MM22 and MM49: Anaerobic Digestion of Livestock Excreta

Category

Livestock management: slurry management

Overview

During the storage of livestock excreta GHGs are formed and released, from liquid systems mainly CH_4, while from solid systems predominantly N_2O (Chadwick et al., 2011). Anaerobic digestion of excreta in a closed system utilises microbial processes, which convert much of the organic carbon into biogas (a mixture of CH_4 and CO_2). This biogas is captured and utilised as an electricity and/or heat source. The nitrogen and phosphorous and the remaining organic material forms the digestate, which can be used as a fertiliser.

The environmental benefits of anaerobic digestion of livestock waste are manifold: in the closed system not only the GHG emissions can be reduced but also NH_3 and odour emissions. However, converting the organic carbon into CH_4 has its drawbacks, as the digestate will have a lower carbon content than the excreta (Nkoa, 2014), reducing the soil improvement and C sequestration benefits of livestock waste. The N_2O and NH_3 emissions during the application of the digestate show no consistent pattern, they can be either higher or lower than those from undigested manure (Hou, Velthof, & Oenema, 2014). A further negative side effect is the increased land use (with related GHG emissions and water and air pollution) if the additional feedstock in the digester is not a material which could not be used at a higher level in the biomaterial value pyramid, e.g. as food or animal feed (Bacenetti, Sala, Fusi, & Fiala, 2016). Furthermore, NH_3 emissions during landspreading could also be higher unless low emission spreading is employed as most of the N is in the form of ammonical N (Kupper et al., 2020), though acidification of digestate would prevent these NH_3 emissions (Finzi et al., 2019).

The technology is highly capital intensive and requires technical skills as well as business skills. The subsidy structure, which has been changing over the years in the UK, has a considerable effect on the profitability of the plant. In general, operating the AD plant solely with livestock manure is usually not financially viable due to low CH_4 / volume ratio, therefore most AD plants co-digest other organic materials (e.g. food waste, maize silage, energy crops).

Mitigation summary

Table 1 Effects on emissions

GHG categories	Effect*	Notes
Enteric CH_4		
Manure CH_4	-	
Manure N_2O	-	

GHG categories	Effect*	Notes
Soil N_2O: applied N	+/-	Emissions from digestate might be higher or lower than from undigested manure
Soil N_2O: grazing		
Energy CO_2: fieldwork		
Energy CO_2: other		
CO_2 liming and urea		
CO_2 sequestration below ground	-	
CO_2 sequestration above ground		
Pre-farm emissions		
Post-farm emissions	-	Substitution of energy and heat derived from
Substitution of higher C products		
Production increases by more than the emissions		
	Rating	
Confidence in mitigation effect	High	
Cost-effectiveness**	Moderate	
Confidence in cost-effectiveness	Low	

*   ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential synergies

Table 2 Likely effects on the abatement potential of other measures

Measure	Impact
	-
	-

Inclusion in other marginal abatement cost curves

Table 3 Past assessment of the measure

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
Yes	Yes	Yes	Yes	Yes	

What does the measure entail?

This measure requires the construction and operation of an anaerobic digester, with related infrastructure (e.g. connection to the grid). It requires the availability of feedstock (livestock manure as well as some additional organic material) and the availability of farmers nearby ready to use the digestate.

For our modelling we defined two systems, described in Table 4.

Table 4 AD systems modelled

Measure	Capacity	Related livestock and cropland	Manure used (fresh t (AD plant)$^{-1}$ y^{-1})	Maize silage used (fresh t (AD plant)$^{-1}$ y^{-1})
22	536 kW	900 dairy cows, 180 beef cows, 231 ha maize	17,186	5,000
49	984 kW	1,500 sows, 12,000 other pigs, 75,000 layer chicken, 225,000 broiler chicken, 370 ha maize	18,957	8,000

Abatement rate

The abatement was estimated by comparing the net GHG emissions from the AD (including GHG replaced in energy exported) with the counterfactual emissions form manure storage (assuming slurry storage, with 17% CH_4 conversion factor (IPCC, 2006)). The CH_4 producing capacity of the feedstock was calculated using Eq.5 and Eq.6, respectively, for livestock manure and maize silage, with data obtained from various sources (IPCC, 2006; Webb et al., 2014; Mistry et al., 2011). We assumed 5% CH_4 and 5 % CO_2 loss during storage before digestion (Møller, Sommer, & Ahring, 2004; Bangor University & Thunen Institute, 2015) and 0.5% CH_4 leakage from the plant (Bangor University & Thunen Institute, 2015).

