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Economic evaluation of biogas plant size utilizing giant reed

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ABSTRACT

Amongst energy crops for the production of biomass feedstock for biogas plants, giant reed (*Arundo donax* L) has been attracting attention in recent years in Italy. Undoubtedly, this is due to its potentially high yield in terms of biomass, low agronomic inputs, as well as for being eligible for European Union energy crop incentives.

The aim of this study was to perform an analysis of plant costs considering three macro-categories (biomass, plant installation and transport). Also, we aimed to describe the economic performances of biogas plants, while progressively altering two key variables. Specifically, we considered electrical power capacity (in the 100–999 kW range) and several combinations of feeding mixtures of livestock waste and giant reed silage, so as to determine the most economically advantageous option for a given power capacity.

The results showed, on the one hand, that plants having diverse power capacities entail costs that vary as a function of the feedstock used and, on the other, that the entrepreneur's options mainly revolve around two variables, i.e. biomass supply costs and plant size.

Contents

1. Introduction

Nowadays, approximately 80% of greenhouse gas emissions (GHG) derives from energy production [1]. Renewable energy sources can help mitigate climate change, reduce dependence on fossil fuels [2] and diversify production activities [3–5]. In line with the above, European energy policies strive to occasion a 20% total share of renewables by 2020 [6,7].

Interest in biogas as a source of bioenergy has progressively been growing. Since the biogas produced in a reactor (i.e. anaerobic digester) can ultimately be used for producing both electricity and/or thermal energy, it exploits renewable energy sources while reducing fossil oil-based consumption [8–10]. Biogas is a biofuel obtained through anaerobic digestion of a wide variety of feedstocks, mainly organic wastes from agriculture, livestock farming and industry [11,12].

Starting as far back as 1970, biomass crops have attracted growing interest, even at the European level in terms of its energy supplies for the future [13]. In fact, they could fulfill a significant portion of the EU's own energy needs, while reducing carbon dioxide (CO_2) emissions [14,15]. In addition to livestock waste, particular attention has

Abbreviations: DEC, dedicated energy crops; GHG, greenhouse gases; RDP, rural development plan.

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been reserved to energy crops thanks to their relatively high content of volatile solids which make for higher yields in biogas production respect to organic waste [16,17]. Agricultural biogas plants, in fact, are currently growing in importance within the EU biogas sector and the biomass supply is increasingly based on the development of dedicated energy crops (DEC) [18]. This development is due to the fact that DEC may represent an interesting use of set-aside land for farmers [19], having a positive environmental impact in terms of carbon and nutrient supply to soils, erosion and desertification prevention and increase of biodiversity and landscape values [20]. Moreover, EU policies have often granted generous subsidies for DEC producing electric energy generated from biogas, allowing farmers to increase their incomes [21,22].

Accordingly, crops such as maize, wheat, triticale, sugar beet and more recently common giant reed, have been cultivated to a significant degree for energy purposes.

Specifically, giant reed (*Arundo donax* L.) 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 EU contributions, under the heading of environmentally beneficial practices [23,24].

Giant reed is a fast-growing polyannual perennial true grass species native to East Asia. Widespread throughout the Mediterranean, it is especially suited for Sicily where the climate is characterized by hot summers and mild winters [25–27] with minimal temperature variations between urban and agricultural areas. In point of fact, it has been designated as one of the most promising energy crops in southern Europe [28]. In fact, with respect to other DECs this species has low or nonexistent agronomic input requirements such as fertilizers, herbicides, pesticides. In addition, its resilience to environmental stress allows it to thrive on marginal, hilly and/or non-irrigated soils, typical of many Mediterranean areas [29–31]. 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. [32].

Italy is third in Europe for biogas production (9.7% of EU total) with 1178.8 ktoe derived from landfill and agricultural facilities [33]. From 2011 to 2013, biogas plants on farms underwent a surprising surge in Italy (increasing nearly 300%), thanks to particularly favorable incentives for EE generation from biogas [34]. In absolute terms, the total agricultural biogas facilities went from 314 (end of 2010) to 994 (end of 2012), 24.5% of which were between 100 and 500 kW, 65.5% had an installed capacity in the 500–1000 kW range, with 2.4% above 1000 kW and 7.6% below 100 kW. Among Italian agricultural biogas plants some exclusively utilize livestock waste (17.7%) or energy crops (20.1%), while 62.2% use both [35]. Most of these plants are located in the Po Valley, where the concentration of large farms is very high [36].

Hence, the aim of this study was to determine how costs of agricultural biogas plants utilizing giant reed silage in Italy vary as a function of the energy produced, both in absolute terms (€ kWh^{-1}), as well as in percentage. In particular, three broad macro-categories (biomass, plant installation and transport) were analyzed, so as to describe the economic performances of biogas plants with progressive variations in the proportions of two key variables: electrical power capacity (from 100 to 999 kW) and feedstock mixture (by substituting livestock waste with giant reed progressively).

Thus the minimum optimal size of a biogas plant was determined so as to suggest the best investment for in term of costs. Among the available options, the discerning entrepreneur opts for those that maximize profit and minimize costs and risk for the enterprise [37–40], a prerequisite of farm competitiveness in an increasingly globalized market, where risk and uncertainty are high [41–44].

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 both of the energy produced and feeding mixture utilized so as to discern the best choice, on the part of the entrepreneur, in terms of costs [45,46].

For research purposes, we intentionally left the conversion efficiency (given by the ratio between manure and energy crops) out of the analysis because the paper aimed at evaluating only the biogas plant costs that, in contrast to revenues, are not affected by it.

In relation to the various possible scenarios, all cost items relating to biomass supply, plant installation and transport were analyzed, by varying simultaneously the two key variables: electrical power capacity and feedstock mixture. As regards the former, since most agricultural biogas plants in Italy are between 100 and 999 kW, this range of power was considered, as well as in other studies [47,48]. With regard to the feedstock mixture utilized, the percentage of livestock waste was incrementally substituted with giant reed silage, in order to find the optimal combination of biomasses destined to anaerobic digestion [49]. In Italian agricultural biogas plants, in fact, the choice of feeding mixture for anaerobic digestion is dictated by the organizational model of the farm, but also by the installed power capacity [50]. In fact, the larger the plant the larger the utilization of silage with respect to manure, while small- and medium-sized plants use exclusively a manure or a mixture of animal slurry and energy crops [51]. This is due to the fact that during the fermentation process livestock manure is less caloric than DEC [52].

To analyze these costs, the following constituent conditions were supposed as the baseline:

(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 linear payback period of 10 years at a 5% capitalization rate.

2.1. Biomass supply costs

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 [53]:

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

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:

$$CLW = [(qN \cdot Vr) * (1 - 75\%)]/ELW \quad (2)$$

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 our 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