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Stochastic modelling of the economic viability of on-farm co-digestion of pig manure and food waste in Ireland

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HIGHLIGHTS

- Assessed economic viability of on-farm manure mono- and co-digestion.
- Assessed three farm sizes: 521 sows; 2607 sows; and 5214 sows.
- Mono-digestion of manure alone not economically viable.
- Co-digestion viable on small farms as food waste likely to be sourced.
- Viability on larger farms dependent on securing sufficient food waste.

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ABSTRACT

The majority of studies analysing the economic potential of biogas systems utilise deterministic models to assess the viability of a system using fixed inputs. However, changes in market conditions can significantly affect the viability of biogas plants, and need to be accounted for. This study assessed the economic potential of undertaking on-farm anaerobic co-digestion of food waste (FW) and pig manure (PM) using both deterministic and stochastic modelling approaches. The financial viability of three co-digestion plants sized to treat PM generated from 521, 2607 and 5214 sow integrated units was assessed. Under current market conditions the largest co-digestion scenario modelled was found to be unviable. Stochastic modelling of four key input variables (FW availability, renewable electricity tariff, gate fees and digestate disposal costs) was undertaken to assess the sensitivity of project viability to changes in market conditions. Due to the high likelihood of accessing sufficient FW, the smallest co-digestion scenario was found to be the least sensitive to any future changes in market conditions. Due to its potential to treat greater amounts of FW than the smallest scenario, a co-digestion plant designed for a 2607 sow farm had the highest revenue generating potential under optimal market conditions; however, it was more sensitive to changes in FW availability than the smaller scenario. This study illustrates the need for farm-based biogas plant projects to secure long-term, stable supplies of co-substrates and to size plants' capacity based on the availability of the co-substrates which drive methane production (and revenue generation).

1. Introduction

The generation of CO_2 neutral and renewable energy is a key challenge facing all economies globally. This has driven an uptake in the use of anaerobic digestion (AD) in many countries (particularly in the EU) [1]. The use of anaerobic digesters has grown significantly in the livestock agriculture sector [1]. On-farm AD of manures can generate renewable energy which can offset greenhouse gas (GHG) emissions from fossil fuels and reduce GHG emissions associated with manure handling and disposal. Digestate can be used to substitute for carbon intensive chemical fertilizer [2].

The agricultural sector (in particular animal production) plays a major role in the economy of Ireland. It contributes 29.2% to national GHG emissions [3]. The average EU contribution of the agricultural sector to national GHG emission is 9%; in this context the contribution of Irish agriculture to national GHG emissions is high [3]. As Ireland

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aims to reduce national GHG emissions by 30% from 2005 levels by 2030, there is increasing pressure on the agricultural sector to reduce or mitigate GHG emissions (even as the sector is expanding) [4]. In addition, Ireland aims to generate 16% of its gross final energy consumption from renewable sources by 2030 [5].

Despite the positive effects that on-farm AD could have on mitigation of GHG emissions from the agricultural sector and on meeting renewable energy targets, the technology is not widely used in Ireland [6]. The pasture-based nature of dairy and beef farming in Ireland means that year round collection of manure for biogas feedstock is not possible [7]. Pig farms may be the ideal locations on which to develop on-farm biogas plants. The pig industry in Ireland is an indoor intensive sector. Farms generate and collect manure all year round, and the pig houses have a heat demand which needs to be met [8].

On-farm biogas plants typically operate by co-digesting manure with energy crops and/or organic waste, in order to increase methane yields (and therefore revenues) [9,10]. EU regulations on the disposal of organic waste to landfill have led to a major increase (480,000 t per annum) in the amount of biodegradable municipal waste, food wastes (FW) in particular, being collected in Ireland over the past 6 years [11]. This has provided an opportunity for the development of on farm co-digestion plants. However, assessment of the viability of such a concept is not straightforward, particularly in a country where biogas plant development has been limited thus far. This study was undertaken to further the development and implementation of on-farm co-digestion biogas plants, by providing research data on typical plant costs, and a methodology to assess financial viability of proposed biogas projects.

Previous studies have assessed the financial viability of agriculture-based biogas plants. Some of these utilised generalised conceptual scenarios to develop deterministic financial models which identify the potential viability of utilizing specific co-substrates (sugar beet [12], energy crops [13], olive mill waste [14]), specific digester sizes [15] or specific biogas utilization regimes [16]. Other studies have modelled the financial viability of specific plants [17], providing guidance for improved operation and design. Few of these studies [13] assessed the potential effects of changes in key market variables on viability of biogas plants.

