Potential and utilization of manure to generate biogas in seven countries

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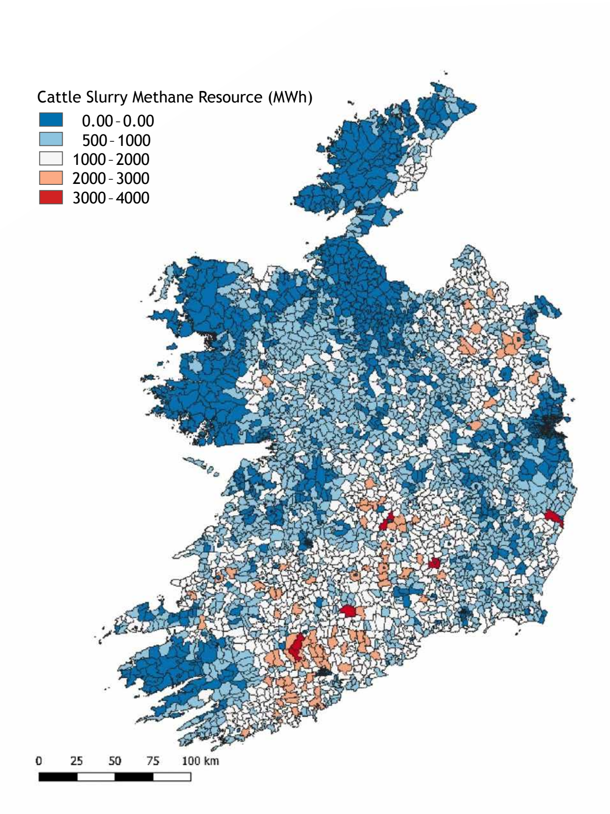

Potential and utilization of manure to generate biogas in seven countries

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Cover graphic: cattle slurry methane resource in the 3440 electoral divisions of Ireland; Richard O' Shea, MaREI, Ireland

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Executive Summary

Production of biogas from manure at a farm level is the very epitome of a sustainable bioenergy system. The system incorporates a circular economy decentralised production of organic biofertilizer and biogas for use in heat, power or transport fuel, whilst simultaneously reducing fugitive methane emissions from open slurry holding tanks, reducing smells and minimising pollution effects on rivers and wells. Why therefore is the practice of producing biogas from manure not more widespread?

The characteristics of manure depend on farm animal source and the method of husbandry, which in turn leads to a wide range of levels of technically available manure resource and costs of biogas produced from manure. To exemplify this, IEA Bioenergy published this report which examines the potential of manure for utilization in biogas facilities across seven countries: Germany; Australia; Austria; Norway; Canada, Ireland and the UK. These countries have differing levels of biogas industry, very different farming practices and a range of climates. It is hoped that the country selection should allow the lessons learned from these seven countries to be applied to many countries across the planet.

The major factors which define the suitability of manure for an economic anaerobic digestion process include: the biogas potential of the manure; the water content of the manure; unwanted and inhibitory materials in manure; the herd size where the manure is processed; and the resulting amount of manure available to the biogas facility. These variables are interdependent as exemplified here. If the manure has a very high-water content (such as from pigs) this impacts greatly on the heat demand for processing and cost sustainability if transportation is necessary. Chicken manure on the other hand has a high solids content and is already transported in Europe for disposal over large distances. Both pig and poultry tend to be associated with more intensive farming, but the manures produced are not as amenable to digestion as cattle manure; chicken manure is nitrogenous and requires innovation in biological digestion or co-digestion with other substrates. Pig manure is dilute, with a low specific methane yield and as such is not ideal for long distance transport or mono-digestion.

Cattle manure is very amenable to digestion, with potentially the lowest cost of abatement; open storage of cattle slurry leads to significant levels of fugitive methane emission, which can be abated by biogas facilities. However, a very significant barrier to collection of cattle manure is an animal husbandry system whereby cattle are pasture grazed for the majority of the year (as is the case for Ireland). This form of husbandry may generate collectable manure only in the winter months when cattle are housed which leads to complexity in a biogas system that includes for cattle manure. This would necessitate a centralised anaerobic digestion model whereby cattle manure is a winter feedstock, and the model depends on other feedstocks for the majority of the year.

Viability of manure-based biogas facilities depend on economies of scale. A herd of 50 dairy cows (close to average in many countries) housed in barns does not produce enough manure for an economic biogas operation. Current trends in agriculture see pressure on small family farms, which is leading to an ongoing consolidation resulting in a smaller number of larger farms. While this may not promote a vibrant rural society, it does increase the potential for an anaerobic digestion industry based on manure. The seven countries described in this report each have specific regions, where the farming of specific animals is concentrated and the potential for a viable biogas industry is high.

Manure might require co-substrates for a successful biological digestion process. Energy rich co-substrates can also improve profitability. Waste materials (such as from food) are a sustainable addition but might come with different regulations for their treatment and subsequent land application. The use of energy crops can have a negative impact in the case of regions with an already high animal density as they add to the quantity of digestate and nutrient load requiring application to, and assimilation in, agricultural land and as such increase the potential for eutrophication.

Anaerobic digestion of manure requires incentives to be financially viable. Any measure or strategy for incentivisation of manure digestion needs to consider the structures of existing farms and characteristics of the produced manures to achieve a significant impact efficiently. Anaerobic digestion facilities using manure as the main substrate typically have a small capacity and consequently high specific costs. Species of animals and type of husbandry have a significant impact on the costs of digestion and biogas yield. Support schemes need to reflect these factors to be effective.

To optimise the benefits of subsidies applied to biogas it is essential to maximise the potential impact on emission reductions and minimise the cost of abatement. This would suggest that incentives should focus on the manure types with high emission reduction potential and the lowest cost to treat; an example of this is liquid cattle manure (or slurry). The biogas system should be designed to ensure the digester has sufficient retention time to optimise the potential for collectable biogas production and minimise the biogas potential in the digestate; the digester needs to be gastight to ensure minimisation of fugitive methane emissions through leakage. Future support or state aid for animal husbandry should facilitate optimization and integration of anaerobic digestion into existing farming practices. The biogas facility should ensure easy collection of manure with minimal storage prior to the anaerobic digestion process to minimise fugitive emissions and to utilise as much of the biomethane potential in renewable energy provision as possible.

An additional aspect with increasing relevance is the role of biogas in organic farming. The increasing share of organic farming requires increasing quantities of organic fertilizers. The potential to integrate the biogas facility into the organic farm model to supply organic fertiliser should be reflected in future policy and support developments. The biogas facility should be seen as an essential constituent in the circular economy agricultural system. Its output must not be focused on energy yield alone but also, as a source of valuable biofertilizer to be recycled back onto agricultural land which is the starting point for feed for animals which produce the manure. Beside the provision of energy and the reduced greenhouse gas emissions, AD facilities have difficult to monetarize co-benefits: reduction in eutrophication of water courses and contamination of wells; recirculation of organic material back to agricultural land; sanitation of digestate; substitution of fossil based mineral fertilisers; support of rural infrastructure and society.

To synthesise, the strategies for manure utilization need to reflect:

- Farming structure, in particular herd size and characteristics of animal husbandry to be targeted (say intensive dairy farms);
- Long term perspective for animal husbandry in the region;
- The particular target sector for biogas utilization (electricity, green gas, transport biofuel, district heating);
- Cost structure for utilization of specific manure type with particular end use of biogas;
- Potential co-substrates and the regional impact on the utilization of these co-substrates in AD facilities;
- Support mechanisms which reflect long term operation of agricultural facilities which will have a lasting positive impact;
- Development of animal husbandry (renovated or newly constructed dairy farms) which optimizes manure handling for usage in AD facilities;
- Impact of the measures on greenhouse gas reduction.

