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The economic sustainability of small–scale biogas plants in the Italian context: the case of the cover slab technology

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Abstract. The growing interest on renewable energies, together with the public financial incentive systems established in several countries, has driven a fast innovation in the field of energy technologies, with the main objective to increase their sustainability.
This paper focuses on the production of biogas from agro–residues and animal manure; with particular attention to small-scale plants.
Based on a real case located in northern Italy, and taking into consideration the Italian public financial incentive system currently in force, the economic profitability of the cover slab technology is analysed, putting into evidence the main factors that affect it.

Key words: Anaerobic digestion, small–scale biogas plants, Italian biofuel plants.

INTRODUCTION

It is a fact that energy demand is growing worldwide, due both to population growth and economic development. At the same time, pressure on the environment to satisfy energy needs is increasing and the risk of compromising the possibility for future generations to get access to natural resources is concrete.

It is therefore our duty to seek for sustainable processes and technologies, in order to control this risk. In this sense, biogas energy seems to be a great opportunity to exploit.

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 (Eder et al., 2007; Deublein & Steinhauser, 2010; Villarini et al., 2011).

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 (Berglund & Börjesson, 2006; Hartmann, 2006; Murphy & Power, 2009; Pöschl et al., 2010; Blengini et al., 2011; Akbulut, 2012). In this regard, public financial incentives for biogas producers guaranteed by different Countries play an important role (Massaro et al., 2015).

This paper is focused on the economic sustainability small sized biogas plants and in particular on the cover slab technology.

To date, small sized plants have been the most diffuse solutions for the production of biogas in developing countries (Food and Agricultural Organisation (FAO), 1996; Asikainen, 2004; Balasubramaniyam et al., 2008; Ulrich et al., 2009; Rakotojaona, 2013; Vögeli et al., 2014), where several technologies have been adopted (Kumar et al., 2015).

Today, the interest around small–scale plants is growing even in some developed countries, such as in Italy, where most biogas plants are of large scale (0.5–1 MW of power) and where recently public financial incentives have been redirected in order to favour small–scale plants.

In this paper, after an analysis of the technologies spreading today in Italy for small–scale plants, the economic sustainability of the cover slab technology is assessed through the analysis of a real case in the context of northern Italy. In the same context, the cover slab technology has demonstrated to be a promising solution with respect to the environmental sustainability (Collotta & Tomasoni, 2017).

Finally, conclusions are drawn also in order to evaluate the dependence of the economic profitability of each technology on public financial incentives.

MATERIALS AND METHODS

The Italian biogas context

General framework

In 2014, the EU biogas energy production was estimated to be about 14,9 Mtoe (Million tonnes of oil equivalent) coming from different sources as landfill gas, sewage sludge gas and other biogas from anaerobic fermentation (agricultural feedstock and agro–residues) (EurObserv'ER, 2015).

With regard to the Italian context, at the end of 2013, the whole biogas plants installed power was about 756 MWe, while the number of plants was close to a thousand (994). Almost all plants are installed in northern regions and about 58% allows the co–digestion of animal manure and energy crops, for example maize, sorghum, and agro–residues. Biogas in Italy is estimated to have the potential capacity to produce about 6.5 billion of m^3 $year^{-1}$ of CH_4 and about 20 t Wh $year^{-1}$ of electric energy (Colonna, 2011; Piccinini, 2013).

Installed power and number of plants are fast growing, as shown in Table 1. In the period 2011–2015, for example the number of biogas plants moved from 521 to the 994: an increase of about 47% in only one year 2011–2012). The same trend is observed also with regard to the whole electric power installed (Fabbri et al., 2013).

Table 1. Biogas plants installed in Italy

	April 2007	March 2010	May 2011	December 2012	December 2013	December 2014
Number of plants	154	273	521	994	1,391	1,491
Whole electric power (MW_e)	49	140	350	756	1,105	n/a
Average power (kW_e)	318	513	672	761	n/a	n/a

With regard to the size of the plants installed, in terms of electric power and its trend, Table 2 shows the distribution of the number of new plants among different electric power classes in the period 2005–2012.

