Waste Management 34 (2014) 1429–1435

Contents lists available at ScienceDirect

Waste Management

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

Production costs and operative margins in electric energy generation from biogas. Full-scale case studies in Italy

C. Riva [a], A. Schievano [a,b,*], G. D'Imporzano [a,b], F. Adani [a,b,*]

[a] Gruppo Ricicla, DiSAA, Università degli Studi di Milano, Via Celoria 2, 20133 Milano, Italy
[b] Gruppo Ricicla, DiSAA, Biomass and Bioenergy Lab., Parco Tecnologico Padano, Via Einstein, Località Cascina Codazza, 26900 Lodi, Italy

ARTICLE INFO

Article history:
Received 3 December 2013
Accepted 16 April 2014
Available online 16 May 2014

Keywords:
Anaerobic digestion
Biogas
Renewable energy
Energy crops
Agriculture
Organic waste

ABSTRACT

The purpose of this study was to observe the economic sustainability of three different biogas full scale plants, fed with different organic matrices: energy crops (EC), manure, agro-industrial (Plants B and C) and organic fraction of municipal solid waste (OFMSW) (Plant A). The plants were observed for one year and total annual biomass feeding, biomass composition and biomass cost (€ Mg^{-1}), initial investment cost and plant electric power production were registered. The unit costs of biogas and electric energy (€ Sm^{-3}_{biogas}, € kW h^{-1}_{EE}) were differently distributed, depending on the type of feed and plant. Plant A showed high management/maintenance cost for OFMSW treatment (0.155 € Sm^{-3}_{biogas}, 45% of total cost), Plant B suffered high cost for EC supply (0.130 € Sm^{-3}_{biogas}, 49% of total cost) and Plant C showed higher impact on the total costs because of the depreciation charge (0.146 € Sm^{-3}_{biogas}, 41% of total costs). The breakeven point for the tariff of electric energy, calculated for the different cases, resulted in the range 120–170 € MW h^{-1}_{EE}, depending on fed materials and plant scale. EC had great impact on biomass supply costs and should be reduced, in favor of organic waste and residues; plant scale still heavily influences the production costs. The EU States should drive incentives in dependence of these factors, to further develop this still promising sector.

1. Introduction

Biogas/bio-methane production from anaerobic co-digestion of different biomasses plays an increasingly important role (Igliński et al., 2012; Murphy et al., 2011; Holm-Nielsen et al., 2009), as microbial conversion of biomass under anaerobic digestion (AD) has several economic and environmental advantages (Ponsà et al., 2011). In addition, this process residue valuable organic substrate, i.e. digestate (Tambone et al., 2010), that can be advantageously used in agriculture as fertilizer or soil conditioner (Murphy et al., 2011).

Today, in Europe, the generation of biogas by AD of organic materials is a spatially-diffused source of energy, split into a huge number of small-medium enterprises (SMEs), each one operating, above all, in its own territorial context, in agriculture as well as in food-industry or waste-management areas. Biogas industry induces, also, the diffusion of additional SMEs involved in the construction, monitoring, management and maintenance of biogas plants (Ahring et al., 2002). All this, plays an important effect on local economy and occupation.

However, this new important and complex industry need deeper study of its potentialities; this fact requires the accessibility to technical and scientific data, experiences, tools, know-how, technical progress that with the availability of capital investments, allow developing this new economy accompanying its development with adequate policies and public incentive. In this context, above all, there is the need of full-scale data about the real production costs of electric energy (EE) or bio-methane producible through the AD technology.

Agricultural biogas plants are currently growing in importance within the EU biogas sector and the substrate supply is increasingly based on the development of energy-dedicated crops (maize, sorghum, wheat, etc.). Nevertheless, if we look for future large-scale diffusion of these kinds of plants, the massive production of dedicated crops poses some energetic, economic and environmental issues. In Italy, the number of biogas plants treating organic waste (44.9% of the total production in 2011) was overtaken by the plants using manure and agricultural and forestry products (53.6%), specifically 10.6% from manure and 42.7% from agricultural and

* Correspondig authors. Address: Gruppo Ricicla, DiSAA, Università degli Studi di Milano, Via Celoria 2, 20133 Milano, Italy. Tel.: +39 0371 4662 669 (A. Schievano). Tel.: +39 0250316545 (F. Adani).

E-mail addresses: andrea.schievano@unimi.it (A. Schievano), fabrizio.adani@unimi.it (F. Adani).

http://dx.doi.org/10.1016/j.wasman.2014.04.018
0956-053X/

forestry products; biogas from sludge represented only the 1.8% (GSE, 2012).

The economical balance of energy-dedicated crops plants, today, is strongly influenced by the prices of agricultural raw materials, which could limit the prospects for further growth in this area (Eurobserv, 2012). Some authors estimated that nearly 20% of the total arable land in the EU can be assumed to be available for purposes other than food-crop production during the coming decades, if the right crop-rotation with food crops is applied (Amon et al., 2007). For farmers, energy-crops cultivation may be an interesting option for the use of set-aside land because the demand for agricultural products often comes to a rest (Hanegraaf, 1998).

Besides, today many agricultural facilities have already chosen to co-digest energy-dedicated crops with refused organic materials, by-products or residues of agricultural and industrial productions. Agriculture and food-industry produce and discard huge amounts of organic materials that can be used in biogas plants for mitigating both the costs and the environmental impact of energy-dedicated crop productions. Moreover, the integration of organic fractions of municipal source-separated waste (OFMSW), civil/industrial wastewaters and animal manures would contribute in further integrating or substituting the use of dedicated crops and in decreasing the biogas production costs (Schievano et al., 2009). The use of OFMSW as co-substrate or as substitute for energy crop (EC) and agro-industrial waste (AW) would not modify the AD process, biogas production and digestate characteristics. The farm-biogas plants are good candidates for treating also OFMSW in a cost-effective way, facilitating future development of a new agriculture economy and providing territorially diffused electric and thermal power (Pognani et al., 2009).

