Potential for anaerobic digestion of dairy farm effluent in New Zealand

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Abstract

Efficient effluent management allows capturing of nutrient benefits while reducing potential environmental impact. In New Zealand research has focussed on ponds and land disposal, whereas digesters are being implemented overseas. When biogas produced by anaerobic digestion is collected, it can be used to produce heat and electricity; this has been done in some countries trying to increase their renewable energy profile (e.g., France), but the cost is not always offset by the benefits. Analysis of policies concerning power supply in France and New Zealand revealed very large differences between the two countries, which, in combination with differences in population density, availability of co-digestion products and dairy shed effluent type, means that the establishment of biodigesters is unlikely in New Zealand unless there are changes in policy to encourage greater renewable energy via implementation assistance.

Keywords: Biodigester, co-digestion, energy

Introduction

The emission of greenhouse gases (GHG) is concomitant with agriculture, and for New Zealand presents a unique challenge. The export economy is linked to food production based on pastoral animals. The high number of ruminants per human population means that New Zealand has a high contribution per capita, dominated by animal-derived methane and nitrous oxides (Ministry for the Environment 2015). Whereas most developed countries have been able to reduce emissions by cleaning up industry, New Zealand is dealing with biology and co-evolution.

New Zealand has committed to decrease GHG emissions, despite the fact that the national contribution is less than 0.2% of world emissions (NZAGRC 2015). Of this small amount, agriculture contributes 48% (Ministry for the Environment 2015). As a consequence, increasing pressure is being put on New Zealand farmers to decrease emissions.

Biodigesters, as used in Europe to reduce methane and nitrous oxide emissions from stored manure, whilst providing a renewable energy source, have been proposed as part of the solution. This research examined the factors enabling their implementation in France, and the economics of their implementation in New Zealand.

Background

France and New Zealand are both important producers of milk. France produced 23.7 billion litres in 2013, and New Zealand produced almost 19 billion litres (AHDB Dairy 2015). However, the average specialised dairy herd size in France (52 cows; Maison du lait 2013) is significantly smaller than the New Zealand average (402 for the 2013/2014 season; DairyNZ 2014). Economies of scale should therefore be easier to achieve in New Zealand than in France, but housing of cows for a significant portion of the year means that the collection potential and concentration of effluent is greater in France than in New Zealand.

In the New Zealand agricultural sector, GHG emissions are dominated (72.6%) by enteric fermentation and nitrous oxides from soil (21.5%) (Ministry for the Environment 2015). A study commissioned by then Ministry of Agriculture and Forestry (Stewart & Trangmar 2008) concluded that reducing GHG by collecting methane from animal waste systems was uneconomic from traditional pasture fed, free-range cows on dairy farms. However, as dairy cows are increasingly brought together to be fed in shelters or on feed pads, and therefore the concentration of effluent collected on farm increases, greater attention is being paid to mitigating effects through effluent management (for a review, see Laubach *et al*. 2015).

In Europe, anaerobic digesters are being used to create biogas which is then used to produce heat and/or electricity (van Doorn *et al*. 2012). This reduces the GHG emission by decreasing the GHG directly produced by the effluent and can also provide a renewable source of energy.

Anaerobic digestion

Anaerobic digestion (AD) is the process by which micro-organisms break down biodegradable matter in the absence of oxygen. During the process, biodegradable waste materials (with the exception of those containing lignin) are degraded and biogas is produced, composed mainly of methane (CH_4) and carbon dioxide (CO_2). The process can be divided into four steps: hydrolysis (carbohydrates, fats and proteins

ISSN 2463-2872 (Print) ISSN 2463-2880 (Online)