Table 2. Trend of Biogas plants in Italy

Electric power	2005	2006	2007	2008	2009	2010	2011	2012
≤ 100 kW_e	1	1	6	7	1	11	5	9
101–500 kW_e	3	3	7	7	14	17	57	68
501–1,000 kW_e	1	4	11	20	33	74	193	256
> 1,000 kW_e	1	3	0	3	1	3	7	2
Total	7	11	24	37	50	106	273	350

As it clearly appears, the large majority of the plants installed in Italy up to the end of 2012 are medium to large sized plants, with an electric power that goes from 500 to 1,000 kW_e.

The public financial incentive system and the small sized plants

The fast growing of the number of biogas plants observed in Italy in the last few years can be largely ascribed to the presence of generous public financial incentives to the exploitation of biogas (Massaro et al., 2015), and in particular to the production of electric energy from biogas 280 € MWh^{-1}), established by the so called 'D.M. 18 December 2008' law (Ministero dello Sviluppo Economico, 2008).

On 1st of January 2013, the structure of the financial incentive system was modified with the coming into force of the so called 'D.M. 6 July 2012' law, which outperformed the former legislation (Ministero dello Sviluppo Economico, 2012). More recently, on 23th June 2016 new financial incentive system has been introduced to encourage the production of electricity and heat using renewable sources (Ministero dello Sviluppo Economico, 2016a).

D.M. 23 June 2016 aims at reaching the objectives defined in the European Directive 2009/28/EC of the European Parliament and of the Council of 23rd April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (European Parliament, 2009). It establishes new ways of encouraging the production of electricity from plants renewable energy sources other than photovoltaic panels, with a power not exceeding 1 kW.

The financial incentives provided by D.M. 23 June 2016 apply to new facilities, fully rebuilt or re–activated plants which came into operation from 29 of June 2016 onwards. This decree establishes also a maximum national cap of €5.8 billion for public funds supporting renewable energy plants.

Further, in December 2016 a national decree allowed for the first time the use of biomethane as a transport fuel (Ministero dello Sviluppo Economico, 2016b). This law encouraging the production and use of biomethane in Italy, where currently circulates more than 800.000 Natural Gas Vehicles (NGV) (Seisler, 2014).

The financial incentives for biogas plants consist of two different parts. A first part, called 'basic incentive', which include also the price of electric energy, is based both on the electric power installed and on the organic matrices used for the anaerobic digestion process. The second part, regardless of the size, is related to the presence of a high efficiency cogeneration system and to the reduction of the nitrogen concentration in the digestate). All financial incentives for biogas plants are guaranteed for a time period of 20 years. Table 3 shows the values of the basic incentives.

Table 3. Public financial incentives for biogas plants in Italy (€ MWh^{-1})

Organic matrices	Electric power (kW_e)				
	1–300	300–600	600–1,000	1,000–5,000	> 5,000
Products of biological origin	170	140	120	97	85
By–products of biological origin > 70 %	233	180	160	112	–

As clearly shown, the highest incentive rates are targeted at small sized plants, which is an innovation with respect to the former legislation. Moreover, small sized plants are today advantaged by the simplified bureaucratic procedure for the authorization. In particular, plants with power installed under 100 kW_e do not require any authorizations, while for larger plants it is required to apply in advance to special registers or to win dedicated auctions.

Finally, plants up to 100 kW_e are connected at low voltage electrical grid instead of medium voltage, which may reduce costs for grid connections. Considering all these evidences, it is expected to observe in the next future a growing interest and an increasing market demand for small sized plants.

Biogas technologies for small sized plants

As stated above, recent Italian legislation favors the diffusion of small sized plants for the production of biogas. At any rate, 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 (Walla & Schneeberger, 2008).

Technologies for small sized plants are not as mature as technologies for medium or large sized plants (Eder et al., 2007; Deublein & Steinhauser, 2010; Villarini et al., 2011). The most adopted approach consists in the miniaturization and simplification of the structure of larger plants (Singh & Sooch, 2004; Kimming et al., 2011; Patterson et al., 2011).

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%.

The anaerobic digestion of biomass is made of four subsequent phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. Traditional medium or large sized plants have a structure that reflects these phases, with one or more digester devoted to each of the four phases, plus other facilities for preparatory or conclusive phases (Eder et al., 2007).