Table of Contents

1 Introduction

1.1 MANURE BIOGAS: SUCCESSFULL APPLICATIONS OF A CIRCULAR ECONOMY SYSTEM

Biogas production from manure is an exemplar of sustainable biomass and circular economy systems (Fagerström et al., 2018). Manure management (in particular open storage) contributes significantly to greenhouse gas emissions from agriculture, mostly in the form of methane and ammonia emissions. Anaerobic digestion of manures and slurries reduces these emissions, while producing biogas to replace fossil fuels as well as digestate which can be used as an organic biofertilizer to replace fossil fertilisers (Liebetrau et al., 2017). Optimisation of the nutrient cycle and good soil health are essential for sustainable agriculture (with organic fertilisers essential for organic farming); anaerobic digestion processes are ideally suited to sustainable agriculture (McCabe et al., 2020).

Publications on biomass available for utilization usually give overarching aggregated numbers on the mass of biomass and energy contained in the biomass. Details on how these particulars have been calculated are many, are varied and quiet often are not given. In particular for manure, it is crucial to assess its composition, its variability in composition over the year and its geographic specific availability, as these factors define the technical and economical accessibility of the manure. Manure availability depends on the structure and organisation of animal husbandry, which varies regionally. Biogas facilities also come with specific technical characteristics and costs. For successful implementation of a manure biogas system, it is essential to optimise the interrelationship between the manure and the biogas systems.

This report aims to provide a short analysis of the situation in seven countries with respect to manure availability and biogas utilization. The authors make no claim on the completeness of this analysis but rather wish to highlight major characteristics of manure utilization and identify critical conditions which may be barriers to an optimized manure biogas system.

There is a long tradition of animal husbandry in most regions of the world. The amount, accessibility and characteristics of manure produced by livestock are dependent on the type of animals, method of housing, feeding regime, purpose (whether it be for breeding or for meat/milk/egg production) and last but not least the number of animals. The many factors affecting the manure quality differ, so manure characteristics differ as well.

Table 1 which is based on German data highlights the effect that the type of animal has on a potential biogas application. Chickens are obviously housed, managed and fed in a different way than cattle and this results in different masses, characteristics and composition of manures. The regional history and development of animal husbandry drives regional agricultural structure. Some countries have small herd sizes, other have large farms with thousands of livestock units. If cattle graze on pasture for the majority of the year, then in this timeframe the manure cannot be accessed. Besides the general characteristics of the manure, the amount of manure at a farm is also of interest. The distribution of nodes of manure production (farms) is an essential element in deciding whether a biogas facility can be viable. Biogas facilities benefit from economies of scale so specific costs reduce with increases in capacity of the biogas facility. Increasing capacity of the facility benefits from concentration in manure production at individual farms or a collection of farms that are well connected by transport infrastructure. Viability of the biogas facility also requires a year-round supply of manure (and/or other feedstocks) and an end market for the produced energy and the biofertilizer.

Animal husbandry has traditionally consisting of small herds or flocks. However, with increasing demand for food products from animal husbandry and lower transportation costs associated with chilled cargo worldwide, competition is increasing and is leading to a worldwide trend towards larger and more cost-efficient farms. The animal husbandry sector in many countries has experienced, or is experiencing, pressure on small farmers and an associated decrease in the number of smaller herd sizes with a commensurate increase in the number of larger herds.

In addition to herd size the number of animals per hectare of agricultural land can influence the regional availability of manure. In some areas there can be multiple high-density herds which leads to competition for land application of manure. There are areas in Europe, where manure has to be treated or

Table 1: Amount of manure per animal and relevant characteristics in a German context

	Amount of manure	Total solids (TS) and volatile solids (VS) content	Biogas yield	Number of animals necessary for 100 kW_{el} (only manure)
	t Fresh Matter (FM) * $(animal*y)^{-1}$	TS: % FM (VS: %TS)	$m^3*t_{VS}^{-1}$ ($m^3/animal*yr^{-1}$)	
Dairy	17-20	10 (75)	380 (527)	800
Fattening pig	1.6	7.5 (70)	420 (35)	11,000
Layer hens	0.02	50 (70)	500 (3.5)	120,000

transported long distances to be applied to agricultural land. A high density of animals can be accompanied by groundwater pollution, contamination of wells and eutrophication of waterways. In such regions the fertilizing effect of the manure is problematic rather than a resource. Anaerobic digestion can help to collect, safely store and condition manure. A nutrient management balance analysis as part of the larger planning process for the biogas facility should include for good management practice for the biogas system and the associated farms (times of application of digestate, matching of applications of NPK to land capacity, cordons sanitaires, water quality management) to minimise potential for negative environmental impact.

The decisive question for a successful application of a biogas system is the availability of manure in sufficient quantities to allow for profitable utilization. It may be that a single farm is large enough to provide a sufficient amount of manure, or the manure (or separated fractions of it) may need to be collected from several farms or sites and transported to the biogas facility. Haulage is costly so the energy content of the manure and the haulage distance have to be considered and compared to the cost reduction arising from economies of scale. A higher density of farms in a locality can reduce transportation distances and increase the potential for economic operation of biogas facilities.

1.2 METHANE POTENTIAL AND YIELD FROM MANURE TYPES

It is difficult to find a common basis which allows for a comparison of the absolute results of manure biogas (or methane) potentials and yields. Potential is defined here as the maximum theoretical amount obtainable from a given substrate, yield is defined as the amount which is actually obtained in a technical process (such as a full scale biogas facility).

It is not recommended by the authors to take a generic value for biogas/biomethane production from a particular feedstock from a book or single source of literature when designing a biogas facility. There are methodical differences in these biogas potential figures that can lead to significant variation when analysed; the potential depends on the animal species who produce the manure (see Table 1), the composition of the manure itself which is influenced by the bedding material used and the diet of the animals and the storage time of the manure prior to anaerobic digestion. Manure is material that has already been digested within the animal, so the potential is lower than the undigested plant materials that formed the feed for the animal. Manure contains to a large extent, substances which are difficult to degrade; the easy degradable fractions have been removed during digestion by the animal. In analysing manure, the kinetic factors highlight slow degradation processes.

Another important factor for the economics of biogas facilities is the addition of water to manure. Many housing systems add water to transport manure within and out of barns which leads to total solid contents less than 10 %. For anaerobic digestion systems this results in a relatively low specific methane yield per unit volume of manure and a high heating energy demand to warm the manure to anaerobic digestion temperature ranges. In particular pig manure tends to be highly diluted and energy rich co-substrates are needed to allow a sufficient biogas production rate and capacity utilization.

Other issues are associated with inert material present in manures. Poultry feed contains inert material to improve feed digestion in birds, this results in a high content of inert materials in the resulting poultry manure. Manure from feedlots without concrete floors can also contain a substantial quantity of inert particles such as sand, gravel and stones which cause abrasion of moving parts, settle out in the digesters occupying digestion volume and overtime leading to a reduction in effective volume of the digester.

Last but not least manures require different technical digestion processes. Cattle manure is rich in methanogens and easy to digest. Chicken manure on the other hand, contains inert material which poses a mechanical challenge and a high nitrogen content which poses a biological challenge as the ammonia produced in the digestion process can inhibit the growth of microorganisms. Pig manure is usually low in total solids and requires co-substrates to be digested. In Table 2 default values of methane potential from the IPCC (2019) for different animals are given.

