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Economic performance of biogas plants using giant reed silage biomass feedstock

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ABSTRACT

With regard to energy crops for the production of raw materials to biomass for biogas plants, has developed a study to determine the optimal minimum size of a biogas plant powered by giant reed (*Arundo donax* L.) and utilizing livestock waste.

In particular, all costs items relating to biomass supply, plant installation and transport costs were analyzed, by changing progressively two main variables: the electrical power capacity and the feedstock utilized (in the range from 100 to 999 kW) and the feedstock utilized, by substituting livestock waste with giant reed silage so as to determine the more economically advantageous option for the entrepreneur in proportion to power capacity generated. Furthermore, we calculated the revenues from the sale of electricity, according to the new incentive policies. The study results showed that, depending on current market conditions, the plants are more favorable results than size equal to 400 and 450 kW. In according to the current economic policies, the best results in terms of economic performance have occurred in plants of 300 kW. The study has highlighted how small-size plants can represent a possible strategy to improve the enterprise and territorial competitiveness.

1. Introduction

At present, the major source (~80% of total) of greenhouse gas emissions (GHG) is that associated with energy production (European Environmental Agency, 2008). The production and use of renewable energies can help mitigate climate change, reduce dependence on fossil fuels (Cherubini and Strømman, 2011) and diversify production activities of companies (Testa et al., 2014a; Tudisca et al., 2015). In line with the above, European energy policies aim to occasion a 20% increase in the quota of renewable energies by 2020 (Squatrito et al., 2014; Tudisca et al., 2013; Directive 2009/28/EC).

Interest in biogas as a source of bioenergy is growing since the biogas produced in a reactor (i.e., anaerobic digester) can ultimately be used for producing electrical and/or thermal energy, thereby contributing to exploit renewable energy sources while lessening fossil oil-based consumption (Comparetti et al., 2012; Monarca et al., 2009). Biogas is a biofuel that can be obtained through anaerobic digestion of a wide variety of raw organic matter, that is feedstocks, mainly organic waste from agriculture, livestock farming and industry (Bacenetti et al., 2014).

At the European level, starting as far back as 1970, biomass crops have attracted growing interest (Messineo et al., 2012a), in terms of its future energy supplies, being viewed as cable of meeting a significant portion of its own energy needs, while reducing carbon dioxide (CO_2) emissions (Ragauskas et al., 2006; Hanegraaf et al., 1998). In addition to livestock waste, particular attention has been reserved to energy crops as potential raw material thanks to their relatively high content of volatile solids which make for high yields in biogas production (Colantoni et al., 2014; Jury et al., 2010).

In Italy, there are 1054 biogas plant (Fabbri et al., 2013). Among them, 994 are operated by farmers, using energy crops and livestock waste. The other plants are found in landfill of organic waste. This study focuses exclusively on biogas plant that using energy crops and livestock waste.

The number of systems has grown rapidly in recent years: in fact, the implants between 2002 and 2012 increased by more than 900 units. Most of these plants are located in the Po Valley, where the concentration of large farms is very high (Colonna et al., 2009).

In Italy, 17.7% of the installation can only use livestock waste, 20.1% use only energy crops and 62.2% make use of both (GSE, 2012). The choice is dictated by the organizational model of the company, but also by the capacity of installed power. The

Abbreviations: GHG, greenhouse gases; RDP, rural development plan.

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capacity of a digester with a capacity of 1000 kW requires only energy crops. Among the plants surveyed by Fabbri et al. (2013), 24.5% between 100 and 500 kW, 65.5% had an installed capacity of 500–1000 kW, 2.4% over 1000 kW and 7.6% less 100 kW.

Moreover, from a physico-chemical perspective, energy crops are more homogeneous than organic waste (Sgroi et al., 2015a; Testa et al. 2014b; Panoutsou, 2007). Therefore, dedicated crops such as maize, wheat, triticale, sugar beet and more recently common giant reed, have been cultivated to a significant degree for energy purposes.

In fact, giant reed represents a good alternative to energy crops more commonly used for biomass production for biogas plants. Moreover, giant reed was recently included among crops eligible for European Union contributions, in matter of environmentally beneficial practices (Regulation EU 1307/201; Sgroi et al., 2014a).

Giant reed is a fast-growing polyannual perennial true grass species native to East Asia and widespread throughout the Mediterranean.

This species is particularly suitable in Sicily, where the climate is characterized by hot summers and mild winters (Lanfranchi et al., 2014a; Di Trapani et al., 2014; D'Asaro and Grillone, 2012; Agnese et al., 2008) also, has been designated as one of the most promising energy crops in Southern Europe (Lewandowski and Heinz, 2003).

This species has also low or nonexistent agronomic input requirements (fertilizers, herbicides, pesticides), resilience to environmental stress and because it thrives on marginal, hilly and/or non-irrigated soils, typical of many Mediterranean areas (Angelini et al., 2005a). Furthermore, although its overall cultivation costs are extremely low, it is highly productive on a per hectare basis and studies indicate that during its 15–20 year crop cycle giant reed reaches productions of 37.7 Mg ha^{-1} year^{-1} D.M. (Angelini et al., 2009).