In small sized plants, one or more of the digestion phases are grouped in order to minimize or reduce the plant costs related to the civil structure (cement tanks) and to the electro–mechanical components such as pumps and mixers (Berglund & Börjesson, 2006; Ishikawa et al., 2006; Poeschl et al., 2012). Fig. 1 shows three possible structures for small sized plants.

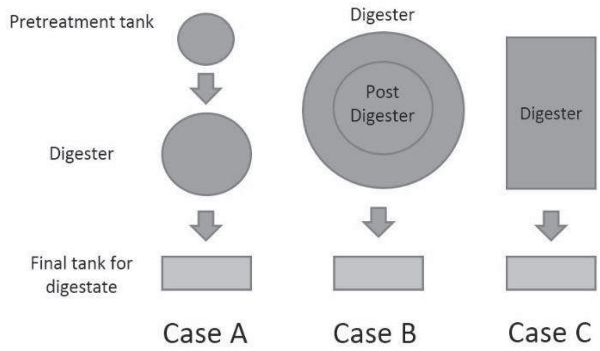

Figure 1. Schemes for biogas small sized plants.

Currently, even though the market is still limited, it is possible to identify different available technologies for small sized plants (presented in Fig. 1). In the following, three different alternatives of case A (bags technology, balloon cover technology and cover slab technology) for plants with a 100 kW_e cogenerator with 8,000 h y^{-1} are introduced.

Bags technology

In this case, the digestion of biomass takes place within a bag. Bags were initially used as a flexible system for the storage of liquid and manure and were subsequently converted in bags digester for the anaerobic fermentation. The scheme of a biogas plant with bags technology is presented in Fig. 2; this scheme is one of the most diffuse even in developing countries (Aguilar, 2001; Cheng et al., 2014). The plant consists of a pre–treatment tank, a digester, a cogenerator and an adjoining room with an adjoining heat exchanger.

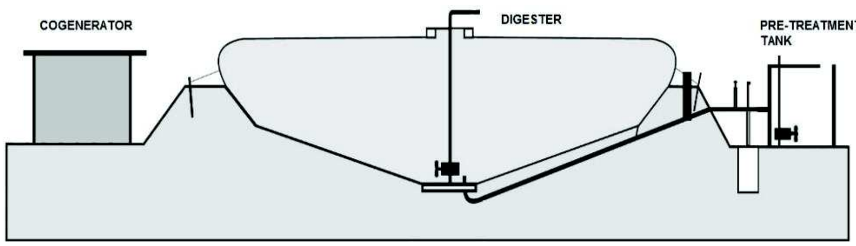

Figure 2. Scheme of a biogas plant with bags technology.

The digester is made of a bag in which the fermentative phenomena generated by the organic substance take place. 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 may be necessary, with an area occupation of about 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.

The pre–treatment tank is a special tank equipped with an agitator that homogenizes manure with substrates that are inlaid. Also during pre–treatment biomass is heated.

Balloon cover technology

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 (Sasse, 1988; Villarini et al., 2011). The digester consists of a concrete circular structure with a balloon cover with a volume of 2,000 m^3 in which biogas is stored (presented in Fig. 3). The digester is equipped with a heating system and mixers that agitates the liquid inside the tank.