The fact that manure is a residue and that manure management emits a significant amount of greenhouse gases is an advantage when considering the use of manure in anaerobic digestion systems. Anaerobic digestion reduces the greenhouse gas emission potential of manures and consequently reduces these fugitive greenhouse gas emissions considerably. Additionally, the energy produced from the biogas can substitute fossil energy carriers and contribute to further greenhouse gas emission reductions. Since methane is a highly potent greenhouse gas and fugitive emissions from manure management represent a significant portion of emissions related to agriculture, anaerobic digestion is a crucial tool to reduce emissions from manure management in particular and from agriculture in general (Liebetrau et al., 2017). Greenhouse gas emissions are dependent on the biogas potential of the manure, the conditions of manure storage (such as water content, crust/cover on the surface, duration of storage period) and particularly the temperature of the stored substances. The IPCC provides standard values for the methane emitted from manure storage systems. Depending on type of storage and temperature, the emissions can reach up to 80 % of the initial methane potential of the manure. Table 3 gives exemplary selected emissions factors for animal manure in different manure management systems. The reader is referred to IPCC (2019) for more details.

Table 2: Default values for methane potential from animal manure (adapted from IPCC, 2019)

Default values for methane potential (Bo) ($m^3 CH_4 * kg^{-1} VS$)						
	Region					
Category of animal	North America	Western Europe	Eastern Europe	Oceania	Other regions	
					High productivity systems	Low productivity systems
Dairy cattle	0.24				0.24	0.13
Non dairy cattle	0.19	0.18	0.17	0.17	0.18	0.13
Buffalo	0.10				0.10	0.10
Swine	0.48	0.45	0.45	0.45	0.45	0.29
Chicken layer	0.39				0.39	0.24
Chicken Broilers	0.36				0.36	0.24
Sheep	0.19				0.19	0.13
Uncertainty values are ±15 %						

The addition of water plays a great role in the methanogenic activity. Lagoons and slurry storage systems which are manure management systems for manure with a high water content have significantly higher methane conversion factors than dry storage systems. This needs to be considered when aiming to achieve emission reductions through anaerobic digestion; significant detail must be focused on systems with liquid manure storage to achieve highest emission reductions. With regards to anaerobic digestion systems, it is clear that the IPCC considers leakage the major issue for emissions and as such for carbon sustainability. Proper technical implementation, leak detection and repair are crucial for a significant positive impact of manure digestion on GHG reduction.

Table 3: IPCC values for emissions from manure management (selected from IPCC 2019)

Methane conversion factors for manure management systems (data from IPCC)											
System		Methane Conversion Factors (MCFs) by climate zone									
		Cool				Temperate		Warm			
		Cool temperate moist	Cool temperate dry	Boreal moist	Boreal dry	Warm temperate moist	Warm temperate dry	Tropical montane	Tropical wet	Tropical moist	Tropical dry
Uncovered anaerobic lagoon		60%	67%	50%	49%	73%	76%	76%	80%	80%	80%
Liquid/slurry and pit storage below animal confinement with storage duration of	1 month	6%	8%	4%	4%	13%	15%	25%	38%	36%	42%
	3 months	12%	16%	8%	8%	24%	28%	43%	61%	57%	62%
	4 months	15%	19%	9%	9%	29%	32%	50%	67%	64%	68%
	6 months	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
	12 months	31%	42%	21%	20%	55%	64%	73%	80%	80%	80%
Cattle and swine deep bedding with storage duration of	>1 month	21%	26%	14%	14%	37%	41%	59%	76%	73%	74%
Cattle and swine deep bedding with storage duration of less than 1 month		2.75%				6.5%		18%			
Solid storage- covered/compacted		2.00 %				4.00%		5.00%			
Solid storage - bulking agent		1.00%				2.00%		2.50%			
Dry lot		1.00%				1.5%		2.0%			
Daily spread		0.1%				0.5%		1.0%			
Pasture/Range/Paddock		0.47%									
Poultry manure with and without litter		1.50%									
Anaerobic Digester, Low leakage, High quality gastight storage, best complete industrial technology		1.0%									
Anaerobic Digester, Low leakage, High quality industrial technology, open storage		3.55%				4.38%		4.59%			
Anaerobic Digester High leakage, low quality technology, high quality gastight storage technology		9.59%									
Anaerobic Digester, High leakage, low quality technology, open storage		12.14%				12.97%		13.17%			

1.3 REFERENCES

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2 Country specific manure potential and utilization

In the following section selected characteristics of animal husbandry, manure availability, utilisation and potential for utilization in a biogas facility are presented for seven countries.

2.1 GERMANY

2.1.1 Overall potential

The population of animals in Germany may be synthesised from a range of references over the last few years as follows:

- 11.4 million cattle;
- 25.5 million pigs;
- 1.6 million sheep;
- 694,000 poultry livestock units.

A more in depth understanding of the quantity of manure and its characteristics requires more analysis based on assumptions and simplifications. This leads to uncertainty in estimating the precise resource of manure that may be available for biogas. On top of this, there are many factors which influence the accessibility or availability of the manure.

DBFZ (2019) undertook an assessment which quantified manure produced from cattle and pigs in mass fresh matter (FM) as: 115 million t FM*yr^{-1} of cattle manure and 31 million t FM*yr^{-1} of pig manure. Of these quantities an estimated 38 million t FM*yr^{-1} cattle manure (33 %) and 5 million t FM*yr^{-1} pig manure (16 %) are already used in biogas facilities. Conversely 77 million t FM*yr^{-1} of cattle manure and 26 million t FM*yr^{-1} of pig manure are not utilized.

2.1.2 Structure of agriculture and spatial distribution of manure

For biogas production relevant cattle farms have substantially varying average farm sizes from a few to several thousand animals. The average farm sizes differ from region to region. In general, there is a long lasting ongoing change in the agricultural structure with closing down of smaller farms and increasing numbers of larger farms. When proposing a strategy for the implementation of an appropriate biogas concept this poses the question as to which plant concepts (in particular size/capacity) shall be incentivized in order to support biogas facilities which will utilize manure in the most cost efficient and sustainable way.

The implementation of a biogas system requires knowledge of the technology and its environmental and financial sustainability; accordingly for economic reasons there is a limit to application of certain biogas technologies to farms or facilities with few animals and associated low levels of feedstock. In Table 1 a rough estimation of the electric equivalence based on the mono-digestion of manure (without any co-substrates) is given according to herd size.

Based on biogas yields which are commonly used as reference in Germany (KTBL, 2013) and the average manure production of (all) cattle livestock systems in Germany it may be assessed (as below) that 1,666 cattle are required to fuel a 100 kW$_e$ co-gen set:

- 9.32 t FM*yr^{-1}r per cow * 10 % TS * 80 % VS * biogas yield of 380 l*kgVS^{-1} * 5.3 kWh*m^3 *35 % electrical efficiency *(365days * 24hours)$^{-1}$ = 0.06 kW$_e$ per cow

Manure digestion at small scale has been supported with an incentive for a particular size of manure-based facility (maximum 75 kW$_e$ average output with a minimum of 80 % of input manure). This tariff scheme was successful only for optimal locations with available substrate potential to provide 75 kW$_e$. For smaller facilities with less animals the remuneration proved insufficient. Discussions are on-going to increase this class to c.100 kW$_e$; this will not help to increase amounts of manure utilized for biogas.

