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Sustainability of Biogas Based Projects: Technical and Economic Analysis

Valeria Annibaldi, *Federica* Cucchiella , *Massimo* Gastaldi, *Marianna* Rotilio and *Vincenzo* Stornelli

Department of Industrial and Information Engineering and Economics, University of L'Aquila, Via G. Gronchi 18, 67100 L'Aquila, Italy

Abstract. Biomethane is a renewable gas produced by the transformation of organic matter. It can lead to emissions reduction and it contributes to increasing methane production. Incentive policies favour its development and for this reason, the objective of this paper is to investigate the economic performance of biomethane plants and their process monitoring by electronic systems. Mathematical modeling is here presented to study the financial feasibility of biomethane plants in function of the size (100 m3/h, 250 m3/h, 500 m3/h, 1000 m3/h), the feedstock used (organic fraction of municipal solid waste and a mixture of 30% maize and 70% manure residues on a weight basic) and the destination for final use (fed into the grid, destined for cogeneration or sold as vehicle fuel). From an economic point of view the plant performance is studied by economic tools as Net Present Value and Discounted Payback Time and the uncertainty analysis is implemented using Monte Carlo method. Moreover, from a technical point of view, process monitoring is analyzed to understand what happens in a biomethane plant and help to maintain a stable process. The results show that the profitability of biomethane plants is verified in several scenarios presenting losses only if subsidies were removed.

1 Introduction

Renewable technologies are considered as clean sources of energy and its optimal use minimize environmental impacts and can encourage a green revolution in the energy context of XXI century. Policies and management practices of renewable energy systems provide an excellent opportunity for reduction of greenhouse gas (GHG) emissions and global warming, but also economic opportunities are very interesting [1-5]. Biomethane refers to methane produced from biomass feedstock, particularly agricultural residues, energy crops, organic-rich waste waters, organic fraction of municipal solid waste (ofmsw) and industrial organic waste [6-8]. It is produced through industrial process, including both biogas produced by anaerobic digestion with purification and biogas upgrading technologies [9-11]. Biomethane offers a renewable alternative to natural gas and can be used as a vehicle fuel, distributed in the main gas supply or used to generate green power. The biogas-biomethane chain can be used for replacement of fossil fuels in heat and power generation and as a vehicle fuel, providing a reduction of green-house gases amounting to the equivalent of 200g of CO_2/kWh of generation (200g CO_2eq/kWh) [12].

A mixture of 20% biomethane, in the transport sector, brings a reduction of green-house gases emission level estimated equal to 24 gCO_2/kWh whereas this reduction is equal to 119 gCO_2/kWh using 100% biomethane. The GHG emissions from methane vehicles are significantly lower than emissions of gasoline vehicles leading to emissions savings of 21-24% [13].

The combustion of biogas in a combined heat and power unit is less environmentally sustainable than upgrading of biogas to biomethane about GHG emissions, reduction of NOx and particulate matter local emission. The recycle of livestock manure will effectively reduce several pollution problems in areas with high density of these wastes and consequently is important to identify the factors impacting farmer's decision-making behaviour.

This paper evaluates the profitability of biomethane plants in function of the size (100 m^3/h, 250 m^3/h, 500 m^3/h and 1000 m^3/h), of two typologies of substrates used (organic fraction of municipal solid waste, ofmsw, and a mixture of 30% maize and 70% manure residues on a weight basis) for each final destination of biomethane. The methodology used is the Discounted Cash Flow (DCF) and the indicators used are Net Present Value (NPV) and Discounted Payback Time (DPBT) [14, 15]. The costs of biomethane production and the role of subsidies are evaluated. Italy is chosen as case study because the contribution of subsidies is strategic to the development of biomethane production and this country presents great potentials not yet developed. Moreover, a process monitoring strategy to understand what happens in a biogas plant is discussed since in many cases, a strongly inhibited microorganism population or a total crash of the whole plant can have severe financial consequences for the biogas plant operator. Consequently, Monte Carlo simulation is applied to evaluate the probability that the biomethane plants will lose money and consequently give solidity to the obtained results.

2 Methods

Discounted cash flow (DCF) is a economic valuation method used to estimate the profitability of an investment opportunity. In this paper are used two indicators: NPV and DPBT. NPV is defined as the sum of the present values of the individual cash flows and DPBT represents the number of years needed to balance cumulative discounted cash flows and initial investment.

