Biomass and Bioenergy 89 (2016) 58–66

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

# Economics of GHG emissions mitigation via biogas production from *Sorghum*, maize and dairy farm manure digestion in the Po valley

Alessandro Agostini [a, b, *], Ferdinando Battini [c], Monica Padella [a], Jacopo Giuntoli [a], David Baxter [a], Luisa Marelli [a], Stefano Amaducci [c]

[a] *European Commission, Joint Research Centre (JRC), Institute for Energy and Transport (IET), Sustainable Transport Unit, Westerduinweg 3, 1755LE Petten, The Netherlands*

[b] *ENEA—Italian National Agency for New Technologies, Energy and the Environment, Via Anguillarese 301, Rome, Italy*

[c] *Department of Sustainable Crop Production, Università Cattolica del Sacro Cuore, 29122 Piacenza, Italy*

A R T I C L E I N F O

*Article history:*
Received 31 August 2015
Received in revised form
24 February 2016
Accepted 25 February 2016
Available online 7 March 2016

*Keywords:*
biogas
maize
manure
sorghum
co-digestion
cost analysis

A B S T R A C T

The Greenhouse gas (GHG) emissions and economic feasibility of electricity production from the anaerobic digestion of different substrates are studied in this paper. Three realistic substrate options for the climatic and soil conditions of a modelled farm in the Po Valley in Italy are analysed: manure from a dairy farm, *Sorghum* and maize.

A detailed cost analysis is performed with field data provided by farmers and suppliers and literature sources. The capital costs (CAPEX) and the operational costs (OPEX), disaggregated by their components, are presented. Investment payback time is then calculated for the different substrates and technologies, while taking into account the Italian government feed-in tariff scheme for biogas plants implemented in 2013.

In the specific conditions assumed, electricity production via anaerobic digestion of manure and co-digestion of manure with at most 30% *Sorghum* (no till) provide both GHG savings (in comparison to the Italian electricity mix) and profit for economic operators.

The anaerobic digestion of silage maize or *Sorghum* alone, instead, provides no (or very limited) GHG savings, and, with the current feed-in tariffs, generates economic losses.

Both economic and environmental performance are improved by the following practices: cultivating *Sorghum* instead of maize; implementing no till agriculture; and installing gas-tight tanks for digestate storage. A tool allowing a customised calculation of the economic performances of biogas plants is provided.



## 1. Introduction

European Member States are committed both to increase their share of renewable energy sources and to reduce their GHG emissions [1]. Within the Renewable Energy Directive [1]), mandatory sustainability criteria are defined for biofuels, but only voluntary recommendations were defined for biomass used for power and heat production.

In Italy the incentives for electricity production from Anaerobic Digestion (AD) have fuelled, in the last 5 years, a rapid growth of investments in biogas plants and biogas production technologies and a significant diversion of maize crops to bioenergy [2].

However, debate over actual GHG emission savings of biogas pathways [3–5] and concerns over indirect land use change [6] have culminated in EU recommendations or mandates capping the use of food crops for bioenergy purposes [7,8].

Starting in 2013, the Italian law [9] concerning the tariffs and subsidies for renewable electricity from anaerobic digestion was modified to respond to the sustainability concerns; feed-in tariffs are now linked to biogas plant capacity, the specific substrate used, and to the technologies employed to reduce the environmental

* Corresponding author. European Commission, Joint Research Centre (JRC), Institute for Energy and Transport (IET), Sustainable Transport Unit, Westerduinweg 3, 1755LE Petten, The Netherlands.

*E-mail addresses:* alessandro.agostini@enea.it, alessandro.agostini@ec.europa.eu (A. Agostini), battifer@libero.it (F. Battini), monica.padella@ec.europa.eu (M. Padella), jacopo.giuntoli@ec.europa.eu (J. Giuntoli), david.baxter@ec.europa.eu (D. Baxter), luisa.marelli@ec.europa.eu (L. Marelli), stefano.amaducci@unicatt.it (S. Amaducci).

http://dx.doi.org/10.1016/j.biombioe.2016.02.022
0961-9534/

impacts.

Chinese et al. [10] analysed the effects of previous and current support schemes on the optimal plant size, substrate mix and profitability in Italy. They concluded that new plants are likely to be manure based and due to the lower energy density of such substrate, wider supply chains are expected although optimal plant size will be smaller. They concluded that the new support scheme will most likely eliminate past distortions but also slow down investments in agricultural biogas plants.

At the end of 2012, there were 994 biogas plants in Italy with a total installed electric power capacity of 756 MW. Of these, 17.7% used only livestock manure as their substrate, 20.1% used only energy crops, and 62.2% used both types of biomass and other agro-industrial waste streams. However when these shares are calculated on the basis of installed capacity, the picture is very different; 74.2% of the installed capacity was based on co-digestion, 22.4% on energy crops only, while just 3.2% on manures only [11].

According to the Italian National Renewable Energy Action Plan (NREAP), Italy is committed to reach an installed electric power capacity of 1.2 GW for biogas-fed power plants in 2020, complemented by 11.1 PJ of heating/cooling final energy consumption covered by biogas in the same target year [12].

