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Use of agricultural by-products in the development of an agro-energy chain: A case study from the Umbria region

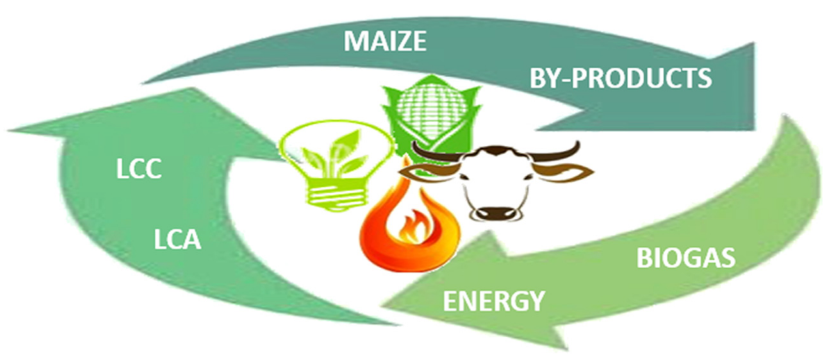
S. Venanzi [a], D. Pezzolla [b,*], L. Cecchini [a], M. Pauselli [a], A. Ricci [b], A. Sordi [b], B. Torquati [a], G. Gigliotti [b]

[a] Department of Agricultural, Food and Environmental Sciences, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy
[b] Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy

HIGHLIGHTS

- Environmental and economic analysis of using by-products in a real biogas plant was conducted.
- Three different mixtures of by-products were tested at laboratory and plant level.
- The mixtures did not show differences in bio-methane production at laboratory scale.
- The complete substitution of maize silage results in environmental and economic savings.
- By-products and maize silage transport distances affect economic performances.

GRAPHICAL ABSTRACT



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ABSTRACT

Use of agricultural and livestock by-products for anaerobic digestion (AD), in total or partial substitution of the maize silage was evaluated from an environmental and economical point of view. The evaluation process included three methodological interdependent and consequential steps: the chemical stage at laboratory and plant level, the environmental and economic steps developing the Life Cycle Assessment and Life Cycle Costing jointly. The laboratory test showed that the two mixtures prepared with by-products, in partial (MIX A) and total (MIX B) substitution of maize silage, did not show differences in bio-methane production compared to a reference mixture with the 33% of maize silage. All mixtures tested at full-scale plant, showed the same performances, resulting in a similar energy production. Environmentally, MIX B increased greenhouse gas credits derived from the avoided production of mineral fertiliser for the energetic crops, resulting also in better economic performances. The break-even transport distances follow the positive environmental pattern result, in contrast to what was found for the break-even transport distances from the economic point of view.

1. Introduction

Anaerobic digestion (AD) is a process that is successfully used in many countries for energy production, but also for nutrient recovery in the digestate (organic matrix resulting from AD), waste stabilization, pathogen and weed seed inactivation (Westerman et al., 2012;

* Corresponding author.
E-mail address: daniela.pezzolla@unipg.it (D. Pezzolla).

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Tambone et al., 2009). In fact, the waste materials are often treated anaerobically to produce renewable energy (Bacenetti et al., 2016) and to obtain more stabilised sources of organic matter, compared to the original feedstock materials (Tambone et al., 2009).

In the last ten years, the use of biomass to produce renewable energy in the agriculture sector has faced an increase in Europe (Fusi et al., 2016; Hijazi et al., 2016), particularly in Italy, tailored by public subsidies for biogas plants that Italian legislators have periodically updated according to the Renewabe Energy Directive 2009/28/EC (Union, E, 2009) (Fusi et al., 2016; Paiano and Lagioia, 2016). Conforming to the legislative framework established by the Italian Minister of Economic Development (2012) as subsequently amended and supplemented, environmental and economic sustainability could be connected to the use of by-products in biogas plants in terms of a circular economy development in agro-energy sector. The above could improve residues efficiency and reduce costs (Blades et al., 2017; Toop et al., 2017). In fact, agricultural by-products are usually underused or not valorised as they should, being an added cost for farmers when treating as waste (Bacenetti et al., 2015). By-products valorisation could reduce land employed for energy crops cultivation avoiding competitiveness with the food sector as well as the agricultural inputs for whose production process that is particularly intensive with environmental benefit in terms of greenhouse gas (GHG) emissions (Paiano and Lagioia, 2016). The legislative framework provides higher tariffs for newly built plants that use agricultural and agro-industrial by-products to produce energy (Negri et al., 2014) compared to those that operate with the same power production capacity and based on energy crops as raw material (Fuchsz and Kohlheb, 2015).

By-products introduction in AD, being converted into energy, could be a successful strategy (Bacenetti et al., 2013), not restricted to new biogas plants but also for those that were installed before the above mentioned legislative framework. Through this perspective, by-products could lead to cost reductions associated with a diminished use of energy crops along the bioenergy supply chain (Massé et al., 2011; Cherubini et al., 2009).

