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Can slurry biogas systems be cost effective without subsidy in Mexico?

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ABSTRACT

Biogas from pig slurry in Mexico has potential to produce 21 PJ per year, equivalent to 3.5% of natural gas consumption in 2013. In this paper, three different scenarios are analysed: mono-digestion of pig slurry in a finisher farm (scenario 1); co-digestion of pig slurry and elephant grass in a finisher farm in situ (scenario 2) and co-digestion of pig slurry and elephant grass in centralised biogas plants (scenario 3). The digesters proposed are anaerobic high density polyurethane (HDPE) covered lagoons. HDPE centralised plants can have capital costs 5 times cheaper than European biogas plants. The economics of utilisation of biogas for electricity generation and as biomethane (a natural gas substitute) were investigated. Economic evaluations for on-site slurry digestion (Scenario 1) and on-site co-digestion of elephant grass and pig slurry (Scenario 2) showed potential for profitability with tariffs less than $US 0.12/kWh$_e$. For centralised systems (Scenario 3) tariffs of $US 0.161/kWh$_e$ to $US 0.195/kWh$_e$ are required. Slurry transportation, energy use and harvest and ensiling account for 65% of the operational costs in centralised plants (Scenario 3). Biomethane production could compete with natural gas if a subsidy of 4.5 c/L diesel (1 m^3 of biomethane) equivalent was available.

1. Introduction

1.1. Sources of energy in Mexico

Energy is a key factor for economic development. Mexico is the 10th largest oil producer in the world [1] and the energy market is dominated by fossil fuels. In 2013, 88% of primary energy production (7945 PJ) was derived from hydrocarbons; final energy consumption was 5132 PJ [2]. Transport was the principal energy consuming sector with 44.1% (2262 PJ) of final energy consumption in that year, followed by the industrial sector with 31.4% of the share (1613 PJ). The demand for natural gas (NG) in the country is growing with the rise in the electricity and industry sectors. NG is progressively replacing oil as a source of fuel in power generation; the demand for NG increased 31% in the 2002–2012 period [3]. The use of NG in the transport sector is still developing, with approximately 4500 natural gas vehicles (NGVs) in operation in 2013. It is expected that the NGV fleet will grow to 255,500 vehicles by 2028 [4]. According to SENER (Ministry of Energy) in 2013, in Mexico, 7% (636 PJ) of primary energy production was renewable [2]. The source of these energies was diverse (Fig. 1), however, 59.6% (379 PJ) was obtained from the combustion of wood and sugarcane bagasse [2]. Wood remains the main source of renewable energy in Mexico and it is extensively used for heating and cooking purposes, especially in rural areas. The federal government has published a new law for the use and production of renewable energy in Mexico (LAERFTE), which states that 35% of the electricity generated in the country by 2024 must come from a non-fossil fuel source and/or employ CO_2 sequestration [5]. In a recent projection made by SENER, it is expected that by 2028 biogas and sugarcane bagasse will have a share of 4.8% of renewable electricity, equating to 4.7 TWh$_e$ [6].

1.2. Biogas and pig slurry treatment systems in Mexico

Biogas can be used as a substitute for natural gas once it is upgraded to biomethane. Biogas that has been upgraded to 95–97% methane content and has been scrubbed to remove water vapor,

Abbreviations: CDM, clean development mechanism; DM, dry matter; HDPE, high density polyethylene; NG, natural gas; NGVs, natural gas vehicles; NPV, net present value analysis; SBP, swine biomethane potential; UAP, unit of animal population; VS, volatile solids; WW, wastewater.

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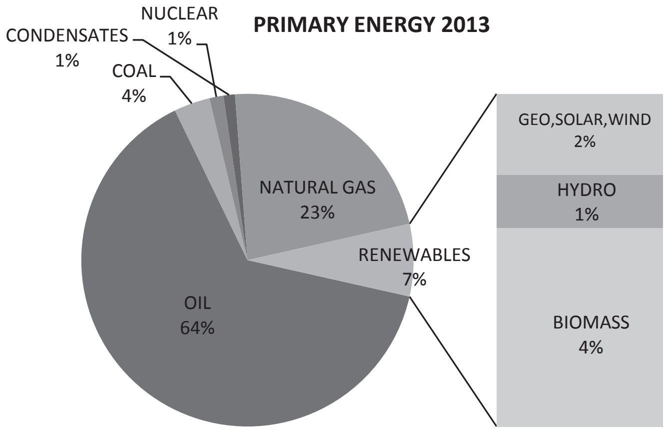

Fig. 1. Primary energy production in Mexico for 2013 [2].

hydrogen sulfide, oxygen, ammonia, siloxanes, hydrocarbons and nitrogen is termed biomethane [7]. Biomethane can be used: as a source of heat distributed via the natural gas grid; as a source of vehicle fuel; and in electric power stations. Compressed Natural Gas (CNG) is used extensively as a transport fuel in countries such as India. Landfill gas may be upgraded to biomethane for use as a transport fuel but there are difficulties as the gas is quite contaminated [8]. However biogas from crops and slurries are more easily upgraded to biomethane, which has been used as a transport fuel (and a natural gas substitute) in countries like Germany, Sweden and Finland since the 20th century. Methane, which is the major component of biogas, can be used in Natural Gas Vehicles (NGVs) [9].