From the economical point of view, the ideal mixture of different organic substrates must guarantee the lowest cost of the biogas producible (€ Sm^{-3}), i.e. coupling the highest biogas productivity ($Sm^3\,Mg^{-1}$) with the lowest biomass supply cost (€ Mg^{-1}). The bio-methane potentials (BMP) of substrates fed can be measured in ideal conditions by laboratory-scale tests (Schievano et al., 2009; Pognani et al., 2009; Hansen et al., 2004; Gunaseelan, 2007; Schievano et al., 2008). In a previous study, Schievano et al. (2009) applied the anaerobic bio-gasification potential test (ABP) (equivalent to the BMP) to a series of organic materials, to evaluate the convenience of the use of each feedstock in the process. By combining different organic materials, different solutions in feeding the biogas plant were evaluated by a new indicator, i.e. the cost of the producible biogas (€ Sm^{-3}). This indicator can help in comparing the convenience of different materials in the feeding mixture and this previous study provided an overview concerning the feedstock supply costs of biogas plants.

Nevertheless, in full-scale biogas facilities the ultimate cost of the energy produced does not depend only on the feedstock supply costs; in fact other contributions must be taken into account, such as the investment depreciation charges, the management-maintenance costs, etc. In addition, these different contributions to the ultimate production cost may considerably vary, depending on plant size and production capacities. On the other side, positive synergies related to the context and the type of biogas plant may contribute in lowering the overall production costs. As already stated by Schievano et al. (2009), the use of OFMSW as main biomass supply source can bring additional income to biogas plants, as a tariff paid for treating waste. Furthermore, through AD, organic materials are converted to valuable solid–liquid slurry that can be used as fertilizer in agricultural land, because of its high-nutrient as well as stabilized organic-matter contents (Tambone et al., 2010; Ahring et al., 2002; GSE, 2012; Eurobserv, 2012; Amon et al., 2007; Hanegraaf, 1998; Schievano et al., 2009; Pognani et al., 2009; Hansen et al., 2004; Gunaseelan, 2007; Schievano et al., 2008; Verrier et al., 1983; Converti et al., 1999). In agricultural contexts, the nutrient and OM contents of digestate may substitute the artificial or exogenous fertilizer/amendment supply to soil, allowing the agricultural firm to avoid their supply cost.

This study represents the third part of a wider work presenting the results of a 1-year survey on three full-scale biogas plants, operating in the Italian agro-industrial context with different characteristics. In the previous two sections biological processes and plant efficiency in transforming the organic matter into biogas were studied (Schievano et al., 2011a,b). In this study an economic survey of the three full-scale plants has been considered with particular, reference on how biomass-type supplied, the investment and the management/maintenance affected the ultimate biogas and electricity production costs.

2. Materials and methods

2.1. Characteristics of the 3 full-scale biogas plants

Three full-scale plants were observed for a one year period starting from April to March 2009; all these plants were operating in an agro-industrial context in the northern Italy. During the year, the main characteristics of the plants were observed: total annual biomass feeding, biomass composition and their cost (€ Mg^{-1}), plant initial investment for constructions, management/maintenance costs and electric power production (Table 1).

All plants operated by continuously-stirred-tank-reactors (CSTR) in "wet" conditions, i.e. with a total solids (TS) content in the reactors below $100\,g\,kg^{-1}$ wet weight (w.w.). In all plants, the digestate output is treated with solid–liquid separation (centrifuge) and the liquid fraction is stored into ponds, before its distribution as fertilizer in agricultural fields.

The first plant (Plant A) is fed with the organic fraction of the municipal solid waste (OFMSW) (approx. 26,000–28,000 $Mg\,y^{-1}$), collected separately from five municipalities, which externalize its treatment to this private facility. The plant was located in a farm that re-utilizes the digested slurry as amendment and fertilizer for agricultural land. The OFMSW pre-treatment includes mixing the organic matrix at a ratio of 3/2 (w.w./w.w.) with re-circulated digested slurry, pulping the mix to a slurry and separating the un-degradable and/or heavy fractions such as residual plastic bags, wood, etc.. This material (about the 5–10% w.w. of the total OFMSW) is then transported to be disposed into a landfill.

The second plant (Plant B) is located in a farm that re-utilizes the swine manure as liquid substrate in the biogas plant (about 23,000–25,000 $Mg\,y^{-1}$). The feeding mixture is enriched by co-digesting with pig slurry, various energy crops (maize silage, triticale and sorghum), agricultural residues (barley thresh from beer industry) and industrial organic by-products, such as glycerin (from bio-diesel production plants), molasses (from sugar cane production), bakery-industry waste and olive mill sludge. The details of the mix ratios are specified in Table 1. The crops silage and the other solid substrates are stored and charged once a week by a bulldozer in an automatic loading machine, which mixes every hour the manure with the solids in a batch, chopping the mix to a slurry and pumping it to the digesters.

The third plant (Plant C), similarly to Plant B, is located in a farm and its feeding mixture is composed of swine plus cow manure (altogether about 58%) w.w., maize silage 10% w.w., cropped within the farm, milk whey 24% w.w. and rice culture by-products 8% of w.w. (from outside the farm) (Table 1). The solid materials