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Techno-economic analysis of electricity and heat generation from farm-scale biogas plant: Çiçekdağı case study

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ABSTRACT

Conventional energy usage has various environmental effects that cause global warming. Renewable energy sources are, thus, more favorable, because they have nearly zero emission. Biogas was merely seen as a sub-product obtained from anaerobic decomposition (without oxygen) of organic residue. One of the key concerns of biogas plants with energy generation is the disposal of comparatively large amounts of digestate in an economically and environmentally sustainable manner. In this article, the economic performance of the given biogas plant has been analyzed based on net present value (*NPV*) and energetic pay-back time (*EPBT*) concepts. The case study has produced an electricity yield of 2,223,951 kWh per year of feedstock digested. The hourly producible electricity energy has been 277.99 kWh. The producible heat energy has been 2,566,098 kWh per year and 320.76 kWh per day, respectively. The produced solid fertilizer and liquid fertilizer, respectively, have been 2047 t/a and 26,055 t/a. The plant with dairy cows and stall is a good economic situation under 3.4 years pay-back time, earning profits and showing a positive *NPV* of €27.74 million. The co-generation system has reduced emissions by 7506 t CO_2 per year.

1. Introduction

Biogas is produced by anaerobic digestion (AD) of organic feedstock, the most common being animal waste and crop residues, dedicated energy crops, domestic food waste, and Municipal Solid Waste (MSW); the integrated process included feedstock supply and pre-treatment and use of digestate. Biogas consists of 50–70% methane (CH_4), 25–45% carbon dioxide (CO_2), 2–7% water (H_2O) at 20–40 °C, 2–5% nitrogen (N_2), 0–2% oxygen (O_2), and less than 1% hydrogen (H_2), 0–1% ammonia (NH_3), and 0–6000 ppm hydrogen sulphide (H_2S) [1]. The biogas system developed from predominantly small on-farm plants, using liquid manure and crop residue mixtures for feedstock.

Manure residues from livestock industries have long been identified as a major source of environmental pollution. Energy generated from manure, via anaerobic digestion, reduces atmospheric emissions of methane, and significant economic value can be obtained from manure as fertilizer if adequate crop production is possible [2]. Livestock industries are seeking alternatives for managing manure residues in an economically, feasible, and environmentally friendly manner. Several studies have shown that AD of organic wastes has the potential to manage these problems in a cost-effective and environmentally sustainable manner [3–6].

Interest has recently been growing in using the AD process of organic waste of farm origin, such as manure, crop residues, and organic residues from food and agro-industries, to generate renewable energy [7]. Processing manure to biogas through AD recovers the energy that contributes no net carbon to the atmosphere and reduces the risk from pathogens from land spreading, as thermophilic or mesophilic AD with a sanitization step destroys all or virtually all pathogens [8]. Besides biogas, AD produces digestate, which consists of a mixture of liquid and solid fractions. Applying digestate to land is the most attractive option in terms of environmental issues, because it allows nutrients to be recovered and reduces the loss of organic matter (OM) suffered by soils under agricultural exploitation [9]. A reliable and generally accepted means of disposing of the comparatively large amounts of digestate produced is of crucial importance for the economic and environmental viability of biogas plants [3].

Previous studies have documented that residual biogas production [10–13] is likely to occur during digestate storage, as it retains significant undigested organic matter. As these authors suggest, abandoning the potential that remains within the digestate may lead to two critical downsides — additional environmental pollution and lost plant revenue. Pollution results from methane (CH_4) and carbon dioxide (CO_2), the main components of

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biogas, which are also greenhouse gases (GHG) that affect the global environment and climate. Thus, gaseous loss abatement during the digestate storage phase will likely make environmental sustainability of anaerobic digestion even more attractive.

The final objectives to be achieved are various: a decrease in air and soil pollution, production of an excellent amendment, and an increase in the amount of energy derived from renewable sources. The AD of manure is a technique that has been applied for several decades. The advantages of biogas plants are varied:

- Economically attractive investment
- Easily operated and safe installation
- Production of renewable electricity and heat resulting in a reduction of CO_2 emissions
- Reduction of methane emissions from manure storage
- Improvement of fertilizing qualities of manure.

Analyses of energy balance in the life-cycle of biogas systems that have been reported to-date often lack bases for comparison, due to varying accounting system and boundaries [14]. Many studies on energy balance have focused on specific raw material [15–20], specific biogas system [16,18,21,22], different waste management strategies [23,24], and on specific utilization options for biogas [25,26].