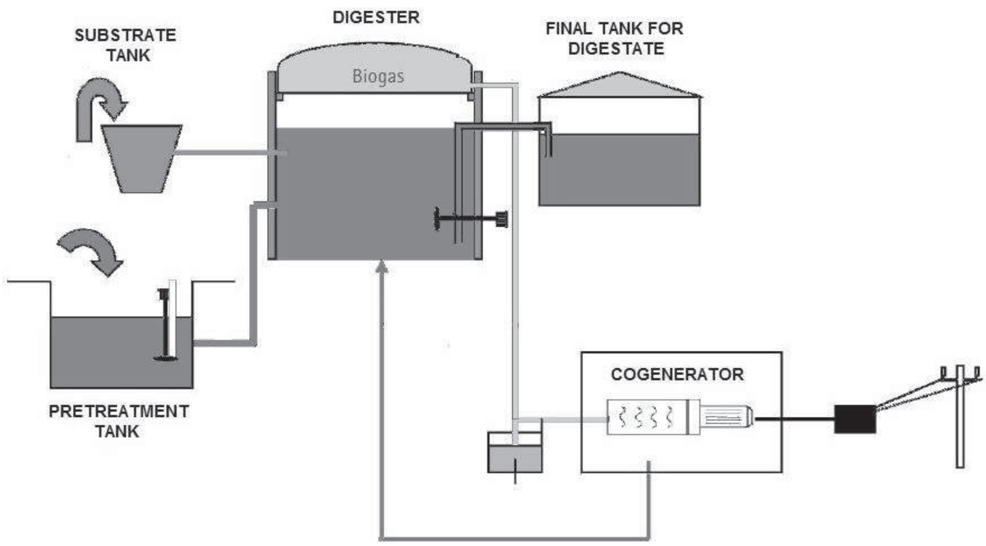

Figure 3. Scheme of a biogas plant with balloon cover technology.

In a typical configuration, the pre–treatment facility needs two different tanks as manure and molasses are loaded in the digester separately through a pump. By–products are loaded with a mixer feeder without preheating treatment. The fermentation phase follows the pre–treatment phase and the digester occupies an area of about 800 m^2.

Cover slab technology

A biogas plant with cover slab technology consists of: a pre–treatment tank, a volumetric pump with shredder, a compact digester, a final tank for digested material and a co–generator (Villarini et al., 2011; Ramatsa et al., 2014; Shukla et al., 2015). The pre–treatment tank volume is about 50 m^3 and is equipped with a system for the mixing and homogenization of manure with substrates.

To ensure a better performance, especially in winter, the pre–treatment tank is also equipped with a heating system. A volumetric pump and a shredder send the heated fluid to the digester and circulate it inside the pre–treatment tank.

The digester consists of a compact circular tank with a volume 700 m^3 and is sealed with a rigid cover slab which allows a high thermal insulation; it is equipped with a heating system that allows maintaining constant internal temperature of 40 °C. Moreover, the presence of the mixers allows agitating automatically the liquid inside the tank. The final tank for digestate collects through a pipe the digestate that comes out of the digester. The scheme of the biogas plant with cover slab is presented in Fig. 4.

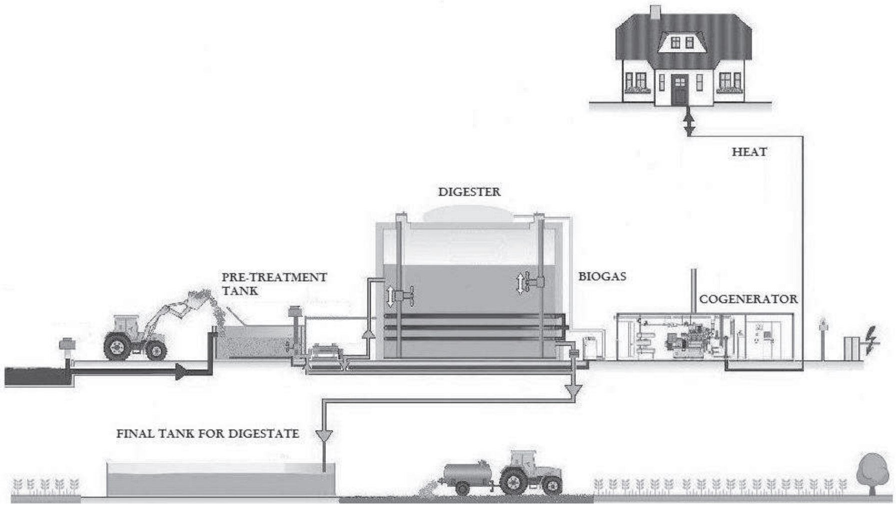

Figure 4. Scheme of the biogas plant with cover slab technology.

This kind of technology introduces the innovative slab in the digester; this structure increases the energy performance of the plants.

Economic analysis

The economic performance of a technology is an important aspect when evaluating its sustainability. In general, leading an economic analysis of biogas plants, it is opportune to consider revenues, coming from electric energy and heat produced, and costs sustained (Murphy & Power, 2009; Akbulut, 2012). With regards to costs, common classifications identify two main types of costs: plant costs and operational costs (including maintenance, insurance, feeding materials, etc.).