Nationwide it can be stated that farm sizes with more than 100 cattle per farm or 400 pigs contain sufficient manure to be of interest for a biogas system. Since there are still many herds with smaller numbers of animals (Figure 1), the overall manure potential available for biogas within a country is not necessarily aligned to the number of animals in the country but must include the farm size and the readily accessible resource typically associated with larger farms.

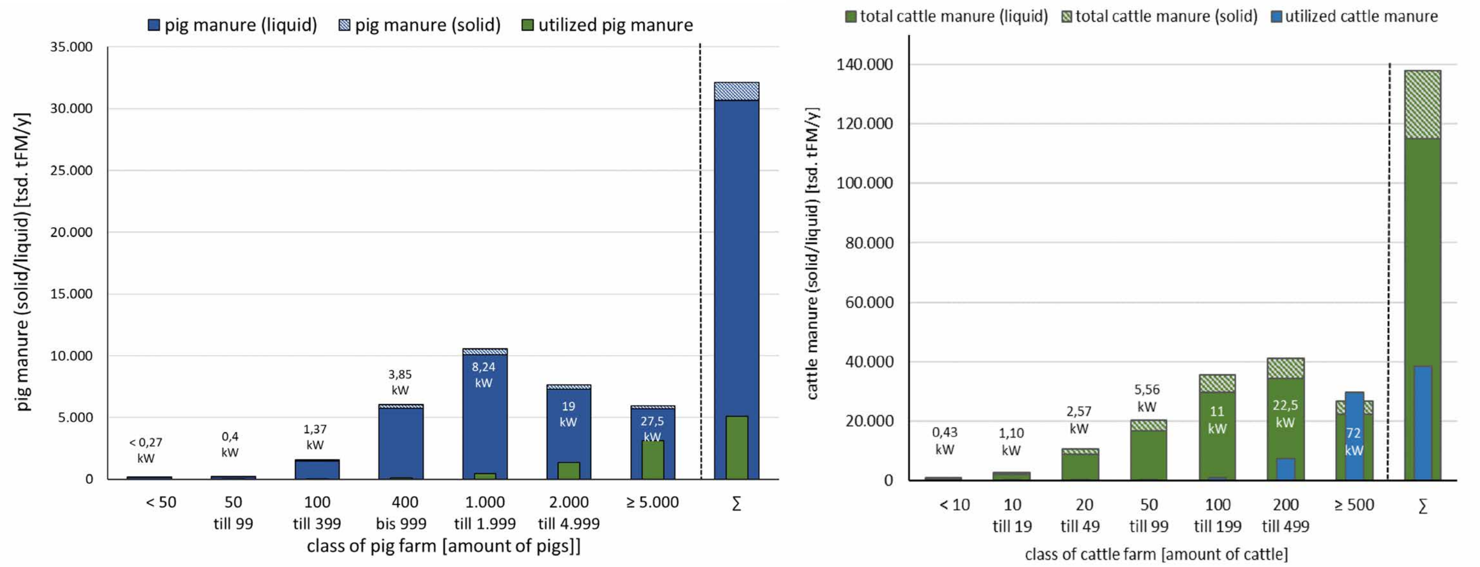

Figure 1: Distribution of pig and cattle manure by farm size in Germany (DBFZ 2019)

Table 4 outlines the average numbers of animals per farm as of November 2017 (Statistisches Bundesamt 2018). It can be clearly seen that agriculture in Germany is still dominated by small farm enterprises (Table 4). This is important to know when it comes to the development of strategies to access the manure and serves as an indication of the challenge in providing economically sustainable biogas facilities at individual farms.

Table 4: Average number of animals per farm (Germany 2017) (Statistisches Bundesamt 2018)

Germany	Cattle	Dairy (as fraction of cattle)	Pigs	Breeding pigs (as fraction of pigs)	Sheep	Goat	Laying hen	Broiler
Average - animals per farm	86	64	1,175	229	160	14	1,160	28,166

In Germany most of husbandry comprises closed barns with manure removal systems. Cattle as well as swine manure is very often diluted and pumped out of barns to lagoons or storage tanks. A total of 204 million m^3 of liquid manure (including digestate from biogas facilities which accounts for 31 % of the mass) was applied on agricultural land; 20 million tonnes of solid manure was applied on agricultural land (Statistisches Bundesamt 2015).

2.1.3 Spatial distribution

There are districts in Germany where the density of animals is very high (Figure 2). In these regions land application of the produced manure has become more and more controversial due to nutrient overload leading to eutrophication and pollution of water resources. Manure and/or nutrient transportation out of the region is an option for farmers to remove manure sourced pollution in these regions.

In the past the support schemes for biogas facilities led to construction of biogas facilities based on manure and energy crops (primarily maize) as substrate. The negative effects included higher prices for maize due to land competition since it is also the main fodder for cattle. It also led to pressure on land application of digestate, since the masses of liquid digestate resulting from energy crop digestion increased overall amounts of farm fertilizer to be applied on limited available land.

Although the described conflict was limited to a few rural districts, the debate had a large impact on overall perception and acceptance of biogas in Germany. Suggestions to solve these issues were to limit the numbers of animals per ha and biogas facilities, but this will not find the necessary agreement with the decision makers. On the other hand there are other regions in Germany with mainly arable farming practices which are in need of organic fertilizers. These regions would benefit from a more even distribution of animal husbandry.

2.1.4 State of the art of manure utilization

In 2016 an estimated amount of 53.3 million tonnes of manure were utilized in German biogas facilities. This translates to approximately 4 TWh of electricity based on manure (Scholwin et. al. 2019).

In the beginning of the agricultural biogas sector industry in Germany, biogas was produced based on manure and waste materials. With 1-2 million ha of unused land in the early 2000 years, the decision to incentivise the use of energy crops in 2004 in biogas facilities changed the industry and the use of manure experienced a drop. The 2009 amendment of the renewable energy sources act (EEG - the period with overall most attractive tariffs), a bonus for manure utilization was introduced. However, since the eligibility to the bonus was bound to a minimum fraction of 30 % (by mass) of manure within the input materials, many "tariff optimized facilities" with roughly 30 % of manure input were build and are operational up to now. In 2012 a new class of facilities with a capacity of lower than 75 kW and a minimum of 80 % of manure in the input was introduced in order to support manure utilization. This class survived all major changes since then and has not been as heavily affected by the tariff reductions as other plant sizes.