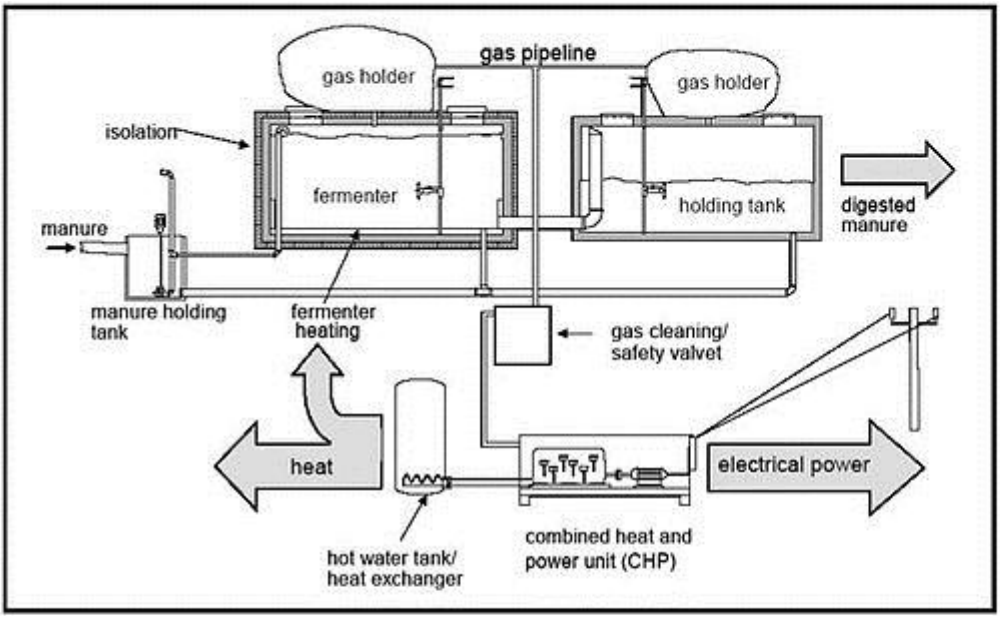

Figure 1 Schematic of European biogas plant. Source: German Gas Association (EUBIA 2012)

are broken down to sugars, fatty acids and amino acids, respectively); acidogenesis (the creation of carbonic acids and alcohols plus hydrogen, acetic acid and carbon dioxide from the sugars, fatty acids and amino acids), acetogenesis (creation of hydrogen, acetic acid and carbon dioxide); and methanogenesis (methane and carbon dioxide as the final compounds). The general equation for the process can be written using a molecule of glucose as an example:

$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$.

Farm dairy effluent (FDE) is a good substrate for AD because it contains all the essential elements needed by the microorganisms. In addition, it has a good buffering capacity, which is an advantage in optimising the process. However, the carbon to nitrogen ratio (C:N ratio) for FDE is 9:1 whereas the optimum ratio for AD is between 15:1 and 45:1 (Atandi & Rahman 2012). The addition of carbon-based co-substrates can enhance biogas production; the process is then called co-digestion.

The digestion of dairy manure alone results in biogas containing 55 to 70% of CH_4, 30 to 40% of CO_2, and between 1 and 4% of other gases such as nitrogen (N_2), hydrogen (H_2) or hydrogen sulphide (H_2S) (Atandi & Rahman 2012). The concentration of these gases determines the amounts of electricity produced. Before use the biogas has to be purified to remove H_2S, which is a corrosive gas. The biogas can then be used in different ways (Stewart & Trangmar 2008):

- conversion into heat through a boiler. The biogas can be used without purification in some boilers
- conversion into heat and electricity through a combined heat and power engine (CHP)
- utilisation through a milk absorption cooling system (biogas is used to run a cooling unit that creates ice which cools the milk vat)
- upgrading of biogas and utilisation as vehicle fuel
- upgrading and injection in the natural grid.

Co-digestion

In Europe co-digestion seems to be by far the most profitable option and a mesophilic (ambient temperature) digestion installation, digesting mainly farm dairy effluent with co-substrates, is now the most common type of installation (Atandi & Rahman 2012). The potential for co-digestion is enhanced by the high population density of France, which is almost seven times that of New Zealand; the difference is exacerbated in rural areas. The current installations in France generally use the effluent from three or four farms and some substrates are added for co-digestion. These substrates include municipal waste, agro-industry wastes or agricultural wastes (Institut National de Recherché en Sciences et Technologies pour l'Environment et l'Agriculture 2014).