With reference to the three technologies above introduced, based on some interviews with several designers, manufacturers and users of biogas plants operating in Italy, it is possible to say that the balloon cover technology has the lower plant cost, avoiding most of the civil works, and the highest operational costs, requiring a higher energy consumption to heat the digestate. On the contrary, the balloon cover technology has the highest plant cost. This is mainly due to the presence of a stationary mixer feeder. Moreover, with reference to operational costs, the net heat production is lower with respect to the cover slab and the self consumption of electric energy is higher.

With reference to the environmental performance of the same three alternative technologies, in a previous work from the authors, a comparison among them 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 (Collotta & Tomasoni, 2017).

The results obtained, referred to the Italian context showed that the balloon cover technology has the worst performance in all environmental impact categories, while the cover slab technology seems 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.

Scenarios overview

For this reason, it is of great importance to conduct a deeper analysis of the economic performance of the cover slab technology. The analysis refers to a real case of a plant located in the Lombardia Region (northern Italy). In particular, plant and operational costs, as far as revenues, were first estimated before the design and the construction of the plant and then refined gathering data on the field for 6 months after the start of plant operations.

To obtain more interesting results, for the estimation and the calculation of the revenues, it was anyway hypothesized to consider the financial incentives of the new D.M. 23/06/2016 law.

Table 4 summarizes the main technical characteristics of the plant under study.

Table 4. Technical characteristics of the plant under study

Capacity of the digester (gross)	858 m^3 (6 m height, 13.5 m diameter)
Capacity of the digester (net)	770 m^3
Biogas storage volume	165 m^3 (90 m^3 digester + 75 m^3 gasometer)
Methane concentration in biogas	55–60%
Retention time of digestate	32 days 2 days pre–treatment + 30 days digester)
Electric power of the cogenerator	100 kW_e
Organic load of the digester	3.29 kg VS m^{-3} day^{-1}
Energy efficiency	0.46 m^3 biogas per kg VS

For the economic analysis, it was originally hypothesized to feed the plant with 7,753 ton $year^{-1}$ of biomass, composed by 7,198 tons $year^{-1}$ of animal slurry with a quantity of straw allowing to reach a solid substance concentration of about 10% to 13%, 360 tons $year^{-1}$ of olive pomace and 195 tons $year^{-1}$ of molasses. Employing a cogenerator with an electric power of 100 kW_e, the expected yearly gross electric energy production was 760,000 kWh_e, while the expected yearly gross heat production was 540,000 kWh_{therm}. All net heat energy recovered is used within the farm where the plant is located.

The comparison between expected and actual data highlighted surprising differences, in particular with respect to costs. In fact, a substantially modified recipe of the biomass feeding the plant was observed and this had a strong effect on the operational costs.

Table 5 shows the expected and the actual quantities of all biomass components, while.

Table 5. Expected and actual biomass composition

Components	Expected values	Actual values
Animal slurry	7.198,0 ton $year^{-1}$	7.198,0 ton $year^{-1}$
Olive pomace	360,0 ton $year^{-1}$	150,0 ton $year^{-1}$
Molasses	195,0 ton $year^{-1}$	0,0 ton $year^{-1}$
Total	7.753,0 ton $year^{-1}$	7.348,0 ton $year^{-1}$

RESULTS AND DISCUSSION

Table 6 shows the expected and actual values of gross and net heat and electric energy production.

Table 6. Expected and actual heat and electric energy production

Output	Expected values	Actual values
Gross electric energy	760,000 kWh_e	–
Net electric energy	690,000 kWh_e	681,160 kWh_e
Gross heat	540,000 kWh_{therm}	–
Net heat	125,000 kWh_{therm}	122,233 kWh_{therm}

The main differences observed belong to the reduction of the employ of biomass other than animal slurry. In fact, the quantity of olive pomace is halved and the molasses are completely avoided. This had a positive impact both on the environmental performance of the plant and on the profitability of the investment, especially for the high cost of molasses, as specified below.

A first effect of the avoidance of molasses consumption is related to plant costs, as it would be possible to avoid the storage tank and pipelines for molasses feeding (for this analysis, this effect was not considered, as the plant studied has both the storage tank and pipelines for molasses feeding).

A second and most important effect is related to operational costs, as it is not necessary to bear the cost of molasses, which can have a great influence on the whole profitability of the investment. This is due to the fact that the thermal insulation of the digester obtainable with the cover slab technology, which is higher than those reachable with other technologies, allowed to reach temperatures above the mesophilic status (about 42–45 °C), as measured on the field, allowing higher efficiency in biogas production even without molasses and olive pomace.

