in all environmental impact categories, while the cover slab technology seem to be the most preferable, mainly thanks to a consistent energy saving, in terms of heat and electricity, due to the reduction of energy dispersions and thus of energy self-absorption, which is about 10 % less with respect to bags technology and 20 % less with respect to balloon technology.

References

[1] European Parliament. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. Off J Eur Union 2009;140:16-62.
[2] Deublein D, Steinhauser A. Biogas from Waste and Renewable Resources: An Introduction, 2nd, Revised and Expanded Edition. Curr. Rev. Acad. Libr., 2010.
[3] Ministero dello Sviluppo Economico. Bilancio Energetico Nazionale; 2014.
[4] Singh KJ, Sooch SS. Comparative study of economics of different models of family size biogas plants for state of Punjab, India. Energy Convers Manag 2004;45:1329–41.
[5] Patterson T, Esteves S, Dinsdale R, Guwy A. Life cycle assessment of biogas infrastructure options on a regional scale. Bioresour Technol 2011;102:7313–23.
[6] Kimming M, Sundberg C, Nordberg A, Baky a., Bernesson S, Noren O, et al. Biomass from agriculture in small-scale combined heat and power plants – A comparative life cycle assessment. Biomass and Bioenergy 2011;35:1572–81.
[7] Kirsanovs V, Blumberga D, Karklina K, Veidenbergs I, Rochas C, Vigants E, et al. Biomass Gasification for District Heating. Energy Procedia 2017;113:217–23.
[8] Villarini M, Caffarelli A, Bocci C, D'Amato A. Sistemi a biomasse: progettazione e valutazione economica. Impianti di generazione di calore e di elettricità, Maggioli Editore; 2011.
[9] Blengini G a., Brizio E, Cibrario M, Genon G. LCA of bioenergy chains in Piedmont (Italy): A case study to support public decision makers towards sustainability. Resour Conserv Recycl 2011;57:36–47.
[10] Poschl M, Ward S, Owende P. Evaluation of energy efficiency of various biogas production and utilization pathways. Appl Energy 2010;87:3305–21. doi:10.1016/j.apenergy.2010.05.011.
[11] Berglund M, Borjesson P. Assessment of energy performance in the life-cycle of biogas production. Biomass and Bioenergy 2006;30:254–66.
[12] Repele M, Udrene L, Bazbauers G. Support Mechanisms for Biomethane Production and Supply. Energy Policy 2017;113:304–10.
[13] Collotta M, Tomasoni G. The economic sustainability of small–scale biogas plants in the italian context: The case of the cover slab technology. Agron Res 2017;15.
[14] EBA – European Association Biogas. Biogas report 2011 n.d. Available: http://european-biogas.eu/biogas/2011
[15] EBA – European Association Biogas. Biogas report 2012 n.d. Available: http://european-biogas.eu/biogas/2012
[16] EBA – European Association Biogas. Biogas report 2013 n.d. Available:http://european-biogas.eu/biogas/2013
[17] EBA – European Association Biogas. Biogas report 2014 n.d. Available:http://european-biogas.eu/biogas/2014
[18] EBA – European Association Biogas. Biogas report 2015 n.d. Available:http://european-biogas.eu/biogas/2015
[19] Ishikawa S, Hoshiba S, Hinata T, Hishinuma T, Morita S. Evaluation of a biogas plant from life cycle assessment (LCA). Int Congr Ser 2006;1293:230–3.
[20] Poeschl M, Ward S, Owende P. Environmental impacts of biogas deployment - Part I: Life Cycle Inventory for evaluation of production process emissions to air. J Clean Prod 2012;24:168–83.
[21] European Committe for Standarization (CEN). ISO 14040:2006, Environmental management – Life cycle assessment - Principles and framework. 2006 n.d.
[22] Collotta M, Busi L, Champagne P, Mabee W, Tomasoni G, Alberti M. Evaluating microalgae-to-energy -systems: different approaches to life cycle assessment (LCA) studies. Biofuels, Bioprod Biorefining 2016;10.
[23] Collotta M, Champagne P, Mabee W, Tomasoni G, Leite GB, Busi L, et al. Comparative LCA of Flocculation for the Harvesting of Microalgae for Biofuels Production. Procedia CIRP 2017; 61.
[24] Collotta M, Busi L, Champagne P, Romagnoli F, Tomasoni G, Mabee W, et al. Comparative LCA of Three Alternative Technologies for Lipid Extraction in Biodiesel from Microalgae Production. Energy Procedia 2017;113:244–50.
[25] Consultants P. SimaPro Life Cycle Analysis version 7.3 (software); 2006.
[26] Frischknecht R, Jungbluth N, Althaus HJ, Doka G, Dones R, Heck T, et al. The ecoinvent database: Overview and methodological framework. Int J Life Cycle Assess 2005;10:3–9.
[27] Goedkoop M, Heijungs R, Huijbregts M, Schryver A De, Struijs J, Zelm R Van. ReCiPe 2008. Potentials 2009:1–44.