Some critical aspects concerning logistical, management and efficiency of the agro-energy chain should be accounted for, albeit the advantages discussed above. Firstly, it is a need to assess the levels of the different types of by-products availability in the study area as well as all the aspects related to their supply (distance and transport), subsequently (Bacenetti et al., 2015). In this regard, the feeding process of the AD is a major factor in influencing the technical efficiency of the anaerobic process, as well as part of the farm's economic success in a perspective multifunctionality. In fact, it is important to evaluate the quality of feedstock characteristics and how the differences in their organic matter composition can affect the biogas production (Lesteur et al., 2010). Within this context, the anaerobic biogasification potential or methane potential of organic materials being used in biogas plants should be estimated (Schievano et al., 2008; Hansen et al., 2004). The residual digestate could become available as nutrient fertilizers (Manninen et al., 2013) or organic amendment (Tambone et al., 2009), ensuring sanitary quality and a minimum degree of stability of these final products, additionally (Mata-Alvarez et al., 2014; Alburquerque et al., 2012).

Albeit the advantages discussed above, some critical aspects should be accounted for evaluating the efficiency of the agro-energy chain using by-products. The use of livestock derived materials can cause some problems during the anaerobic process, for their high content of ammonia and low C/N ratio (Nasir et al., 2012; Sakar et al., 2009; Callaghan et al., 2002). For this reason, the co-digestion of these materials is recommended to improve the nutrients balance and the biogas yield, e.g. through the use of crop materials and other agro-residues or by-products (Nasir et al., 2012; Wang et al., 2012; Lehtomäki et al., 2007). Nonetheless, the use of mixtures made with only by-products, such as slurry and animal manures (Nasir et al., 2012; Holm-Nielsen et al., 2009), or their addition as co-substrates can also cause the production of inhibitory compounds and process instability (Yuan and Zhu, 2016; Mata-Alvarez et al., 2014; Chen et al., 2008). Best of the above considerations, laboratory experiments are needed to test co-digestion impact with by-products for improving the substrate selection and their proportion rate in the mixture (Yuan et al., 2016; Mata-Alvarez et al., 2014; Astals et al., 2011). According to Fusi et al. (2016) and Bacenetti et al. (2016) review on Life Cycle Assessment (LCA), different combinations of energy crops with by-products have been analysed to evaluate the biogas production from AD processes focusing on GHG emissions and fossil fuel depletion mainly (Poeschl et al., 2012; Börjesson and Berglund, 2006). Most LCA studies have focused on one (Zhang et al., 2015), two or more different feedstocks in the mixture to feed biogas plants (Fusi et al., 2016; Bacenetti et al., 2016), since co-digestion of these matrices increases biogas production (Poeschl et al., 2012). As far as it is known, a limited number of studies have focused on the use of a single by-product. Bacenetti et al. (2015) analysed tomato by-product utilization for energy production finding a small saving in GHG emission when this type of by-product is used in AD. Yet, researches on the exclusively agricultural by-products mixtures for biogas production have been neglected (Lijó et al., 2017; Fuchsz and Kohlheb, 2015). Recently, Lijó et al. (2017), evaluated the environmental effect of substituting energy crops for food waste, showing this residue to be able to improve the environmental profile of biogas production.

In such a context, while acknowledging the environmental benefits of mixture matrices used in a biogas agro – energy process (Bacenetti et al., 2013; Poeschl et al., 2012), few studies jointly analyse both the economic and environmental performance of the AD (Blumenstein et al., 2016; Torquati et al., 2016; Bacenetti et al., 2015; Torquati et al., 2014; Yabe, 2013; Franchetti, 2013). In this respect, the net present value (NPV) and internal rate of return (IRR) concepts have been applied to analyse the economic performance of such systems. Most of these studies, albeit based on different assumptions, scopes and economic contexts, have found interesting economic performance when different matrices co-digested and public subsidies are considered (Bacenetti et al., 2015). As mentioned above, many studies in the biogas agro-energy process have been conducted under LCA standard to evaluate the environmental impact, although none of them has been carried out with Life Cycle Costing (LCC) jointly. There is still a nascent literature on this type of integration, and it is focused on the agricultural production mainly (Mohamad et al., 2014). Considering the information provided thus far, the present study is drawn to contribute to the discussion on the environmental and economic sustainability of the biogas agro-energy supply chain. The aim of the paper is to evaluate the effectiveness of using agricultural and livestock by-products, in total or partial substitution of the maize silage to develop a sustainable agro-energy chain, from an environmental and economical point of view.

2. Materials and methods

2.1. Case study

Environmental and economic sustainability of using by-products for AD was evaluated in a dairy farm located in Trevi (Perugia, Italy) equipped with a biogas plant, which runs on 620 kW_{el} of power combined with a cogeneration unit, where biogas is burnt to produce electricity and heat, and a composting plant. The biogas plant operates under wet and mesophilic condition (35–40 °C) and the organic livestock materials produced in the farm, i.e. slurry and manure, are co-treated with maize silage and by-products derived from neighbouring farms. To provide the fed of biogas plant, part of maize silage is produced on owned land by the farmer (hereinafter referred to as “in-farm”), and part is grown on rented land within an average distance of 3 km (hereinafter quoted as “out-farm”). Since the by-products supply depends on the oil and wine processing residues (olive pomace and grape marc respectively), the materials for feeding the biogas plant are