Biogas plants in Europe usually involve several elements (Figure 1; EUBIA 2012):

- the production unit, which includes the anaerobic digester, possibly a holding tank and/or a sanitation unit and the manure removal system
- the gas storage and gas upgrading system
- the equipment for gas and manure utilisation.

The co-digestion of manure with others substrates increases the yields of biogas by optimising the C:N ratio. The addition of some co-substrates to raise the C content can lead to a rise in the production of biogas up to 70%. However, some co-substrates can cause foaming, change in the pH and inhibition of the process. As a result, more time and skills are needed to manage the process (Atandi & Rahman 2012).

The minimum size system in France has capacity to deliver 30 kW electrical output (Ademe 2006). For instance, it can use the effluent from 100 dairy cows (housing and dairy shed) with 100 t of grease from a slaughterhouse and 100 t of cut grass. The capital cost is approximately $NZ 377 500. The motor will run for approximately 8000 h/year (approximately 333 days in a year). This will produce 240 000 kWh/year, selling for $NZ 39 900. Other potential income streams include selling surplus heat and processing of waste materials (Ademe 2006).

An alternative option to "tanks" is covered anaerobic ponds. These have been investigated in New Zealand (e.g., Craggs *et al*. 2008; Heubeck & Craggs 2009) and modelled (e.g., Stewart & Trangmar 2008). Stewart &Trangmar (2008) concluded that a significant increase in manure collection for dairy cows (e.g., through feeding on hard standing pads, or animal housing for longer periods) was needed to achieve economic viability.

Incentives given to farmers in France and New Zealand

France wants to increase the proportion of renewable energy to 20% by 2020 (Ministry of Ecology, Sustainable Development and Energy 2013). Some incentives are given by the government in the "Plan Energie Methanisation Autonomie Azote" (a plan for creating energy and nitrogen autonomy through methanisation of biological materials) that was launched in 2013. The objectives are to decrease the GHG emission on the farm, to increase the production of renewable energy, to make a better use of the nitrogen produced on the farm and to create a French sector of AD. The target is to develop 1000 anaerobic digestion systems by 2020 (there were 90 anaerobic digestion systems on farms in 2012) (EDF 2014). The French Government helps the development of these units by giving subsidies reaching 20% to 30% of the investment costs and tax exemptions (starting in 2015) for the 5 years following installation. The payback period for an anaerobic digestion plant of 30kW capacity, without or with a government contribution of 50% of the investment (which is more than the usual rate), ranges from 29 to 6 years (Table 1). Government subsidies make these projects viable.

Table 1 Effect of government subsidy and heat exploitation on investment payback (years) *(Adapted from FranceAgriMer 2012)*

	Payback period (yrs)
No investment subsidies - No heat exploitation	29
No investment subsidies - Heat exploitation	14
Investment subsidies - No heat exploitation	12
Investment subsidies - Heat exploitation	6

The value of the biogas depends on the efficiency of the installation (the heat exploitation rate). The AD system uses 20 to 40% of the heat. The remaining 80 to 60% can add to the income of the installation, and in France it is commonly used to heat houses, cheese factories, and sheds, and to dry crops, hay or wood.

Like France, the New Zealand Government intends to increase the production of renewable energy, particularly the share of renewable electricity, and has set a goal to increase from 73% in 2012 (from wind, geothermal and hydro) to 90% in 2025. To achieve this aim, the government role is to oversee the electricity market and to remove any unnecessary regulatory barriers to the development of renewable generation (Ministry of Economic Development 2013a). Most projects being planned and built use geothermal and wind energy. At this stage, the government has not given any incentive to anaerobic digestion installation.