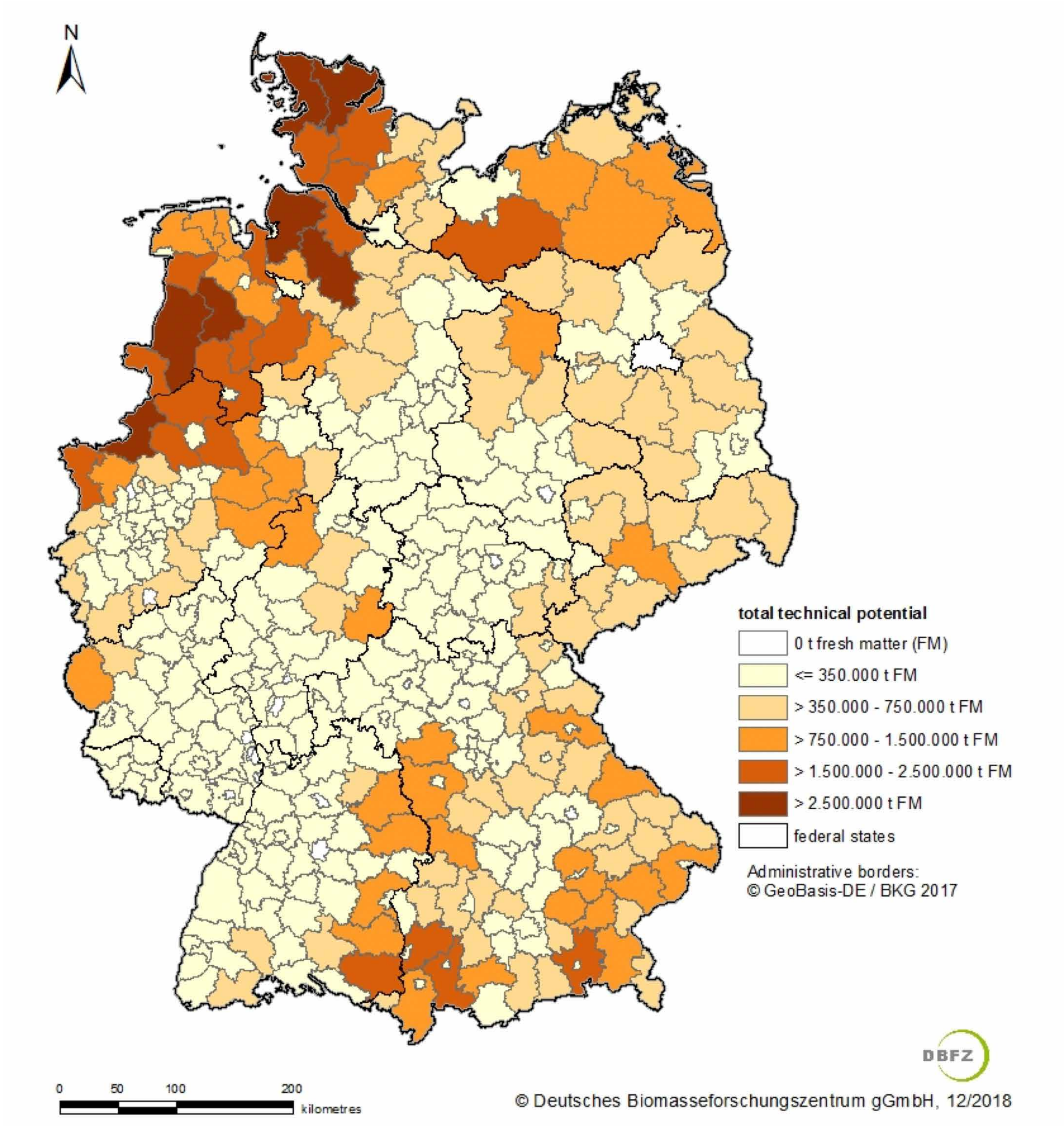

Figure 2: Spatial distribution of manure potential, given as t per rural district.

When examining herd size distribution (Figure 1) it is apparent that 75 kW_e is hard to be reached for most farms. However, when looking from the biogas plant perspective – a 75 kW_e facility is a small biogas plant with high specific costs – and even more costly when operated with water rich substrates such as liquid manure. In 2012 within the EEG, a classification of substrate was introduced which allowed a higher tariff to “sustainable” substrates such as manure. Unfortunately, this rather progressive instrument to steer the used substrates to manure was abandoned in 2014; since then, economics have driven the development with little regulation on the substrates. The specific tariff class for manure based small scale facilities survived all changes beyond 2012. Despite the flaws of this 75 kW_e category it represents the only class of biogas facilities where currently new (but still few) installations are to be seen.

For many facilities the end of the 20-year funding period (guaranteed by the German renewable energy sources act (EEG)) is approaching. Since tariffs in the recent amendments of EEG are much lower a substantial number of facilities are likely to phase out. This means that manure utilization in biogas facilities might decline in the future. Manure utilization in biogas facilities in Germany can be characterised as per Figure 3 and 4.

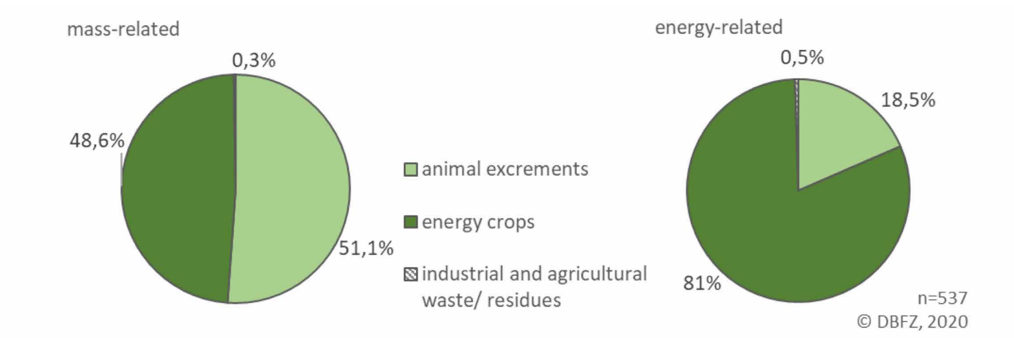

Figure 3: Mass and energy related fractions of manure and energy crops in Germany (all biogas facilities).

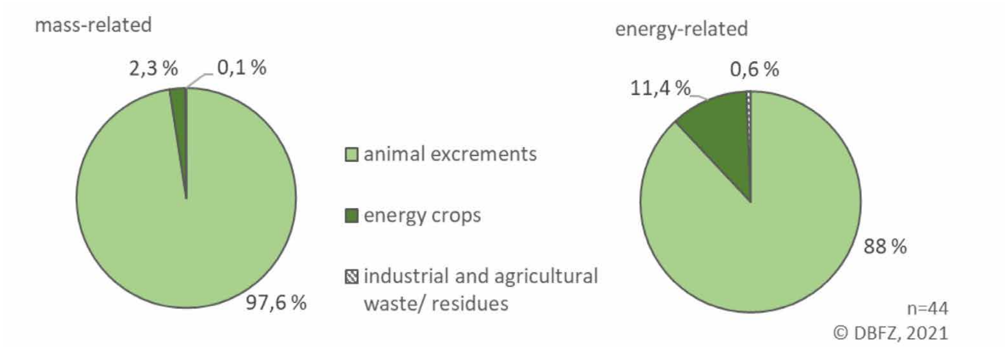

Figure 4: Mass and energy related fractions of manure and energy crops in Germany (only for small scale (75kW_e) manure-based facilities (with a minimum of 80 % manure required in the input feedstock)).

The difference in biogas potential within the substrate becomes obvious, when comparing the mass and energy related shares. Small scale biogas facilities use very little energy crops, although they are allowed to use up 20 % by mass in the input. The rationale for this is specification and cost related. Manure is for free if available in sufficient quantities on site and facilities with 100 % manure input do not have a requirement to have a retention time of 150 days in a gas tight system; this facilitates cost reduction in the digester dimensions and construction.

The amounts of manure applied in German biogas facilities are not specific to certain plant capacities. Looking only at cattle manure (Figure 5), 36 % of the facilities use 75 % of the overall utilized manure. These 36 % use 5,500 $t*yr^{-1}$ or more of cattle manure which equals approximately to an average of 39 kW_e

electrical capacity or higher. These facilities need to stay operational in the future if the amount of used manure shall not decline significantly. Again, it becomes obvious that a significant number of facilities utilize manure with an electrical equivalent below 75 kW_e, meaning that a transition into currently available support systems for manure utilization is not a cost-effective option.

