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Energy production from piggery waste using anaerobic digestion: Current status and potential in Cyprus

Elisavet Theofanous [a], Nicoletta Kythreotou [b], Gregoris Panayiotou [a], Georgios Florides [a], Ioannis Vyrides [a,*]

[a] Cyprus University of Technology, Department of Environmental Science and Technology, 95 Eirinis Str., P.O. Box 50329, 3603 Lemesos, Cyprus
[b] Department of Environment of the Ministry of Agriculture, Natural Resources and Environment, Cyprus

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ABSTRACT

In this work the current status and the potential of biogas production and energy generation through the anaerobic digestion of piggery waste in Cyprus are presented. The onsite use of anaerobic digestion for treating piggery waste not only generates renewable energy, but it is also a sustainable waste management solution. The actual values of the biogas production (20,475 m^3/day) and the energy generation are compared with the theoretical values, which are in line with several units. The value 20 m^3/tonne of pig waste was found to predict more accurately the biogas, heat and electricity production compared to the value of 36 m^3/tonne of pig waste. Moreover, an empirical equation ($R^2 = 0.9939$) is proposed for calculating the biogas production per day, according to the volume of pig waste treated per day BGP = 14.64 (PWT) + 535. The potential biogas production from the total pig population of Cyprus equals to 29,734,356 m^3/yr and the potential thermal and electrical energy are calculated to be 90.85 GWhth/yr and 63.59 GWhel/yr, respectively. Finally future alternatives on anaerobic digestion in Cyprus are presented such as co-digestion, centralized anaerobic digestion, hydrothermal pre-treatment, possible use of fuel cells and efficient utilization of pig slurry.

1. Introduction

Cyprus has no indigenous energy sources and thus its power system is totally isolated and depends completely on imported oil which contributes to 96.4% of total primary energy supply and 100% of electricity production. Given the increasing prices of fossil fuels on a worldwide level, the need to include Renewable Energy Sources (RES) into the current energy system is becoming imperative. During the past years, due to the efforts of both governmental agencies and private investors, many RES production units have been installed in Cyprus. These units comprise of photovoltaic (PV) systems, wind parks and biomass-biogas production units. According to data from the Cyprus Energy Regulatory Agency (CERA) [1], the production of electricity from RES for 2013 was as follows: 230.61 GWh by wind parks, 35.83 GWh, by biomass-biogas units and 44.99 GWh by PV systems. The target for Cyprus is that by 2020 renewable energy should account for 13% of the total energy consumed compared to the 3% in 2005.

In 2013, 11.5% of the electricity produced from RES was from biomass-biogas units. However, the potential of biomass-biogas units is considerably great and this is the main focus of this work. The first anaerobic digester in Cyprus was installed in 2007 for the treatment of pig waste. According to the Department of Environment of the Ministry of Agriculture, Natural Resources and Environment, today, there are 13 biomass-biogas units in Cyprus, of which 12 units use anaerobic digestion (AD) (Fig. 1) and 10 units use animal waste as their main substrate. These 10 units are connected with the power distribution grid of the Electricity Authority of Cyprus (EAC) supplying their output. Noteworthy is that, 8 of the AD units, use mainly piggery waste. In Cyprus there are 78 pig farms (2011) and thus the potential to use AD for biogas production from piggery waste is highly attractive.

During 2003, biodegradable waste was estimated to be 3203 tons and their separation by origin is depicted in Fig. 2 [2]. Animal waste consisted of 59.7% of biodegradable waste of which 82% was piggery waste. Indeed, Kythreotou et al. [3,4] assessed the total biomass potential in Cyprus available for energy production, through AD. They estimated that the total amount of solid and liquid biomass of the specified waste streams was 9.2 million tons while the potential biogas production was estimated in two ways,

* Corresponding author. Tel.: +357 25 002218.
E-mail address: ioannis.vyrides@cut.ac.cy (I. Vyrides).

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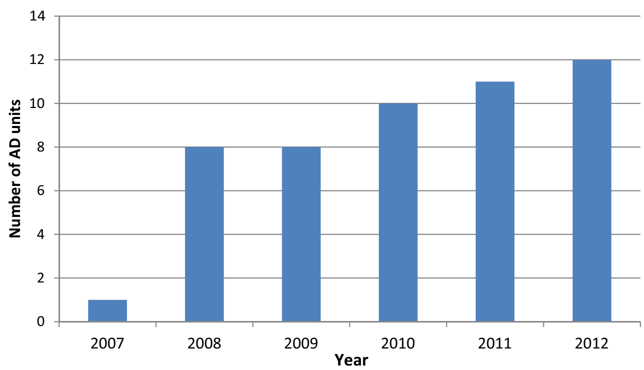

Fig. 1. Number of AD units in Cyprus.

the Chemical Oxygen Demand (COD) consumption method and the Mass of Waste Digested method, was found to be 114 and 697 million m^3, respectively.