Several authors analysed the economic performance of biogas plants in Italy [13–15]. Schievano et al. [14] provided on-field data on the production costs of electricity from biogas using different dedicated energy crops cultivated along the Po Valley (northern Italy) and concluded that in order to compete with traditional fossil fuels and other forms of renewable electricity, the production cost of electricity from biogas must be reduced as much as possible in the near future with biomass supply being the most important cost item. Only by introducing organic wastes and residues could production costs be lowered sufficiently to compete with other energy sources.

Scholz et al. [16] analysed the GHG emissions mitigation costs for biogas plants in Germany and found a wide range of potential $CO_2$eq mitigation costs from 95 € $t^{-1}$ to 378 € $t^{-1}$.

Biogas can be produced from nearly all kinds of biological materials deriving from the primary agricultural sectors and from various industrial and domestic organic waste streams.

The production and use of biogas is normally perceived as a clean and sustainable energy generation option that can guarantee significant GHG savings if compared to fossil fuels [1]. However, the environmental impacts associated with AD are strongly dependent on many factors, mainly: the choice of substrate, the technology adopted and the operational practices [3–5].

Currently, no mandatory sustainability criteria at European level have been formulated for solid biomass and biogas used for power and heat production. However, the European Commission (EC) provided recommendations to Member States to develop criteria similar to the ones designed for transport biofuels [17]. A recent document from the EC presented the state of play of bioenergy in the EU [81] and introduced updated typical and default GHG emissions values for a large selection of bioenergy pathways, including several pathways for the production of power by anaerobic digestion of manure, maize and biowastes [5]. This document suggests the application of a GHG emission savings threshold of at least 70% for all biogas pathways compared to a specific fossil fuel comparator. According to JRC data [5] which accompanied the EC document [8], only manure based plants would reach such a threshold. However, with the suggested suspension of the mass balance approach for biogas plants and, therefore, the possibility to 'average' the GHG emissions among co-digested substrates, the use of about 30% (wet mass) of maize substrate in co-digestion plants with a gas-tight storage for digestate would still allow a facility to comply with the criteria [5].

In previous work the environmental impacts associated with several biogas systems employing a variety of substrates and technologies [3–5,18] were analysed. It was found that on-farm biogas production from manure shows high potential to mitigate some of the environmental impacts associated with intensive dairy farming, especially as a consequence of the emissions avoided from manure management. However, local impacts (i.e. photochemical ozone formation) may actually worsen with the introduction of a biogas plant [18]. On-farm manure anaerobic digestion is an effective method to significantly reduce GHG emissions and non-renewable energy consumption; however, it was found that GHG emissions of biogas electricity are strongly influenced by the actual plant design, with GHG savings (referred to the emissions of the European electricity mix) ranging from more than 100% for manure based systems (thanks to credits for avoided methane emissions from raw manure storage) to 3% for maize-only based systems with open storage of the digestate [4].

In a recent study, the environmental impacts of three biogas systems based on dairy manure, *Sorghum* and maize, in the Po Valley were analysed [35]. This research found that GHG emissions for maize and *Sorghum*-based systems, instead, are similar to those of the Italian electricity mix; maize-based systems cause higher environmental impacts than *Sorghum*, due to more intensive cultivation practices [3,19].

These studies have confirmed, thus, that: i) manure digestion is the most efficient way to reduce GHG emissions, although there are trade-offs with other local environmental impacts; ii) that the management of digestate, specifically having an open or a gas-tight storage tank, is an essential element to reduce GHG emissions; iii) that biogas systems based solely on energy crops have very high GHG emissions, equal or barely lower than the current power generation mix.

This work builds on the previous research of this team, mainly on the work of Agostini et al. [3], and expands upon it to include the economic analysis of the biogas plants.

In [3] the results of the environmental analysis are reported for all possible mixtures of the three substrates analysed (maize, *Sorghum* and manure). However, for simplicity, as the Italian law [9] that defines the criteria for biogas feed-in tariffs allows the mixtures with up to 30% wet mass of energy crops to benefit from the same tariff granted to biogas produced from residues only, this work was limited to plants running only on manure, *Sorghum* and maize, or on a mixture of manure and 30% energy crops.

In this work, as in [3], manure refers to the untreated excretion of dairy cattle (sometimes referred to as slurry).

The aim of the economic analysis is to calculate the Net Present Value (NPV), Internal Rate of Return (IRR) and payback period of the plants analysed to evaluate the feasibility of the investments. Calculating the production costs shows whether the support tariff is sufficient (break-even analysis), and by combining the units costs of the electricity produced with the GHG emissions calculated in [3], the unit cost for the reduction of GHG emissions via biogas production from different substrates is calculated, which is the final aim of this work. This will provide guidance to policy makers on the most cost-effective way to pursue the objective of mitigating climate change by exploiting the anaerobic digestion of biomass and on-site electricity production.

## 2. Materials and methods

### 2.1. Systems description

The economic analysis is performed on the same biogas systems defined in Agostini et al. [3]. The systems analysed are biogas plants producing electricity from different substrates (manure, maize, *Sorghum*), with different cultivation management (conventional till, CT or no till, NT) and different ways of storing the digestate (in