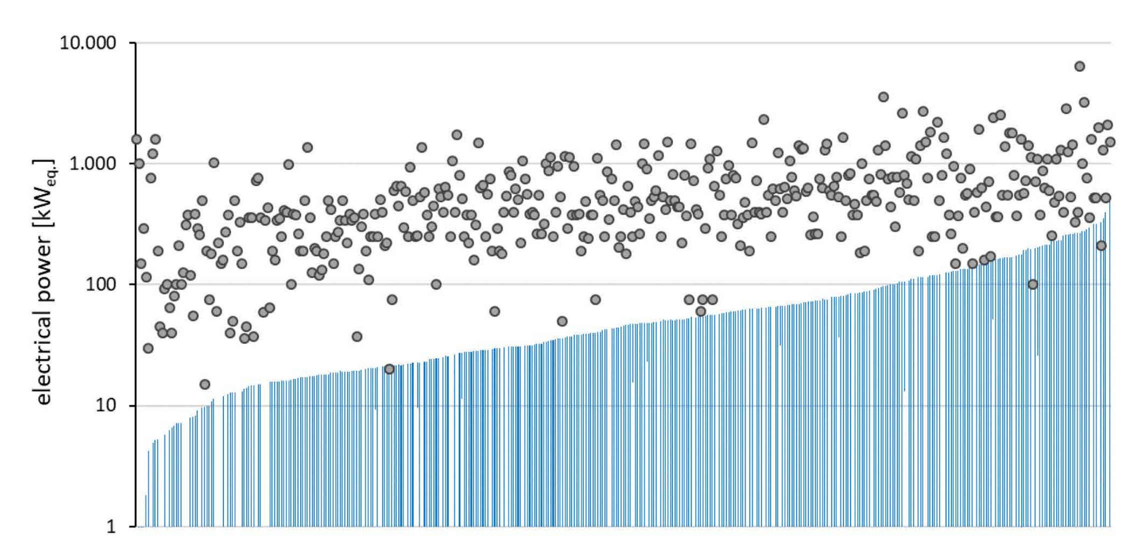

Figure 5: Plant capacities (kW) and manure mass per plant (in kW_e).

Looking at the types of manure used (Figure 6) it becomes apparent that cattle manure is more often used (with a share of 66 %) than pig manure. Pig manure is simply less available, and digestion is also technically more demanding than cattle manure. Pig manure is higher in water content and much more difficult to digest in mono-fermentation. When examining small-scale facilities (75 kW_e) which are obliged to use a minimum of 80 % manure, the share of cattle manure within these types of manures is 83 %.

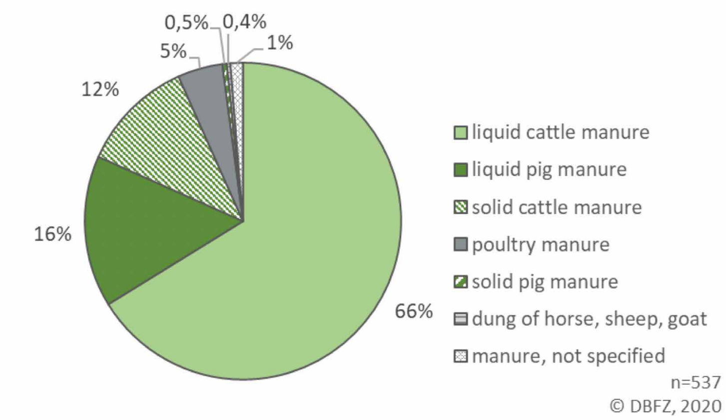

Figure 6: Shares of manures used in the biogas sector in Germany

2.1.5 Cost structure

If available on site in sufficient masses manure is a cheap substrate; liquid manure is rather easy to handle especially if some basic infrastructure such as tanks and pipes are in place. Digestion is easy to implement within the farming system and existing structures and cattle manure in particular is also easy to process. However, the large fraction of water in the manure and the low specific gas yields make the addition of co-substrates desirable and in the case of pig manure even essential. High water content leads to high retention times, which adds to the cost.

The cost curve for cattle and pig manure (with associated economies of scale highlighted) can be seen in Figure 7. The current assigned tariffs of roughly 22 (euro cent per kilowatt hour) €ct*kWh^{-1} are not sufficient for a standard 75 kW$_e$ facility and consequently it cannot be sufficient for locations with smaller herd sizes and consequently lower capacities. Furthermore, facilities which use pig manure are more costly than facilities that use cattle manure as feedstock, because of the lower energy content of pig manure. Site specific conditions differ in detail such as existing infrastructure like storage tanks. There are several options for cost reduction, but caution must be exercised in accepting costs from others; quite often facilities are stated to have lower costs by assigning costs from the biogas facility to cattle production or by not putting an economic value to their own labour during construction or maintenance. This may be a reason these facilities are still built, even though a general cost estimate would suggest they are not favourable.

Transportation to concentrate mass of manure to achieve a capacity which allows a cost efficient operation can be commendable if the gain in cost reduction by mass concentration and economy of scale exceeds the transportation costs. For transportation of liquid manure, the water content again represents a limiting factor, since transportation of water only produces costs. In case of the very specific situation with the support scheme with an upper limit of 75 kW$_e$ installed capacity in Germany it can be stated, that since the tariff is not sufficient for a location where all the manure is available on site, it cannot be sufficient with additional costs of transportation.

Chicken manure disposal costs are very high and as such processing in a biogas facility may be a cheaper option. As chicken manure is already transported across the country the avoidance of these disposal costs may lead to economic biogas facilities.

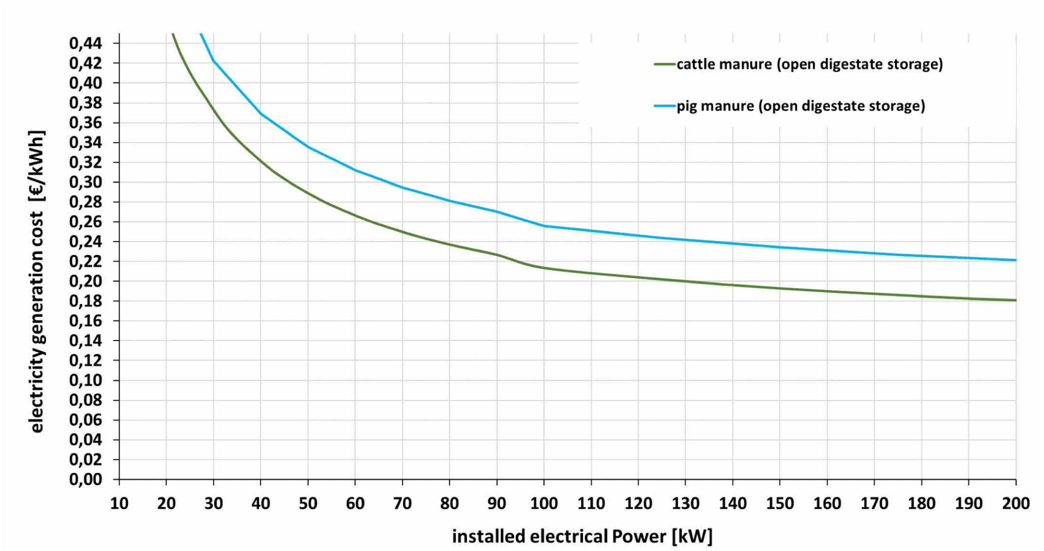

Figure 7: Cost-capacity relation of manure-based biogas facilities in Germany (60 d retention time, open digestate storage)

2.1.6 Lessons learnt and perspectives of manure utilization

In Germany the reduction of emissions from manure management was identified as one of the major leverages to reduce agriculture emissions. Consequently, the target to increase manure utilization was expressed by the Federal Ministry of Food and Agriculture (BMEL, 2019). However, the extent of the present biogas industry suggests that the low hanging fruits are gone, meaning easily accessible manure is already used in biogas facilities. For further increase in utilization, additional instruments are needed, and these instruments need to reflect the distribution of farm sizes and numbers of farms in geographic specific regions to be effective.