$$CH_4(m^3/plant/year) = VS_L * Housing\% * Livestock\ number * B_0 * (1 - Predigester\ CH_4\ loss - Predigester\ CO_2\ \ loss) * (1 - CH_4 leakage) \qquad \text{(Eq.5)}$$

$$CH_4(m^3/plant/year) = VS_C * Amount\ of\ silage * B_0 * (1 - CH_4 leakage) \quad \text{(Eq.6)}$$

VS_L: volatile solid production of livestock manure (kg VS (head*year)$^{-1}$)

B_0: CH_4 producing capacity of organic material (m^3 CH_4 (kg VS)$^{-1}$)

VS_C: volatile solid production of maize silage (kg VS (kg fresh matter)$^{-1}$)

The net electricity generation was calculated by converting the volume of CH_4 to the energy (kWh) which can be generated by oxidising it (assuming 38% efficiency in electricity generation (Bangor University & Thunen Institute, 2015)) and subtracting from it the electricity needed for the operation (0.78 MJ (m^3 biogas produced)$^{-1}$, assuming 53% CH_4 content of the biogas (Bangor University & Thunen Institute, 2015)). The net heat production was calculated by the same method, assuming 43% heat production efficiency and 1.64 MJ (m^3 biogas produced)$^{-1}$ heat needed for operation (Bangor University & Thunen Institute, 2015). We assumed that 100% of the electricity and 60% of the heat is used on the farm or exported (i.e. reduces costs or generates income). The GHG replacement value of the electricity and heat were 0.03 and 0.269 kg CO_2e kWh^{-1}, respectively, using the long-run marginal emission factor of electricity for the commercial sector and the average of oil and soil fuel based sectoral heat emission factors for agriculture (DECC, 2014).

Cost

Establishing and running an anaerobic digester entail significant costs, though it also generates an income stream from the energy (electricity and heat) produced. The capital and operating costs vary case by case, and as AD is not widely adopted in the UK, there is relatively limited empirical data available.

MacLeod *et al*. (2010) estimated the unitary capital (Eq.1) and operating costs (Eq.2; includes the cost of feedstock) from published cost data.

$$Capital\ cost(£M/MW) = -0.939\ln(Power\ output\ (MW)) + 3.1714 \quad \text{(Eq.1)}$$

$$Operating\ cost\ (£M/MW) = 0.3108 * Power\ output(MW)^{-0.331} \quad \text{(Eq.2)}$$

Similarly, Mistry *et al.* (2011) calculated a relationship between capital cost and feedstock capacity from published cost data (Eq.3) and used an industry estimated for operating cost (Eq.4).

$$Capital\ cost(£) = 79.5 * Feedstock\ capcacity(t/y) + £516{,}000 \text{ (Eq.3)}$$

$$Operating\ cost(£) = 218.3 * Feedstock\ capacity(t/y)^{-0.306} \text{ (Eq.4)}$$

For on-farm AD Jones and Salter (2013), based on UK industry sources, established an incremental capital cost relationship (Table 5) and derived the operating costs for a 500kW AD unit as a total of £124,500.

Table 5 Capital installation costs of AD, on a per kW basis, at a range of AD unit sizes up to 500 kW (includes cost of silage clamp for the arable farm and grid connection) (Jones & Salter, 2013)

AD unit size (kW electricity)	Total capital cost (£M)	Capital cost per kW electricity
50	0.4	8000
100	0.57	5700
200	0.94	4700
300	1.29	4300
400	1.64	4100
500	2.0	4000

In our analysis the equations from Mistry *et al.* (2011) was used as it is the most up-to-date capacity – cost correlation for the UK we could find. As the capacity of the AD plants evaluated mean that the feedstock needs to be transported from nearby farms, transportation costs are also considered, assuming 11t trucks, 10 km average transport distance and £1.78/km transport cost.

To calculate the income streams we assumed that both the electricity and the heat generated is utilised, using an electricity price proxy of projected European electricity price in final demand sectors (European Commission, 2016) which estimates electricity price to be €1.68 MWh^{-1} in 2050 and assuming that heat price is half of electricity price. Currently no subsidy payments are included.

Applicability

Anaerobic digestion is applicable to all kinds of organic material, however, the methane producing capacity and other important properties (e.g. dry matter content, physical contamination) differ by type and origin of the feedstock. As mentioned above, sole livestock manure AD is usually not financially viable, therefore other organic materials, preferably waste materials, needs to be co-digested. On the other hand, the digestate needs to be used as fertiliser on nearby land, therefore the applicability is constrained by livestock density, availability of other feedstock materials and availability of land to spread the digestate. As a simplification, in the MACC calculation we set the applicability rate at 50% of the housed populations (approximated as 30% and 44% of dairy cow and pigs, respectively).