More pork is eaten in the world than any other meat. It is expected that in 30–50 years, meat consumption will double [10]. In Mexico, pig farming has increasing from 14 million pigs produced in 2000 to 15 million in 2010 [11]. Pig farming activities produce large quantities of manure, often producing the waste equivalent of a small city [12]. The quantity and composition of manure vary depending on the feed, the age of the pigs and the type of farm. Manure production increases as pigs grow from feeders to finishers. Pig manure is made up of urine and faecal material [13]. Typically, between 85 and 90% of dry matter (DM) are volatile solids (VS) [14]. The most common way to treat slurries in Mexico is in open anoxic lagoons [15], however, this trend has changed recently with the introduction of more high specification biodigesters (anaerobic covered lagoons which employ impermeable liners and a membrane cover to prevent escape of gas). The use of anaerobic digestion in the treatment of pig slurry prevents volatile organic compound emissions, controls odours and mineralizes nutrients [16]. The biogas produced, if it is upgraded to biomethane can replace NG [17]. The first large scale anaerobic covered lagoons built in Mexico were promoted by the clean development mechanism (CDM) functioning under the Kyoto protocol [18,19]. The main purpose of these systems was for the sale of carbon credits; the biogas generated was combusted in industrial flare stacks. According to REMBIO (Mexican Bioenergy Network), there were 966 anaerobic digesters treating cattle and pig slurries in 2012 [20]. Manure generated in farms is flushed through slatted floors to a collecting pit. In farms where there are no slatted floors, manure is sent to canals using hoses and then sent to a collecting pit. Slurries are subsequently pumped to an anaerobic covered lagoon.

Of late in Mexico there is a realisation of the potential to produce electricity from biogas. The first biodigesters to treat pig manure were built without agitation systems leading to low efficiencies and low biogas yield [18]. A recent report showed that 47% of these digesters are not well designed while 61% of the digesters analysed had a biogas production lower than 80% of the value expected [18]; low electricity generation efficiencies between 14% and 18% were also found during site visits. In a European Context electrical efficiencies between 30 and 40% would be normal [21]. Operational problems included: lack of removal of solids in the digester leading to blockages in pipes and pumps; persistent problems in gas blowers; operational problems in H_2S filters; short circuits in generators; equipment maintenance; and mixing system failures.

1.3. Potential for co-digestion of pig slurry with grass

Co-digestion of pig slurry and crops (residual or energy crops) can increase methane yields [22]. Grass silage has a high VS content and is considered to be a good feedstock for AD, since it can decrease ammonia inhibition; maintain a suitable pH for methanogens and provide a better carbon/nitrogen ratio [23]. Grasses are composed of lignin, cellulose and hemi-cellulose. Lignin is not easily degradable during AD [24,25]. Methane yields between 253 m^3CH_4/tVS to 400 m^3CH_4/tVS can be expected in mono-digestion of grass [22,25]. Due to the lack of trace nutrients in grass, biological failure may occur in long term mono-digestion [26]. Several types of grasses are used in Mexico as forage for grazing animals. Elephant grass and Napier grass have been used as a forage grass in recent years due to good DM yields and low fertilization and water requirements [27]. In pig farms, the effluent of digesters is commonly used to irrigate grass, which can be later cut and sold to cattle farmers.

1.4. Benefits of centralised biogas plants

A biogas industry can be farm scale based when the skill sets are available in the farming community. It requires a new skill set of the farmer, which may hinder the farm scale biogas industry. Centralised biogas facilities treat mixtures of animal manure, biodegradable feedstocks such as waste from the food industry, sewage sludge and the organic fraction of municipal solid waste [28]. Centralised plants have several advantages over farm scale plants. Improved technology can be used in centralised biodigesters; larger plants can benefit from economies of scale and farmers can delegate plant responsibilities to external operators [29], these external operators will have experience of other developments and employ the necessary skill sets based on previous knowledge. As of 2010 there were 23 centralised biogas plants in operation in Denmark with a total installed capacity of 50–600 m^3 manure per day. There were also 60 farm plants with a capacity of 5–50 m^3 per day [30]. Alternatively, in Asia, most biodigesters are small scale and many are household plants. Latin America is developing a biogas industry supported by favourable policy frameworks [31], however the use of centralised plants in both regions is not well documented. At present there are no centralised biogas plants in Mexico.

1.5. Requirement for cost effective digestion in tropical and less developed countries

Many European countries employ numerous digestion systems of high specification and associated high cost [21]. Subsidies are required to allow developers of biogas plants to remain in production. These subsidies can be in the range of 15–25 US c/kWh_e. This is not feasible in tropical countries which are not wealthy. There is a need for simple cheaper technologies for treatment of wastes (such as slurries), that allow for clean water free from eutrophication associated with slurry run-off to water courses, and that provide sustainable decentralised renewable energy to large populations.