Model Description. This paper aims to propose the profitability of biomethane plants in function of the plant dimensions (100 m^3/h, 250 m^3/h, 500 m^3/h, 1000 m^3/h), the feedstock used (organic fraction of municipal solid waste and a mixture of 30% maize and 70% manure residues on a weight basic) and the destination for final use (fed into the grid FITG, destined for cogeneration CHP or sold as vehicle fuel VF). Combining these variables, there are 24 case studies that will be examined.

From the revenues point of view, the subsidies are calculate in according to a decree dated 5 December 2013 by the Italian Ministry of Economic Development which provides incentives for use of biomethane fed into the grid, destined for cogeneration or sold as vehicle fuel.

Producer has the right to one CIC (Certificate for the release in consumption of the produced biomethane) when he produces emission of 41.840 MJ of biofuel energy for 20 years. 1 CIC corresponds to 0.837 t of biomethane because the heat power of biomethane is equal 49.978 GJ/t. For each CIC the incentive corresponds to 300-500€ [16].

Furthermore, the weight of incentives depends by the feedstock used; in fact, a corrective coefficients equal to 2 is applied if the substrate is ofmsw and equal to 1.7 if the feedstock is a mixture of 30% maize and 70% manure residues.

For feeding into the grid, the subsidy is estimated on the amounts of biomethane excluding the energy consumption of biomethane production process. Up to 500 m^3/h it is possible to sell biomethane directly to Gestore Servizi Energetici (GSE) at an all-inclusive price equal to twice the 2012 market value for natural gas; otherwise it can sell directly on the natural gas market with a subsidy equal to twice the 2012 market value for natural gas less the monthly cost of the gas itself. The incentives are valid for 20 year. These values are increased and decreased by 10% for plants with a production capacity ≤ 500 m^3/h and >1000 m^3/h respectively. Moreover, if the feedstock is 100% by residues or waste, the combination of incentive and corrective coefficient is increased by 50%.

For biomethane destined for cogeneration, the value of the incentives is obtained from the current electricity rates for biogas net of the energy consumption for the high-yield cogeneration plant and it is valid for 20 years. This bonus depends by the type of substrate used and the size power.

From the costs point of view, there is three phases about biomethane production: (i) biogas production; (ii) upgrading and (iii) compression and distribution. However, additional compression cost is not needed, if the gas distribution grid operates at levels of pressure similar to those in output by upgrading phase and cost of distribution is lower than other costs if the production location is near the distribution grid.

Investment costs are calculated in function of the substrates used and the size power, furthermore there is additional cost giving from treatment of the ofmsw. Instead, the operational costs are given from: (i) substrate; (ii) transport; (iii) maintenance and overheads; (iv) depreciation fund for mechanical and electrical elements; (v) electricity consumption and (vi) insurance. The substrate cost is null if the feedstock used is animal manure instead it represents a source of income when ofmsw is used.

The cost of upgrading is a function of the technology used and the quantity of biogas processed. Furthermore, operational costs are typically low and they include: (i) electricity consumption, (ii) maintenance and overheads, (iii) depreciation fund for components that will be replaced and (iv) insurance.

The mathematical model used to measure the financial feasibility of biomethane plants is reported below:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{n} \frac{I_t - O_t}{(1+r)^t}$$

$$\sum_{t=0}^{DPBT} \frac{C_t}{(1+r)^t} = 0$$

Revenues-vehicle fuel

$$I_t = R_{t,vf}^{\text{subsidies}} + R_{t,vf}^{\text{selling}} + R_{t,vf}^{\text{ofmsw}}$$

$$R_{t,vf}^{\text{subsidies}} = Q_{biomethane} * i_{cic}^{u} * c_c^{vf}$$

$$R_{t,vf}^{\text{selling}} = Q_{biomethane} * p_{sng}$$

$$R_t^{\text{ofmsw}} = Q_{ofmsw} * (R_{gross,t}^{ofmsw} - C_t^{ofmsw})$$

Revenues-feeding into the grid

$$I_t = R_{t,fitg}^{\text{subsidies}} + R_{t,fitg}^{\text{selling}} + R_{t,fitg}^{\text{ofmsw}}$$

$$R_{t,fitg}^{\text{subsidies}} = Q_{biomethane}^{fitg} * ((2p_{ng}^{2012} * c_{c,si}^{fitg}) * c_{c,su}^{fitg})$$

$$R_{t,fitg}^{\text{selling}} = 0$$

with $S_{biomethane} \leq 500\, m^3/h$ or

$$R_{t,fitg}^{\text{subsidies}} = Q_{biomethane}^{fitg} * (((2p_{ng}^{2012} - p_{ng}^{c}) * c_{c,si}^{fitg}) * c_{c,su}^{fitg})$$