An important issue to highlight relates to the composition of the animal slurry and, in particular, to the particular straw used. In fact, for the specific case considered, the animal straw consisted of pellets straw, instead of bulk straw commonly used.

Pellets straw is a matter that is now spreading among farmers and is a substitute of bulk straw, i.e. it is used to create a layer of litter on the mats of the bunks. The special shape (the diameter of pellets varies from 7 to 8 mm), the specific weight and the high absorption capacity of pellets straw allow farmers to obtain a very persistent and dry layer of litter. Thin dimensions of pellets straw favors also the anaerobic digestion of animal slurry and thus increase its efficiency.

The following Table 7 and Table 8 show the expected and actual annual revenues and costs.

No significant differences were observed between expected plant costs and actual plant costs, which were equal to 600,000 €.

For the economic analysis, the net present value and the payback time were calculated with a discounting rate of 4% and an useful life of 20 years. Even though this is a long time period for the evaluation of investment returns, we adopted it as it is the time period in which the financial incentives are guaranteed. Table 9 shows the results of the analysis.

Table 7. Expected annual revenues and operational costs

Revenue items	Quantity	Unit revenue	Total revenues
Net electric energy	690,000 kWh_e	0.233 € kWh_e^{-1}	160,770.00 €
Net heat energy	125,000 kWh_{therm}	0.01 € kWh_{therm}^{-1}	1,250.00 €
Total revenues	–	–	162,020.00 €
Cost items	**Quantity**	**Unit cost**	**Total costs**
Service and maintenance	760,000 kWh_e	0.03 € kWh_e^{-1}	22,800.00 €
Supervision and external assistance	–	–	4,000.00 €
Olive pomace	360 ton	25 € ton^{-1}	9,000.00 €
Molasses	195 ton	200 € ton^{-1}	39,000.00 €
Insurance	–	–	4,000.00 €
Other costs	–	–	6,000.00 €
Total costs	–	–	84,800.00 €

Table 8. Actual annual revenues and operational costs

Revenue items	Quantity	Unit revenue	Total revenues
Net electric energy	681,160 kWh_e	0.233 € kWh_e^{-1}	158,710.28 €
Net heat energy	122,233 kWh_{therm}	0.01 € kWh_{therm}^{-1}	1,222.33 €
Total revenues	–	–	159,932.61 €
Cost items	**Quantity**	**Unit cost**	**Total costs**
Service and maintenance	760,000 kWh_e	0.03 € kW_e^{-1}	22,800.00 €
Supervision and external assistance	–	–	4,000.00 €
Olive pomace	150 ton	25 € ton^{-1}	3,750.00 €
Molasses	0 ton	200 € ton^{-1}	0.00 €
Insurance	–	–	4,000.00 €
Other costs	–	–	6,000.00 €
Total costs	–	–	40,550.00 €

Table 9. Expected and actual annual profit and payback period

	Net present value	Payback period
Expected values	449,445 €	9.4 years
Actual values	880,717 €	5.7 years

As Table 9 shows, the net present value is almost doubled and the payback period almost halved, bringing to a result that is quite better that what was expected. Greater results could be obtained with further simplification of the plant, in particular avoiding the adoption of the storage tank and pipelines for molasses feeding.

CONCLUSIONS

To improve the biogas energy diffusion and to exploit its potential, the availability of sustainable technologies for biogas plants is a necessary condition, particularly from the environmental and economic point of view.

In Italy, a recent innovation of the public financial incentive system for biogas energy, due to a renewed legislation, favors small sized plants instead of traditional larger plants.

In this paper, an economic analysis of the cover slab technology for small sized biogas plant has been carried out. In particular, an investment profitability assessment is reported, referred to a real case of a plant installed in northern Italy and adopting the cover slab technology. Thanks to the high insulation of the digester obtainable with the rigid cover slab, this technology allows to reach high temperature of biomass and enhance efficiency reducing the use of biomass other than animal slurry. This has a positive effect on the operational costs, which are halved.

Considering the overall profitability of the investment, public financial incentives for biogas energy still play an important role, as without them revenues would be halved and payback time would not be acceptable.

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