Such analysis is crucial when considering novel biogas plant concepts. The use of stochastic models which can account for the potential variation in key model inputs across estimated or known probability distributions can allow for identification of the most sensitive system inputs, as well as providing an assessment of the overall financial risk associated with a proposed plant [18,19]. In particular, by analysing the effects of the variation of input parameters (across specified distributions) on financial metrics, the likelihood of a project being financially viable can be quantified [17]. This is a key advantage of stochastic modelling compared with the more established sensitivity analysis of deterministic modelling. Such stochastic predictions are very valuable, however it should be noted that the accuracy of such methods is proportional to the accuracy of the distributions of input values assumed likely in future [18,19].

This stochastic modelling approach has been applied to a small number of studies. De Clercq et al. [17] used Monte Carlo simulation to assess how sensitive the economic viability of a Chinese biogas plant treating a range of biowaste was to changes in market conditions and operational efficiency, and to quantify the likelihood of the facility to return a profit. In a study to determine whether to generate biogas or produce butanol in a biorefinery treating sugarcane biomass, _ENREF_20 similarly undertook Monte Carlo simulation to assess the risks associated with changes to key inputs (prices of sugarcane, sugar, ethanol, and butanol as a biofuel).

However, no studies have been undertaken which use this approach to assess the viability of biogas plants in a broad conceptual, scenario-based context. Further to this, few studies have undertaken an in-depth analysis of the concept of on-farm biogas plants [8]. The studies published have focused on biogas utilization pathways [8,19] and quantification of the energy potential of available substrates [20,21], rather than economic viability.

The objectives of this study were to assess the financial viability of on-farm biogas plants co-digesting FW and PM. In particular, the study aimed to

1. Identify and quantify the key revenue streams, capital (CAPEX) and operational (OPEX) costs associated with mono- and co-digestion.
2. Assess the current financial viability of co-digestion and mono-digestion plants using a deterministic model.
3. Present a methodology which can assess the sensitivity of overall profitability of co-digestion plants to changes in key revenue streams and operational expenses using stochastic modelling.

2. Materials and methods

2.1. Description of scenarios

Six scenarios were chosen to assess the effects of farm size and either mono- or co-digestion on project feasibility. The scenarios comprised three hypothetical farm sizes with the digester tank volume based on the utilization of the PM generated and the operation of the digester at a hydraulic retention time (HRT) of 50 days (1500 m^3, 7500 m^3 and 15,000 m^3 respectively). These corresponded to three farm sizes of 521, 2607 and 5214 sows and are illustrated in Table 1. These three scales were chosen in order to represent a wide spectrum of potential farms in Ireland, from average [8], to large and large co-located farms. Each farm was then assumed to either operate with a biogas plant treating manure only (mono-digestion; scenarios m1, m2 and m3), or treating manure along with source segregated FW (co-digestion; scenarios c1, c2 and c3). It should be noted that due to the EU Animal By-Products Regulations (Regulation (EC) 1069/2009), biogas plants co-digestion FW and PM cannot be placed directly on farm, but rather must be located in an adjacent fenced site with entrances and exits separate to the farm.

All scenarios utilised biogas via CHP generation.

The most commonly used digester configuration for on-farm biogas plants in Ireland was applied to this study [22]; mesophilic digestion (at 40 °C) comprised of two tanks in series, each with a HRT of 25 days, resulting in an effective HRT of 50 days. Such reactors are typically limited to operating with a feedstock comprised of between 15% and 20% total solids [23]. This limits the amount of FW which can be co-digested with manure to approximately 30% on a fresh weight basis. The digestate storage was comprised of lagoons with 6 months' storage capacity. For the mono-digestion scenario it was assumed that no substrate reception or feedstock maceration facilities were required, with manure being pumped directly from beneath the pig unit to the digester equalisation tanks. Additionally, no digestate pasteurization

Table 1
Digester capacity, farm size, and feedstock availability for scenarios c1, c2, c3, m1, m2 and m3.

Scenario	c1	c2	c3	m1	m2	m3	Comments
Digester size (m^3)	1500	7500	15,000	1500	7500	15,000	
Farm size (no. of sows)	521	2607	5214	521	2607	5214	
Annual manure available (t)	10,950	54,750	109,500	10,950	54,750	109,500	21 m^3/sow and progeny/year [21]