In Figure 8 the mass of manure, the herd size distribution and the costs (retrieved from cost curve given in Figure 7) for the respective biogas facilities to utilize the manure have been assessed to highlight costs associated with increasing manure utilization and resulting GHG emissions reductions. The calculations for figure 8 are based on combined heat and power (CHP) production from biogas.

At the moment 43.5 million tonnes of manure is utilized in Germany in biogas facilities, which results in utilization expenses of €0.82 billion per year and an annual GHG reduction of approximately 1.2 million tonnes of CO_2.

As shown in Figure 1 currently manure is utilized mainly at farms with large herds. In order to pursue the target of further GHG reduction, it is necessary to expand manure utilization to the smaller farms. Obviously, the resulting costs increase disproportionally with increasing utilization rates due to the increasing specific costs associated with smaller farms.

A complete manure utilization would result in a cost of €3.97 billion per year which would save of the order of 3.6 million tonnes of CO_2. Biogas end use in Germany at the moment is dominated by electricity production. The acceptance for expensive electricity from biomass is due to high overall electricity costs in Germany. As an alternative the use of biogas as fuel is currently under discussion. German legislation in the fuel sector, EU regulation and the GHG reduction credit for manure make manure a promising substrate for biomethane production and use as a renewable fuel for transportation. However, biogas upgrading has even higher specific costs and requires larger plant capacities to reduce these costs. Depending on the gas utilization option and scale of the plant, the GHG abatement costs show a range from 100 to about 900 €tCO_2 equivalent; in specific cases it can be even higher (especially for very small plants). Economies of scale has a particular effect here.

On the long term it has to be considered, that avoided emissions are calculated based on a given state of the art or a standard technology. Given an emission free future, gas tight covers for manure storage will be state of the art (including for destruction of methane or suppression of methane formation) and as such future analysis may not include for the manure credit for avoided emissions. Any perspective for emission reduction in manure management should consider alternatives to the production of a renewable energy carrier (biogas) to reduce emissions. Biogas applications should be part of the overall strategy but may not be the only measure to address emissions from manure management and specifically manure storage. Concepts should be assessed on a whole life cycle basis and should include for the co-benefits (improved water quality, reduced smells, improved fertilisation characteristics of digestate over manure) and indeed the externalities of biogas systems.

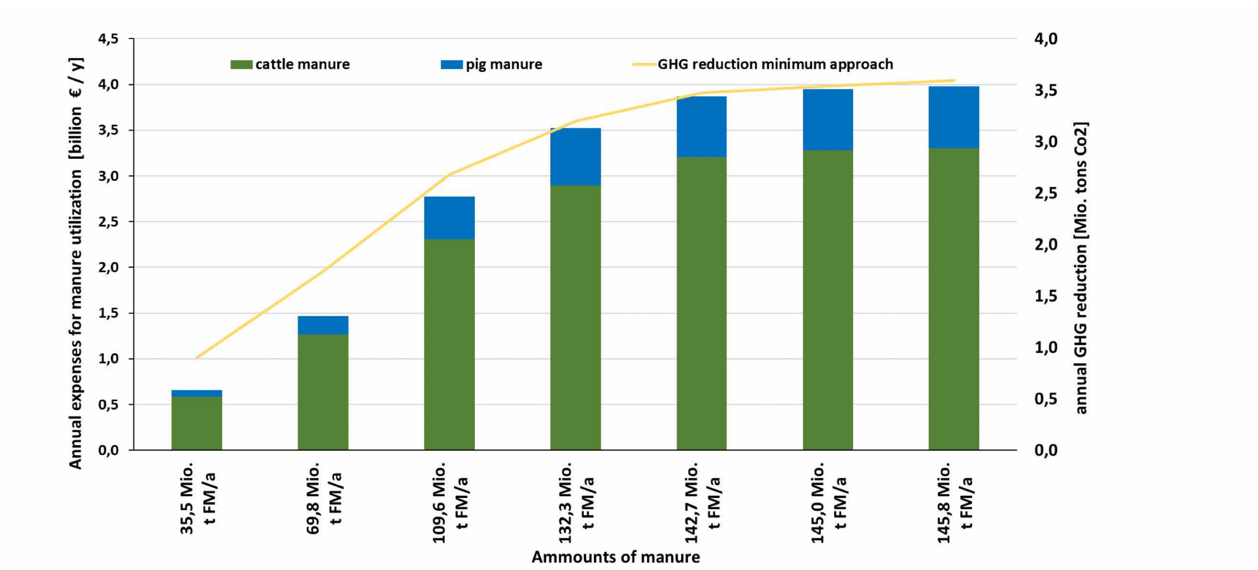

Figure 8: Costs for increasing manure utilization in Germany (at the moment 43.5 million tonnes are in use at a cost of €0.82 billion*yr^{-1}, doubling this would result in 87 million t*yr^{-1} at a cost of 2 billion €*yr^{-1})

2.1.7 Conclusion

Although Germany has large amounts of manure used for biogas production, two thirds of the manure is not in use. In the long term, the government has declared an ambition to reduce emissions from manure management and biogas is seen as the primary first option to effect this. However, the support system for biogas in Germany in the future is not certain and a strategy for a transition of existing facilities (and for new constructions) to increase manure utilization is not evident. Consequently, there is a considerable risk that with more and more biogas facilities going offline, that in the long-term manure utilization will decrease rather than increase.

Experience with support instruments in the past show that manure utilization requires precise support schemes which reflect regional conditions, agricultural practise and farming structures. Small herd sizes do not align with the aspiration for cost effective solutions. Additional instruments are required to enhance the economic favourability of digestion of manure and to achieve emission reduction in manure management at the large number of smaller farms with small herd sizes.

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2.2 AUSTRALIA

2.2.1 Overall potential

The largest and most relevant livestock sectors include cattle in both feedlots and dairies, pigs, and poultry for both meat and eggs. While there are other large livestock industries in Australia, they are typically raised in environments not conducive to practical manure collection (such as cattle, sheep and goats raised on pasture, range or paddock). Consequently, only intensive livestock agriculture will be considered further in this report. Table 5 and Table 6 show the number of animals, mass of manure and methane potential from Australian intensive agriculture industries and the amount of manure per animal and relevant characteristics respectively.

Table 5: Number of animals, and manure masses and methane potential from Australian intensive agriculture industries.

