Renewable and Sustainable Energy Reviews 38 (2014) 537–550

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Livestock manure and crop residue for energy generation: Macro-assessment at a national scale

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ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form
25 May 2014
Accepted 18 June 2014

Keywords:
Manure
Crop residue
Biogas
Co-digestion
Upgrading
Biomethane
Chile

ABSTRACT

Livestock manure and crop residue can be processed in an environmentally acceptable way through anaerobic digestion to generate biogas, also, under an integrated production scheme, providing fertiliser and heat as by-products. The most valuable use of the produced biogas (i.e. for the generation of electricity or a gaseous biofuel) depends on specific economic conditions and other constraints which cannot be generalised.

From a GIS-based biomass resource inventory, manure and agriculture residue were evaluated as substrates for the generation of electricity or biomethane for injection into the natural grid, and then comparatively assessed at national level in Chile. Mathematical modelling was used to calculate supply–cost curves for the purpose of estimating the representative generation cost of both secondary energy end-products as well as their technical and economic potential. The mono-digestion of manure and mono-digestion of agricultural residue as well as the co-digestion of both substrates were assessed.

From manure processing, the estimated economic potential was 0.8 $TWh_e\ y^{-1}$ of electricity at a representative generation cost of 25 ct€ kWh_e^{-1}, while that of biomethane was calculated to be 182 MM $Nm^3\ y^{-1}$ at a representative generation cost of 98 € MM BTU^{-1}. In addition, the economic potential for the mono-digestion of agricultural residue was estimated to be 1.1 $TWh_e y^{-1}$ at a representative generation cost of 15.4 ct€ kWh_e^{-1}, while that of biomethane generation was 280 MM $Nm^3\ y^{-1}$ at a generation cost of 40 € MM BTU^{-1}. Manure co-digestion offered a significant increase of roughly 46% of the economic potential at the same representative cost as mono-digestion. The co-digestion option of using biomethane production for injection does not seem to be adequate when considering a national policy to boost biogas production. Electricity generation, however, may be a viable option that has major economic advantages with or without a feed-in tariff scheme.

Contents

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http://dx.doi.org/10.1016/j.rser.2014.06.005
1364-0321/

1. Introduction

The production of biogas through anaerobic digestion, a state-of-the art technology, has recently attracted considerable attention as a means of generating energy, given its significant environmental, social and political benefits – a fact supported by a series of studies in the field [1–5]. However, unlike other alternative technologies for sustainable energy generation, it is associated with a number of uncertainties, making generalisation of technical or economic potential at a national or regional level difficult. This is principally due to the diversity of potentially suitable raw material substrates, the geographical distribution of the resource, scale of generation, not to mention local environmental and energy policies, which demand a case-by-case analysis [6].

Anaerobic digestion is particularly attractive when searching for an environmentally friendly solution for the sustainable disposal of manure generated by farms [7]. While the intensification of farming practices has brought about an increase in the production of edible goods, this increase has inevitably led to growth in the volume of manure, thus creating higher disposal cost and posing a risk to the environment. Although manure has historically been employed as a natural fertiliser to increase the quality of farmland and return nutrients to the soil, its employment can be responsible for the eutrophication of waterways, and the loss of nitrate or phosphate when applied at non-optimal rates [8].

In recent years, Chile's livestock industry has undergone considerable development. The country was a net importer of dairy products until 2001, at which point a surplus in production made it a net exporter. The poultry industry supplies most of the internal demand with 594,000 $t\,y^{-1}$ (data from 2010) accounting for 45% of the total demand of meat. Pork follows with 498,000 $t\,y^{-1}$ (expressed as dressed meat), and has exhibited steady growth throughout the last decade (6.7% annually). Both are attributable to higher demand from export markets such as South Korea and Japan as well as an internal increase in consumption [9]. The dairy industry is made up of approximately one hundred medium and large milk supplying plants principally located in the central and southern zones [9]. In the context of the expansion of the feedstock industry, the country needs to confront this new environmental challenge in order to ensure its long-term economic competitiveness in a sustainable fashion. The introduction of anaerobic technologies is seen as a promising approach to overcoming this environmental issue.