So, the aim of this study is to determine how costs vary for the biogas plant utilizing giant reed silage as a function of the energy produced in absolute terms (€ kWh^{-1}), as well in percentages, analyzing three broad macro-categories (biomass, plant installation and transport) in order to describe the economic performance of biogas plants while progressively changing two main variables: the electrical power capacity (in the range from 100 to 999 kW) and the feedstock utilized, by substituting livestock waste with giant reed silage (Ragazzoni, 2012). In this way, it has been determined the minimum optimal size of a biogas plant in order to choose the best investment for entrepreneur in term of costs.

In fact, with reference to the available options, the entrepreneur opts for those that maximize profit and minimize risk for the enterprise (Lupo, 2014a,b, 2013; Sgroi et al., 2014b).

Furthermore, revenues were calculated in relation to energy generated, according to the new incentive system of the Ministerial Decree of 6 July 2012, which provides a uniform tariff which varies according to the power capacity plant and the diet administered, for a duration than twenty years.

It was considered the capacity of the systems up to 999 kW, because, according to the Ministerial Decree of 6 July 2012, these installations owned or managed farms in connection with agricultural, agro-food, livestock and forestry, powered by biogas, biomass and sustainable bioliquids, after the entry into commercial operation, have the opportunity to access incentives combined with other public incentives do not exceed 40% of the investment cost.

2. Materials and methods

In order to determine the minimum optimal size of a biogas plant utilizing giant reed silage, costs were estimated as a function of the energy produced so as to discern the best choice, on the part of the entrepreneur, in terms of costs (Sgroi et al., 2015b). In relation to the various possible scenarios, all costs items relating to biomass supply, plant installation and transport costs were analyzed. To analyze these costs, as a baseline a range of constituent conditions were supposed as given, such as:

1) the plant with minimum power capacity (100 kW) should be fed only with livestock waste and the one with maximum capacity (999 kW) only with giant reed silage, whereas with increasing capacities there should be a 10% increment in silage for each 100 kW increase in capacity;
2) the enterprise should be entirely self-sufficient from a biomass supply viewpoint, both for livestock waste and giant reed silage as well;
3) the entrepreneur relying on a credit institute for a bank loan, covering 100% of the total investment and considering a payback period of 20 years at a 5% capitalization rate.

In particular, the total cost of biomass is given by the sum of the supply cost for livestock waste plus the cost of giant reed silage supply (Ragazzoni and Castellini, 2012):

$$CB = CLW + Cs \quad (1)$$

where CB is the total cost of biomass (€ kWh^{-1}), CLW is the cost of livestock waste and CS is the cost of silage.

Livestock waste was evaluated as a portion of the total fertilizer possessed. The cost of livestock waste, as a function of its energy potential, was calculated as follows:

$$CLW = \frac{((qN \cdot Vr) \times (1 - 75\%))}{ELW} \quad (2)$$

where CLW is the cost of livestock waste (€ kWh^{-1}), qN is the amount of total nitrogen set at 4.5 kg Mg^{-1} of waste, Vr is the replacement value of the livestock waste matter equal to 0.55 € kg^{-1}, ELW is energy equivalent of livestock waste equal to 35 kWh Mg^{-1}. In addition, for the purposes of the study a reduction coefficient of 75% was applied to the value of the waste so as to account for handling, transport and extra spreading expenditures, as compared to the use of synthetic fertilizers. The value of livestock waste decreases to the extent of its replacement with silage.

The cost of biomass crops for silage supply was estimated considering an installation of giant reed with 1.50 × 0.65 m plant spacing (10,256 plants ha^{-1}) grown in irrigated soil, with a 20 year cycle and a production of 37.7 Mg D.M. ha^{-1} year^{-1} (Angelini et al., 2005b). The cost of the plant was calculated by summing the items relating to both explicit (deep tillage costs, rhizome, plant setting, irrigation equipment, fertilizer, harvest and chipping) and calculated costs (intellectual work, taxes, interest on working capital, lost income, depreciation quota).

The cost of the plant was considered net of public contributions according to measure 121 of Sicilian Rural Development Plan (RDP) 2007–2013 (Rural Development Plan, 2007, equating to 50% of the total cost. The depreciation quota is calculated using the formula:

$$a = A \times \frac{r}{q^n - 1} \quad (3)$$

where a is the depreciation quota, A is the total deferred plant cost at the end of the second year, r is the interest rate equal to 5% at current market conditions, n is the number of years of the investment, from which two years for establishing the planting were subtracted.

The annual cost that the entrepreneur must sustain was calculated by adding to the costs related to the farming operations (fertilizer, harvest and chipping, irrigation water) and the depreciation quota. Our analysis of cost makes reference to