$$R_{t,fitg}^{\text{selling}} = Q_{biomethane}^{fitg} * p_{ng}^{c}$$

Revenues-combined heat and power

$$I_t = R_{t,chp}^{\text{subsidies}} + R_{t,chp}^{\text{selling}} + R_{t,chp}^{\text{ofmsw}}$$

$$R_{t,chp}^{\text{subsidies}} = Q_{biomethane}^{el} * (i_{aifit}^{u} + c_c^{chp})$$

$$R_{t,chp}^{\text{selling}} = Q_{biomethane}^{th} * p_z^{th} * p_u^{th}$$

Con $S_{biogas} \leq 1\, MW$ or

$$R_{t,chp}^{\text{subsidies}} = Q_{biomethane}^{el} * (i_{aifit}^{u} + c_c^{chp} - p_z^{el})$$

$$R_{t,chp}^{\text{selling}} = Q_{biomethane}^{el} * p_z^{el} + Q_{biomethane}^{th} * p_z^{th} * p_u^{th}$$

Costs

$$O_t = C_{lcs,t}^{1°s} + C_{lis,t}^{1°s} + C_{lcs,t}^{2°s} + C_{lis,t}^{2°s} + C_{lcs,t}^{3°s} + C_{lis,t}^{3°s} + C_{l,t} + C_{s,t} + C_{ts,t} + C_{mo,t}^{1°s} + C_{df,t}^{1°s} + C_{e,t}^{1°s} + C_{i,t}^{1°s} + C_{mo,t}^{1°s} + C_{df,t}^{1°s} + C_{e,t}^{2°s} + C_{i,t}^{2°s} + C_{o,t}^{com} + C_{o,t}^{dis} + C_{tax,t}$$

$$C_{inv}^{1°s} = C_{inv}^{u,1°s} * S_{biogas}$$

$$C_{lcs,t}^{1°s} = C_{inv}^{1°s}/n_{debt}$$

$$C_{lis,t}^{1°s} = \left(C_{inv}^{1°s} - C_{lcs,t}^{1°s}\right) * r_d$$

$$C_{inv}^{2°s} = C_{inv}^{u,2°s} * S_{biomethane}$$

$$C_{lcs,t}^{2°s} = C_{inv}^{2°s}/n_{debt}$$

$$C_{lis,t}^{2°s} = \left(C_{inv}^{2°s} - C_{lcs,t}^{2°s}\right) * r_d$$

$$C_{inv}^{3°s} = C_{inv}^{com} + C_{inv}^{dis}$$

$$C_{lcs,t}^{3°s} = C_{inv}^{3°s}/n_{debt}$$

$$C_{lis,t}^{3°s} = \left(C_{inv}^{3°s} - C_{lcs,t}^{3°s}\right) * r_d$$

$$C_{l,t} = C_l^{u,a} * n_{op}$$

$$C_{s,t} = C_s^{u} * Q_{feedstock}$$

$$C_{ts,t} = C_{ts}^{u} * Q_{feedstock}$$

$C_{mo,t}^{1°s} = p_{mo}^{1°s} * C_{inv}^{1°s}$
$C_{df,t}^{1°s} = p_{df} * C_{lcs,t}^{1°s}$
$C_{e,t}^{1°s} = c_e^{u,1°s} * Q_{biogas} * p_e$
~~$C_{i,t}^{1°s} = p_i * C_{inv}^{1°s}$~~
$C_{mo,t}^{2°s} = p_{mo}^{2°s} * C_{inv}^{2°s}$
$C_{df,t}^{2°s} = p_{df} * C_{lcs,t}^{2°s}$
$C_{e,t}^{2°s} = c_e^{u,2°s} * Q_{biogas} * p_e$
$C_{i,t}^{2°s} = p_i * C_{inv}^{2°s}$
$C_{o,1}^{com} = C_o^{com}$
$C_{i,1}^{dis} = C_o^{dis}$
$C_{tax,t} = p_{tax}^{unit} * ebt$
$C_{i,t}^{1°s} = p_i * C_{inv}^{1°s}$

