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Economic performances of anaerobic digestion plants: Effect of maize silage energy density at increasing transport distances

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ABSTRACT

In Italy, more than 1150 agricultural anaerobic digestion (AD) plants are currently running. Their concentration in specific areas resulted in an increase in the biomass price and transport distances. For the AD plants located on farms with small area, often the feedstock are purchased on the market. However, when transport distances increase, it can be less expensive to buy biomasses with high energy density.

With this regard, maize experimental tests were carried out to evaluate the methane production by harvesting the whole plant, the plant cut at 0.75 m and only the ear.

The aim of this paper is to evaluate the economic performances of biogas plants fed with different maize silages by considering increasing extra-farm transport distances. Two different scenarios were considered with regard to the subsidy framework and to the maize biomass yield.

The results show that, for short distances (<3 km), the economic performances are similar for AD plants fed with the whole plant silage and with that from the plant cut at 0.75 m; however, they are substantially better than those of the plant fed with ear silage. Beyond 14 km ear silage becomes more interesting than the whole plant; up to 32 km the plant fed with silage from the high cut is the most profitable whereas, beyond this transport distance, the ear silage is the best solution. The achieved results are interesting for stakeholders and policymakers involved in the biogas agro-energy processes, because they can be useful to reduce the cost of feedstock supply.

1. Introduction

The EU objectives can be met by the development of all the different renewable energy sources [1,2]. Among these, the biogas deriving from Anaerobic Digestion (AD) of different feedstock has proved to be interesting for energy generation in rural areas in particular, especially when the AD plants are fed with feedstock locally available and the generated energy

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(above all the heat) [3–5] is used close to the plant [6–12]. In Europe, Germany is the leading country with more than 9000 agricultural AD plants [12]. However, a considerable development of this agro-energy took place also in Italy, Sweden, Switzerland and Austria [5,12,13]. Each of these countries is supporting with a different subsidy framework this typology of renewable energy production.

In Italy, nowadays, more than 1150 agricultural biogas plants are running, mainly in the northern regions [6,9,12,14,15]. Most of them operate in co-digestion and, consequently, are fed with energy crops (mainly cereal silage), agricultural residues (animal sewage) and residues from the agro-industry [4–6,13,15–18]. Strong public incentives were granted for electricity produced from biogas, especially for the AD plants put into operation before the 31st December 2012 and with electrical power lower than 1 MW. An "all-inclusive tariff" (electricity selling price + subsidy) equal to 280 € MWh^{-1} of electricity was the fixed incentive for the electricity fed into the grid, with no consideration about by-products utilization for feeding and about heat valorisation. With the D.M. of 6th July 2012 [19] this incentive has been updated and, generally, strongly reduced (15–35%); in addition, more importance has been paid, by means of the introduction of bonus, to the heat valorisation and by-products utilization.

Nevertheless, for AD plants put into operation before the year 2013, cereal silages are the key feedstock. Compared to animal slurry (the most widespread agricultural by-product in Northern Italy), these biomasses are characterized by high specific biogas productions (600–650 $m^3\ t^{-1}$ of volatile solids for maize silage and 450–560 $m^3\ t^{-1}$ of volatile solids for wheat and triticale silages) [9,12], approximately 6–25 times higher than pig and cow slurries [9]. Among cereal silages, the maize one is the most used [12,20–28].

Over the years, the concentration of AD plants in specific areas resulted in the increase of biomass prices and transport distances. For the AD plants located on farms with little agricultural area, which is not sufficient to produce the needed amount of biomass for the supply of digesters, the only achievable solution is to purchase the feedstock from the market. It must be considered that, when transport distances increase, it can be less expensive to buy biomass with high energy density.

In this context, with regard to biogas production from maize silage, the most important portion of the plant is the ear [25]. The ear represents a very good feedstock for biogas production because, given the high starch content, it is characterized by a higher biogas production if compared to the whole plant silage. Negri et al. [25] evaluated the biogas production from different maize plant portions (the whole plant - WP; the plant cut at 75 cm of height - HC; the ear only - OE). Although the silage production by harvest of the whole maize plant allows maximizing the methane production per hectare, the other two solutions produce silages with a higher specific methane production and, consequently, higher energy density. In more details, the methane production by harvesting and ensiling the whole plant (about 10,400 $m^3\ ha^{-1}$) is higher than the ones achievable by: only the ear (about 7850 $m^3\ ha^{-1}$, −24.4%) and the plant cut at 75 cm (9420 $m^3\ ha^{-1}$, −9.4%). Finally, for WP a higher silage mass must be transported.

In addition, when long extra-farm transport distances are considered, even if there is a reduction of biogas producible per unit of area, it can be cheaper to feed the AD plants with high energy density silages (e.g., obtained by a high cut or by the ear only).

The aim of this paper is to evaluate the break-even distance for the three different maize silages beyond which it becomes less expensive to buy biomass with a higher energy density. For AD plants with an electrical power of 1 MW, the economic performances have been evaluated by considering the feeding with the three different maize silages at increasing extra-farm transport distances. To assess their impact on the economic performances two different scenarios have been considered with regards to the subsidy framework and the maize biomass yield.

The results of this study can be useful for future studies that require maize silage as an input for energy purposes as well as, at present, for policymakers and stakeholders involved in the biomass supply chain of AD plants.

2. Materials and methods

2.1. Energy system description

This energy chain, similarly to other biomass to energy processes, can be divided into four subsystems (Fig. 1):

i) Subsystem 1 (SS1) - Field Production: maize cultivation at farm;
ii) Subsystem 2 (SS2) - Extra-farm transport of chopped maize from fields to the AD storage point;
iii) Subsystem 3 (SS3) - Storage: ensilage and handling operation of maize biomass;
iv) Subsystem 4 (SS4) - Conversion: transformation of biomass into biogas and then into electricity and heat.

Subsystem 1 is performed by farmers that sell the biomass; subsystems 2 and 3 are carried out by agricultural contractors while subsystem 4 takes place at the AD plant.

2.1.1. Silage production

The experimental field tests were carried out on a farm sited in the district of Lodi (Lombardy Region), a region located in the middle of the Po valley (45° 60′ − 44° 77′ lat. N, 7° 65′ − 12°22′ long. E). A maize hybrid FAO Class 700 was grown in single crop system, so no other crops were sown after the maize harvest. The field operations carried out during the crop growth can be subdivided in 4 sections:

i) Seed bed preparation and sowing, this section is performed in spring on soil with stubble and it involves an organic fertilization with cattle slurry (85 t ha^{-1}; Average composition N = 0.40% P_2O_5 = 0.08% K_2O = 0.31%) [12,25,26] carried out before a 35-cm-depth ploughing and two interventions with rotary harrow. The sowing is performed using a pneumatic precision drill seeder in April with 77,000 plants ha^{-1} (20 kg ha^{-1} of seed);