The aim of this study is to analyze the technical and economic performance of AD of a given farm-scale biogas plant. Technical analysis is carried out on the basis of quantity and description of the substrates, gas yield, size of the components, electricity and heat energy production, electricity and heat energy consumption of biogas plant, and available energy. The economic performance of the given system has been carried out on the basis of net present value (*NPV*) and energetic pay-back time (*EPBT*) concepts. None of the analyses reviewed have coupled the investment costs accounted for include land value, stall value, dairy cow value, and biogas plant construction value and process chains (production, conversion and utilization) on energy balance of biogas systems. The farm-scale biogas plant is located at the center Anatolia of Turkey. Large-scale biogas plants typically produce more than 1.8 million m^3 of biogas per annum, with feedstock handling capacity of 20,000 t per annum [27]. The plant is a relatively large plant with an installation capacity of 29,930 t of input on an annual basis. The plant produces electricity, heat, and digested solid and liquid fraction via the separator unit.

2. Materials and methods

2.1. Case-study description

The case study was carried out in Çiçekdağı, 180 km from Ankara. The farm-scale biogas plant was projected in 2008 and inaugurated in May 2010 by 2200 dairy cow stables, with an installation capacity of 29,200 t of input on an annual basis. The installation, in addition to dairy cow manure, uses other co-digestion materials, such as sheep dung. Stages of the biogas production system are depicted in Fig. 1. Fig. 1 shows the study boundary, encompassing feedstock resources and transport, biogas plant operation, biogas-to-energy conversion technologies, and digestate handling. Such plants are organized in farms and produce approximately 125–250 m^3/h (0.5–1 MW) of biogas from a wide range of feedstock. The Turkish company of İlci farm, livestock, and energy is credited with developing the first biogas plant running with animal manure at Çiçekdağı, Kırşehir, with a capacity of 500 kWh_{el}.

Fresh manure derived from 2200 dairy cow stables was collected by means of the scraper system. The dairy cows were a constant during the experimental period. Dairy cow manure was extracted from the dung pit and then discharged into the slurry tank of the biogas plant (Fig. 2). Dairy cow stables, scraper systems, and dung pits are shown in Fig. 2. Sheep dung was transported by a tractor to the slurry tank of the biogas plant. The input materials are mixed and pumped to the main digester and stay there for 33 days at 40 °C.

The slurry tank, AD, produced gas recovery unit, separator unit, solid–liquid digested manure reservoirs, and lagoon are shown in Fig. 3. The slurry tank was constructed with open-cellars storage with a 12 m (*D*) and 6 m (*H*). Methane production in the slurry unit will lower the biogas yield of the digester. In the case of an open slurry unit, methane emissions are also undesirable for an animal's well-being. Therefore, it is best to transport the manure from the slurry unit to the digester as soon as possible. This was done

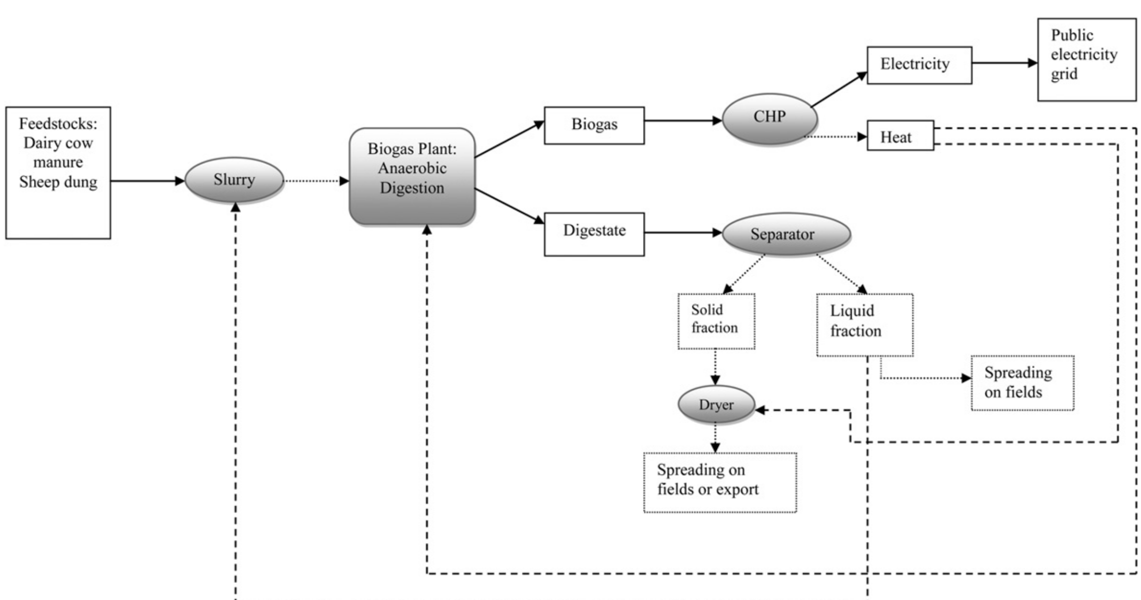

Fig. 1. Stages of biogas production system.