Flow rate

$Q_{biogas}^{nom} = S_{biogas} * n_{oh} * \%CH_4$
$Q_{feedstock} = Q_{biogas}^{nom} / (p_b^u * (\%vs/ts) * (\%ts/(ww + ts)))$
$Q_{biogas} = Q_{biogas}^{nom} * (1 - l_{bs})$
$Q_{biomethane}^{nom} = S_{biomethane} * n_{oh}$
$Q_{biomethane} = Q_{biogas} * (\%CH_4) * (1 - l_{us})$
$Q_{biomethane}^{fitg} = Q_{biomethane} * (1 - p_{esc})$
$Q_{biomethane}^{el} = Q_{biomethane} * c_f^{el} * (1 - l_f^{el})$
$Q_{biomethane}^{th} = Q_{biomethane} * c_f^{th}(1 - l_f^{th})$
$Q_{biomethane}^{chp} = Q_{biomethane} * (1 - l_f^{el})$

In this analysis the lifetime of the plant is equal to lifetime of the subsidies (20 years) and the investment cost is covered by third party funds considering that the opportunity cost is fixed to 5%. The final specification of the gas (as for example composition and pressure) must be real time monitored in order to be adjusted to their final use. Generally, biomethane plant process monitoring is useful also to give an overall picture of the biogas process [17]. The costs of basic monitoring are often much lower than the costs and lost revenue associated with re-establishing a biologically destabilized plant. In general it is crucial that values of relevant process parameters, such as temperature and pH, are established during stable operation. By recording these process parameters over the life of the plant, any change from "normal" can be identified quickly. Apart from recording these parameters, general process information such as mass of input, organic loading rate and operational problems should be documented. This means that the off-line analysis of parameters, which means analysis of samples in a laboratory, a minimum of on-line process monitoring equipment will have to be installed in every biogas plant. In general, the level of investment in on-line equipment should always be made in relation with the economic risks in the biogas plant.

Two different technique can be used for on-line process plant monitoring. These two approaches are the NIRS (near-infrared spectroscopy) and the so called "electronic nose". Nowadays such technique have not often been in use at biomethane plants due to high costs but have the strengthens of being remote connected and achieved data can be directly stored or remotely downloaded for monitoring at any time on any place.

Concerning upgrading technology, this paper evaluates the use of two technology so that the investment cost of upgrading phase can be minimize: membrane separation for 100 m^3/h and 250 m^3/h and water scrubbing for 500 m^3/h and 1000 m^3/h.

When biomethane is injected into the grid only distribution is needed instead when biomethane is sold as vehicle fuel compression and distribution are required because vehicle fuel has a higher pressure that the other two final destinations.

3 Results

Table 1 reports the results of the economic analysis, in particular NPV and DPBT of 24 case studies examined in this work. In 10 of 12 scenarios obtained by ofmsw substrate, biomethane plants are profitable, instead considering mixed substrate the profitability is verified only in 2 scenarios. In fact, NPV varies from -324 k€ in 100 m^3/h plant for use of biomethane fed into the grid to 49059 k€ for 1000 m^3/h in vehicle fuel destination when the feedstock is ofmsw. Instead NPV has range from -26142 k€ in 1000 m^3/h for use of biomethane destined for cogeneration to 2734 k€ in 1000 m^3/h in vehicle fuel destination if the substrate is mixed. Therefore, the profit is high positive in many scenarios but also great losses can be obtained. These different results depend on the use of substrate because there are both profits linked to the treatment of ofmsw equal to 0.29 €/m^3 that the application of corrective coefficients present in the incentive scheme ($c_{c,su}$ is equal to 1 and 1.5 for mixed and ofmsw, respectively).

The DPBT analysis shows results consistent with the analysis previously examined. In fact, when NPV is negative DPBT is 20 therefore even if the investor defines the cut-off period equal 20 years investment cannot be recovered within this date and so is unprofitable.

Table 1. Profitability analysis

Final Use	Vf	Fitg	Chp	Vf	Fitg	Chp
Substrate	Ofmsw			Mixed		
	100 m^3/h			**100 m^3/h**		
NPV (k€)	-364	-324	837	-3481	-5265	-2302
DPBT (y)	>20	>20	2	>20	>20	>20
	250 m^3/h			**250 m^3/h**		
NPV (k€)	6993	5966	3998	-2961	-8526	-3555
DPBT (y)	1	1	1	>20	>20	>20
	500 m^3/h			**500 m^3/h**		
NPV (k€)	21104	18300	5664	807	-11115	-13181
DPBT (y)	1	1	2	2	>20	>20
	1000 m^3/h			**1000 m^3/h**		
NPV (k€)	49059	26672	17328	2734	-24364	-26142
DPBT (y)	1	1	1	1	>20	>20

In 12 scenarios DPBT is < 20 and it varies from 1 to 3 years; these values are so low both because operating costs are much greater than investment costs that are covered by third party funds.