The production of biogas from manure can be supported by adding co-substrates to increase the biogas yield [10] and the content of methane in the gas, thus improving reactor efficiency and, in turn, the economic viability of the plant. This is a plausible possibility as feedstock industries are normally located near agricultural complexes where residues are, to some extent, readily available. However, the supply of biomass is limited by logistical issues and the cost of substrates. The agricultural residue available after harvesting straw, stover, leaves or cobs can be used as a co-substrate for biogas generation. Nevertheless, this residue must be employed in a sustainable way, with respect to ensuring that the rate of removal does not have a detrimental effect on soil fertility [11].

Much attention has been given to assessment of biogas generation from manure and crop residue in large areas [12,13], mainly as a consequence of the environmental gains already mentioned, but also because of the rural development opportunities and the contribution it could make towards renewable energy generation goals [14]. With this in mind, Sliz-Szkliniarz and Vogt [15] sought to assess potential sites for the anaerobic co-digestion of manure and crop silage in the region of Kijawsko-Pomorske, Poland. Through a GIS approach, spatial data was integrated to calculate the cost of electricity production and biomethane for injection into the grid. They concluded that the introduction of incentives is needed to boost the use of biogas and, therefore, to reach the goal set by the government. Tranter et al. [16] assessed the potential for energy production from on-farm digestion in England, and analysed the main barriers to the implementation of anaerobic digestion. In that study, the figures are expressed as a technical potential, and no information on the spatial distribution of farms or cost of production is given. Lantz [17] assessed the production of energy by combined heat and power (CHP) using manure in Sweden, and came to the conclusion that energy production is not profitable under the current conditions and that policy instruments are needed to make it economically viable. Moreover, it was concluded that a major impact on the economics of the process lay in the use of electricity and heat, whereas digestate utilisation as by-product played only a marginal role. Finally, Yabe's [18] study considered Hokkaido, an 83,000 km^2 island in Japan. This study aimed to select a location for biogas plants in each county and evaluate the cost of production for electricity from cow manure by using a GIS-based method to estimate the required number and location of centralised biogas plants. Most recently, a study by Höhn et al. [19] attempted to determine energy potential and feasible location of biogas plants in southern Finland by using a GIS-based method. The methodology focused on minimising the transportation distance for feedstock so that an optimal allocation could be found. In this study, no economic assessment was conducted.

In Chile the introduction of on-farm anaerobic technology has been slow and has taken place only recently. Total biogas generation reached a mere 0.4 $PJ\,y^{-1}$ in 2011 [20] but, nonetheless, preliminary evaluations have shown that the theoretical potential of biogas is roughly 15 $PJ\,y^{-1}$ and 9 $PJ\,y^{-1}$ from the digestion of manure and crop residue [21], suggesting that less than 2% of the potential is currently being realised.

The use of residue seems to be the most reasonable starting point for the development of an energy production strategy focused on biogas because it brings direct environmental advantages. The use of energy crops does not seem to be appropriate for implementation, at least at the first stage as it would be unwise for Chile to change the land currently used for food production and force the country to revert to imports in order to address internal consumption for biofuel production [22]. Although the biofuel alternative has not been thoroughly assessed at a national level yet, either technically or economically, preliminary evaluations indicate that the main constraints arise from the limited suitable land available for the most promising crops both for liquid and gaseous biofuels [23].

The present research seeks to assess the potential of biogas production based on the utilisation of manure and crop residues as mono-substrates, and to assess the possibility of co-digesting them. The assessment includes a cross-economic comparison between the possibility of using biogas for electricity or for gaseous fuel production. The geographical parameter used to conduct the evaluation is