Energy context in France and New Zealand

In France, 93.8% of the electricity residential market share is held by EDF, the historical French company. Fewer than ten companies compete for the remaining 6.8% of market share (Garric 2012). The price of electricity is the same across all regions and there is little difference between EDF and competitors. Since 2010 it has been obligatory for these companies to buy any electricity produced with renewable energy or co-generation (Ministry of Ecology, Sustainable Development and Energy 2010). The price for purchasing this renewable electricity is set by the French Government for the next 15 years, contributing to securing the investment (EDF 2014).

In New Zealand, numerous companies generate power but the largest five generate 92% of the electricity. The core electricity grid is operated by a State owned monopoly, Transpower. The distribution is operated by 28 companies and there are also many retail companies; the five largest companies hold 95% of the market. These companies operate in different geographical regions and electricity prices vary depending on region and company. In 2012, 25 000 consumers switched their electricity company per month (Ministry of Economic Development 2013b). The situation is far more complicated in New Zealand than in France for anyone who wants to buy or sell electricity. In addition, changes last year to do with purchasing solar power have created uncertainty (RadioNZ 2014) for those people thinking that they might be able to contribute power and receive payment. The lack of government financial support and incentives, plus lack of export opportunities to the national grid, means on-farm consumption must be viable; this is the focus of subsequent analysis in this paper.

New Zealand challenge and the possibilities of development of AD system

Anaerobic digestion systems in France benefit from the support of the government because AD has the potential to assist with: decreasing the production of GHG; producing renewable energy, reducing consumption of heat, fuel and fertiliser on the farms; improving use efficiency of nitrogen produced on farm; diversifying the income of farmers and increasing the integration of the farm activities in the region (integration in a project of sustainable development). Only the first two of these objectives are priorities of the New Zealand Government. In addition, the organisation of the electricity supply, the low rural density of population and the availability of numerous other renewable resources for the production of electricity create a situation where anaerobic digestion systems on farms, as they have been developed in France, or more broadly in Europe, is less likely to be feasible in New Zealand

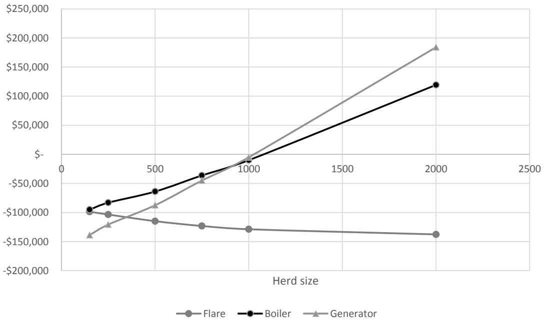

Figure 2 Net Present Value of anaerobic digestion system without a feed pad.

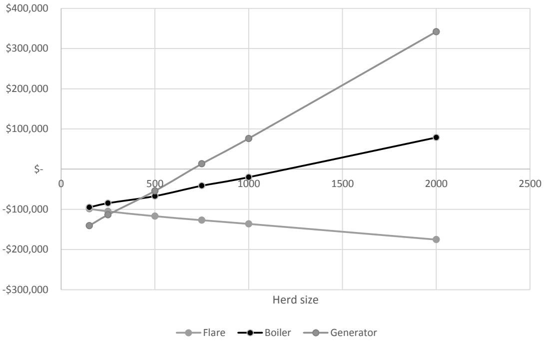

Figure 3 Net Present Value of anaerobic digestion system and a covered feed pad.

Economies of scale

New Zealand dairy herds are increasing in size, and an increasing number of farms have invested in a feeding pad or herd shelter. Increased volumes of effluent are collected as it has not been deposited directly to pasture, and is more concentrated in solids.

The herd size required to support an AD system was examined using a recovery of 0.36 kg of total solids per day per cow (Heubeck, S. pers. comm., 23 January 2015), which corresponds to a recovery rate of 10%, given a faeces and urine production of 3–4 kg DM per cow per day. Further assumptions included the use of maize silage at 1.3 t per cow per year to complement pasture consumption, and values given in Table 2.