Furthermore, Fig. 1 presents the ratio between NPV and biomethane size for all 24 case studies in order to examine the economies of scale.

However, in these cases studies the economies of scale have a low relevance because of the presence of corrective coefficients of incentive scheme. In fact, this

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ratio increases as the size of the plant increases only when the biomethane is sold as vehicle fuel.

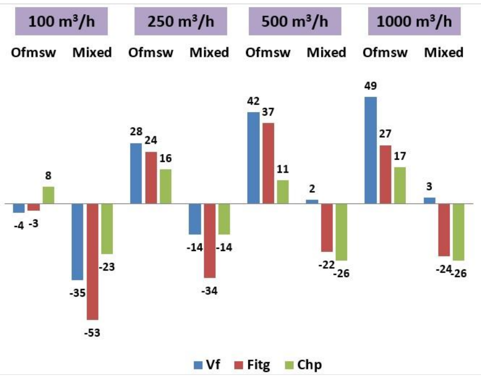

Fig. 1. NPV and biomethane size

Monte Carlo Stochastic Modeling of NPV

Monte Carlo modeling is a type of simulation that estimate the chance of biomethane plants to lose money. It is useful when investors face conditions of uncertainty. This study makes random sampling with uniformly distribution in the variables' neighborhood and finally it uses the statistical analyses to compute the results.

This simulation can be summarized in the following key points:

1. Choosing the uncertain variables $x_1, x_2, \ldots, x_n$and their interval;
2. Building a parametric function, $y = f(x_1, x_2, \ldots, x_n)$;
3. Generation of random input chosen variables $x_{i1}, x_{i2}, \ldots, x_{in}$;
4. Calculate results of function y_i;
5. Repeat points 3 and 4 for $i = 1$ to 1000;
6. Analyzing the results through statistical indicators.

In this study, Monte Carlo methodology is performed under varying economic conditions:

• i^{u}_{aifit} plant unitary revenue from incentive for CHP with an interval of 0.02 €/kWh respect to the value in the base scenario;

•$c^{u,1°s}_{inv}$ investment unitary cost with an interval of 400 €/kW respect to the value in the base scenario;

•c^{u}_{ts} substrate unitary cost with an interval of 4€/t respect to the value in the base scenario;

•$p^{1°s}_{mo}$ plant maintenance cost with an interval of 10% respect to the value in the base scenario;

Monte Carlo analysis is applied in all 24 scenarios examined in this study.

The results (Table 2) show that if the feedstock is ofmsw the probability to have NPV >0 is around 100% in 9 of 12 scenarios. It is possible to note that these 3 scenarios have all a 100 m^3/h plant size. From the other side, using mixed as substrate only 2 scenarios have a sufficiently high probability that NPV is greater than zero. This is verified when biomethane is sold as vehicle fuel and plant size is greater than 500 m^3/h.

Table 2. Montecarlo analysis

			Mean Value	Prob. of NPV>0		Mean Value	Prob. of NPV>0
Size	Use	Scenario (OFMSW)	[%]	[k€]	Scenario (MIXED)	[k€]	[%]
100	VF		34.0	-359,8		-3585,7	0.0
250	VF		100.0	6967,4		-3081,5	1.9
500	VF		100.0	21079,9		850,6	63.5
1000	VF		100.0	49110,6		2635,9	88.3
100	FITG		35.7	-318,9		-5242,4	0.0
250	FITG		100.0	5942,0		-8329,1	0.0
500	FITG		100.0	18277,3		-1086,6	0.0
1000	FITG		100.0	26724,9		-24112,1	0.0
100	CHP		85.4	840,8		-2255,5	0.0
250	CHP		99.7	3973,2		-3469,0	0.1
500	CHP		97.3	5650,3		-12433,5	0.0
1000	CHP		100.0	17396,2		-26271,5	0.0

4 Conclusions

There is a great interest around biomethane and this paper demonstrates clearly the link between incentives and profitability in this sector. The development of biomethane requires the feasibility of investments and the analysis of the results indicates that high profits can be obtained, but are possible also great losses.

Biomethane used as vehicle fuel is often the best choice among the three final destinations and this is determined by incentive scheme favouring the development of biomethane in the transport sector. In according to values proposed in this paper urgent actions are required in Italy in order to increase the share of renewable energy in transport. Moreover, also for biomethane grid injected is opportune to introduce corrective coefficient since Italy presents a strong dependence of gas by foreign supplies. The use of biomethane in natural gas vehicles reaches significant reduction of emissions favouring the development of circular economy.

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