Current uptake and maximum additional future uptake

The total AD capacity in 2018 was 393 kWe, which is equivalent of 3.4 TWh energy (~ 1% of electricity consumption of the UK). This is in line with the UK Government's aspiration back in 2011, which was to have 3-5 TWh AD capacity by 2020 (DECC & Defra, 2011).

According to the Anaerobic Digestion and Bioresources Association[1], there are 374 agricultural AD plants in operation in the UK, the majority of them generating electricity only, 23 producing both electricity and heat, 7 plants are heat only, and 13% produce only biomethane (purified biogas, identical to natural gas). To gauge the extent of livestock manure co-digestion, the NNFCC AD plant database[2] (updated in 2018) contains 329 AD partially or entirely based on agricultural products (including purpose grown crops and crop waste) with 170,897 kWe capacity, 249 of which co-digesting or digesting livestock excreta (111,035 kWe capacity). The number of existing agricultural AD plants falls behind the National Farmers' Union's 2013 ambition, which was to have 1000 farm-based AD plants in 2020 (NFU, 2013).

The 249 livestock (co-)digestion plants utilise 3.8 Mt mixed feedstock annually. For a comparison, 83 Mt livestock manure is available in the UK each year (Smith & Williams, 2016). Without further information on the proportion of manure in the feedstock of these farms, if we assume 50% of the feedstock is of livestock origin, then the current uptake of AD in the livestock sector is 2.5%.

Results

Table 6 Abatement and cost-effectiveness results, without interactions, 2050, MTP

Measure	DA	Number of AD plants	Cost-effectiveness (£ CO_2e^{-1})	Abatement (kt CO_2e)
MM22	E	362	-214	419
MM49	E	163	-291	408
MM22	W	77	-212	90
MM49	W	2	-291	4

[1] http://adbioresources.org/map
[2] http://www.biogas-info.co.uk/ad-portal-map_site-list_external_april-_2018/

Table 7 Detailed abatement results, without interactions, 2050, MTP

Measure	DA	GHG emissions from AD plant and pre-storage	Abatement from energy replacement	Abatement from avoided storage loss
		(t CO_2e (AD plant)$^{-1}$ y^{-1})		
MM22	E	326	655	828
MM49	E	754	1201	2,050
MM22	W	329	657	836
MM49	W	754	1201	2,050

Table 8 Financial results, without interactions, 2050, MTP

Measure	DA	Capital cost (£ (AD plant)$^{-1}$)	Annual costs and income (£ (AD plant)$^{-1}$ y^{-1})				
			Operating cost	Feedstock cost (maize only)	Transport cost	Income from heat	Income from electricity
MM22	E	2,279,798	226,275	110,000	71,763	585,427	193,957
MM49	E	2,659,100	259,027	176,000	87,195	1,073,217	355,566
MM22	W	2,292,973	227,447	110,000	72,299	586,929	194,454
MM49	W	2,659,100	259,027	176,000	87,195	1,073,217	355,566

1.1.1 Wider effects

Table 9 Wider effects of the measure

Aspect	Effect	Reference
Positive effects		
Off-farm GHG	Reduced emissions from energy generation (included in the GHG effect)	
Production		
Adaptation		
Environment	Reduced odour, reduced NH_3 emissions (and related negative environmental effects, like acidification, eutrophication) N_2O emissions from the digestate can vary, though yield-scaled emissions tend to be lower than of untreated manure	(VanderZaag, Amon, Bittman, & Kuczynski, 2015; Baral, Labouriau, Olesen, & Petersen, 2017)
Negative effects		
Off-farm GHG		
Production		
Adaptation		

Aspect	Effect	Reference
Environment	The use of non-waste material as feedstock increases the demand for land and the overall environmental impact	(Bacenetti et al., 2016)
	The digestate's Cu, Zn and Mn content might be higher than that of the undigested manure, especially if co-digested with blood or food waste.	(Nkoa, 2014)

Identified implementation challenges and barriers

Table 10 Potential barriers of the measure

Barrier to uptake	Reference
Difficulty in raising the capital	(Bywater, 2013)
Administrative burden (e.g. feedstock regulations, connection to the gas and electricity grid for small plants)	(Bywater, 2013; DECC & Defra, 2011; Tranter, Swinbank, Jones, Banks, & Salter, 2011)
High capital costs, low returns	(Bywater, 2013; Tranter et al., 2011)
Financial risk in support as well as insufficient information for robust business plan	(DECC & Defra, 2011)
Seasonality of availability of manures from partly housed herds	(Jones & Salter, 2013)
Lack of maintenance skills	(Ford, 2017)
Other key risks/uncertainties	**Reference**

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