Profitability of the installation

The analysis considered three scenarios: the gas being flared, the gas being utilised with a generator and the gas utilised with a boiler. Profitability of investment in an anaerobic pond was assessed by calculating the herd size required to achieve a positive present value (NPV) with a 6% discount rate.

The calculated net present value was negative if the methane is flared, without (Fig. 2) or with (Fig. 3) a

Table 2 Electricity Production

	Value	Reference
Biogas per kg VS (m^3/kg VS)*	0.21	Heubeck & Craggs 2012
Methane (%)	65.0	Craggs 2006
Energy value of pure methane (kWh/m^3)	9.39	Craggs 2006
Electricity conversion of generator (%)	30.0	Hartman 2006
Heat conversion efficiency of generator (%)	50.0	Hartman 2006
Heat produced by boiler (kWh/m^3)	9.38	Craggs *et al.* 2008

*VS volatile solids

covered feed pad, as there is no significant benefit to offset the costs. Generators gave increased NPVs in both scenarios, with financial benefits being greater with the use of a covered feed pad.

Achieving a positive net present value from an AD system is dependent upon several key elements: the amount of gas generated, the value of the gas, and the cost of the system utilising the gas. Data on the capacity to generate gas and the volume generated is available and appears to be robust. The cost of alternative usage systems is more uncertain. This analysis has higher initial investment costs associated with generators as opposed to boilers. The value of gas is also debatable, as it is a matter not only of price but the volume that can be effectively utilised on the farm given the absence of a viable market into which to sell gas or electricity.

In this analysis, a herd of more than 1000 cows was required to generate a positive NPV if no covered feed pad was involved (Figure 2). With a covered feed pad, a herd of 600 cows gave a positive NPV with a generator, but over 1000 cows was required with only a boiler.

These results align well with research by NIWA (e.g., Heubeck & Craggs 2012).

Since 2000/01, the proportion of system 1 farmers (all grass) has decreased from 41% to less than 10% of dairy farms; systems 3 (10–20% imported feed), 4 (20–30% imported feed) and 5 (at least 30% imported feed) farmers have increased from 17, 11 and 1% to 40–45, 20–25 and 4–9%, respectively (Greig 2012; DairyNZ 2015). This intensification has resulted in the use of feed pads, now used by approximately 30% of farms. As herds increase in size, and as barn systems are explored, the potential for anaerobic digesters increases. This potential is likely to be explored further as regulators pay more attention to ammonia emissions, carbon pathways and other environmental performance indicators.

Larger farms and farmer groups are also expected to further explore these options and alternatives. Pannett Dairies (Canterbury) is working with Zeecol Ltd, to create value from waste (Lefferink, W. pers. comm., 18 February 2015). They are investigating the concept of photo-reactors and growing plants in order to recycle all wastes into useful products for the farm. Although the relevant biogas technologies are embedded in Europe they are still immature in a New Zealand context and is anticipated New Zealand entrepreneurs have the potential to adapt and enhance them so they are more fit for purpose in the New Zealand context.

Conclusions

Economic analysis suggested that at current energy prices and alternative energy usage regimes a herd size approaching 1000 cows would be required to generate enough effluent to warrant considering installation of an AD system. Although an increasing number of farms are of this size (approximately 3%; DairyNZ 2014), the net benefit is modest and is sensitive to assumptions about capital and operating costs and the value of energy. It is acknowledged that a covered anaerobic pond might be associated with benefits such as a separation of solids, but the up-front investment required is considerable. It is because of the absence of financial viability that the French Government subsidises investment on behalf of farmers and their locale. Although further analysis is recommended to validate assumptions and develop straightforward models for estimating the viability of AD systems in New Zealand, it is unlikely there will be significant uptake of the technology unless the New Zealand Government chooses to subsidise investments.

ACKNOWLEDGEMENTS

Stephan Heubeck, NIWA, for valuable discussion. AgroParisTech for supporting the internship of the senior author in New Zealand.

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