Anaerobic digestion is a natural process in which a variety of species from two biological kingdoms, the Bacteria and the Archaea, work together to convert organic wastes, through various intermediates into methane gas [5]. During the past 30 years, the treatment of piggery waste through AD has increased considerably and the amount of anaerobically digested substrate from waste has increased at an annual growth rate of 25% [6]. The main advantages of AD are low biomass generation, low nutrient requirements and energy production in the form of methane gas. Biogas production, of which about 60% is methane, has considerable potential because it may replace fossil fuels and vehicle fuels. Moreover, biogas has advantages, compared to other renewable energy alternatives: it can be produced on demand, is easily stored and it is already a mature technology [7]. Besides, the digestate (anaerobic sludge) from AD is a valuable fertilizer because of its high nitrogen content. AD considerably reduces the survival of pathogens, which is important when the digested residue is used as fertilizer [8]. Inappropriate handling, storage and application of digestate as fertilizer can cause ammonia emissions, nitrate leaching phosphorus overload [7]. The nitrogen load on farmland is regulated inside the EU by the EU nitrate-directive (91/676/EEC nitrate). This piece of legislation aims to protect the ground and surface water environment from nitrate pollution. A more novel application is to transform the digestate into biochar, which can be further used as soil enhancer or as an adsorbent to purify wastewater or flue gas [6].

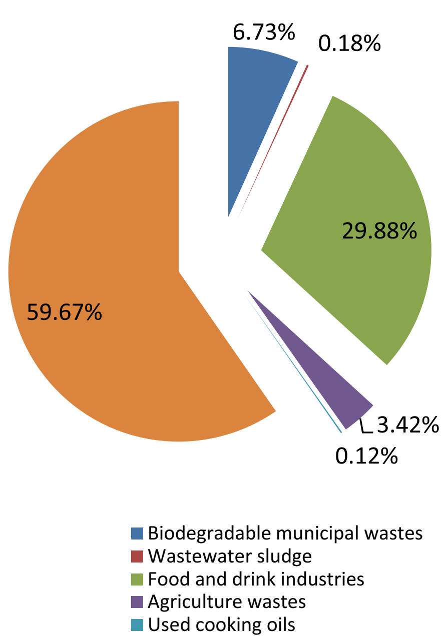

Fig. 2. Biodegradable wastes in Cyprus by source during 2009 [2].

Some laboratory studies exist on the treatment of piggery waste in a laboratory scale bioreactor [9,10]. However, only a few studies investigate the treatment of piggery waste on a full-scale level and on a national level.

Aggarangsi et al. [11] found that up-flow digesters in Thailand used to treat piggery waste were able to produce up to an average of 0.261 m^3/kg of COD removal. Monteiro et al. [12] studied the prospective application of animal manure for bio-energy production in Portugal and found that the biogas, thermal and electrical energy produced from swine manure were 0.015 Gm^3/year, 52.563 GWh/year and 26.282 GWh/year, respectively. Kaparaju and Rintala [13] estimated that in typical Finnish farms producing 2000 m^3 sow manure and 2500 m^3 of pig manure the energy production would be 21.8 and 47.7 MWh electricity per year and 36.3 and 79.5 MWh of heat per year, respectively in a Combine Heat and Power (CHP) unit. Tsai and Lin [14] in an overview analysis of biogas production to energy generation in Taiwan found that the potential of methane generation from livestock manure management during 1995–2007 was between 36 and 56 Gg per year. Thus, for the total swine population a methane reduction of 21.5 Gg per year, electricity generation of 7.2×10^7 kWh/year and equivalent carbon dioxide mitigation of 500 Gg/year were achieved.

Several full-scale studies [11,12] have identified the potential of using animal waste for biogas production. However, few studies analyse the treatment of piggery waste from full-scale Anaerobic Digesters for biogas, electricity and thermal energy production on a national level. Therefore, the aim of this study was to present the current status of AD from piggery waste in Cyprus with particular attention on biogas, heat and electricity production. Moreover, this study suggests methods to estimate biogas from a full-scale anaerobic digester treating piggery waste. Based on the current 78 pig farm units, the potential of AD in Cyprus for biogas, electricity and thermal energy production is estimated. We also suggest ways to extend the use of AD for piggery waste in Cyprus as well as to make it more efficient.

2. Methodology

Data on the characteristics of AD units using piggery waste in Cyprus as well as the consequent biogas production were obtained using a questionnaire. Questionnaires sought information on the following: animal population per unit, volume of waste (m^3/day), volume of the digester (m^3), retention time (days), COD (g/l), type of waste digested, operating temperature (°C), pre-treatment method, post-treatment method, % of CH_4 in produced biogas, use of produced biogas, input waste quality and output waste quality. The results are presented in Table 1. Additionally, data on the energy generation by these units were given by CERA for the year 2011 [1].

It should be noted that calculations of theoretical values were based only on complete data and that no calculations were done where data were incomplete, to avoid misinformation.

3. Current status

The stages of AD are as follows: (A) *Reception and pre-treatment of piggery waste*: it should be noted that pig waste passes through a homogenization tank before entering the anaerobic digester. In the