Animal/industry	Number	Fresh matter $t*yr^{-1}$	Dry matter $t*yr^{-1}$	Volatile solids $t*yr^{-1}$	B_0 m^3_N $CH_4 \cdot t$ VS^{-1}
Beef Feedlots Fresh & (stockpiled)	3,040,000	12,279,168 (643,416)	1,426,368 (514,733)	1,215,514 (303,878)	218 (13)
Dairy cattle	1,411,000	9,820,512	1,178,461	1,013,477	200
Pigs (SPU)[a]	2,485,103	2,210,279	289,441	223,659	300
Chicken (meat)	651,000,000	1,119,720	895,776	772,607	390
Chicken (layers)	1,193,467	1,016,711	244,011	146,406	360

[a] 1 standard pig unit (SPU) = 90 kg $VS \cdot annum^{-1}$ (Tucker, 2018);

Table 6: Amount of manure per animal and relevant characteristics

Units	t FM·head^{-1}·yr^{-1}	TS % FM	VS % TS	Gas yield[c] m^3_N CH_4·t^{-1} VS	No. of animals Per 100 kW_{el}*
Dairy	6.96	12	83	209	1,586[a]
Beef feedlots[b] (Fresh manure)	4.04	11.6	85.2	218	2,732
Beef feedlots (Stockpiled manure)	0.046	72.1	58	13[d]	249,226
Pigs (SPU)[b]	0.889	13.10	77.3	300	8,820
Layer hens	0.039	24	60	390	33,408
Chicken (meat)	0.00172	80	86.25	360	512,780

[a] Assuming 40% of manure deposited on a surface is collectable;

[b] The standard pig unit (SPU) is based on 90 kg VS·annum^{-1}. A single sow represents herself and the rest of the pig herd onsite associated with her. Consequently 1 sow represents 10.7 SPU;

[c] Methane yields as cited in Tait, Harris and McCabe (2021);

[d] MLA (2017b);

* Number represents annual turnover of animals. Assumed CHP electrical conversion efficiency is 35%.

2.2.2 Structure of agriculture and spatial distribution of manure

One of the challenges with manure management in Australia is the large spatial distribution of animal agriculture (Figure 9). Consequently, this report will focus on the manures which are practically collectible; typically this refers to intensive farming. These animals include beef cattle on feedlots, dairy cows on feedpads and in milking sheds, pigs in slatted floor sheds and deep litter sheds, and meat chickens and layer hens (Table 7). While there are other farmed livestock in Australia, the low stocking densities result in impractical manure collection, and these will not be considered further in this report.

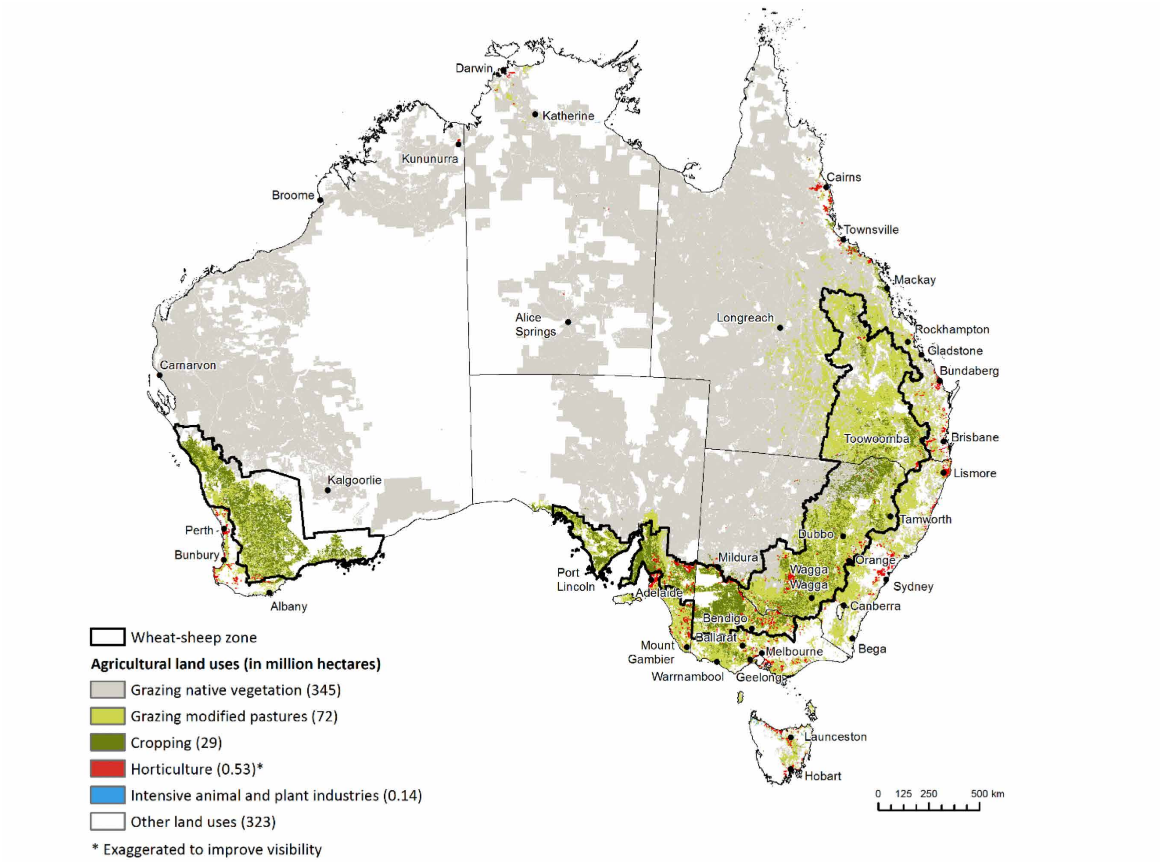

Figure 9: Spatial distribution of agriculture in Australia; Wheat-sheep zone - Agricultural and Grazing industries Survey, 2016, ABARES; Land use of Australia, 2010-11, ABARES, ABARES (2019).

Table 7: Relevant livestock numbers for manure collection in Australia, sorted by State.

Animals (,000)	QLD	NSW	VIC	TAS	SA	WA	National
Cattle (beef feedlot)[a]	1,763	790	213	0	122	152	3,040
Cattle (Dairy)[b]	65	145	895	182	69	54	1,411
Pigs (Sows)[c]	64	59	68	2	46	37	232
Poultry (meat, head)[d]	135,408	207,669	127,596		180,327		651,000
Poultry (Layers & Pullets)[e]	7,151	9,440[f]	7,438	286	2,002[g]	2,288	28,606

[a] Meat and Livestock Australia (2020) ; [b] Dairy Australia (2020) ; [c] Acil Allen Consulting (2017) ; [d] Australian Chicken Meat Federation (2020); [e] Australian eggs (2020b); [f] Value is for New South Wales and the Australian Capital Territory; [g] Value is for South Australia and the Northern Territory.

Manure management varies both between and within each livestock sector, and consequently so do the baseline emissions and methane potential. Tait, Harris and McCabe (2021) explored manure management in Australia in more depth, however, the following subsections will aim to give a brief overview of each industry.

Beef feedlots represent a good opportunity to capitalise on cattle manure as the spatial distribution of manure is minimal, but facilities are not currently equipped to effectively capture manure which is most suitable for methane production. Currently, cattle are contained in pens for an average of 136 days (Commonwealth of Australia 2020), though this time depends on the animal and the desired finish weight. During this time, manure is deposited onto the pen surface and cleaning is conducted after this period (Tucker et al., 2015). The infrequency of cleaning is due to labour and practicality considerations (Tucker et al. 2015). Pens are either scraped clean down to the soil level, or a manure interface is left on the surface. Scraping down to the soil has the benefit of recovering more manure but to the detriment of collecting dirt and stones as contaminants (MLA, 2017b). Conversely, leaving a manure interface results in a lower manure yield, but recovers a product with fewer contaminants (MLA, 2017b). Currently, manure is commonly composted and or stockpiled onsite and sold as fertiliser (Tucker et al., 2015). Both activities result in significant greenhouse gas emissions, though, according to Bai et al. (2020) stockpiling can result in half the emissions that composting produces.

Dairy farms are predominately pasture-based in Australia; however, intensive feeding systems are increasingly more common in order to improve performance and climate resilience and as a result currently represent approximately 26 % of total production (Watson & Watson, 2015; Dairy Australia, 2017; Christie et al., 2018). Consequently, manure is only practically available for collection from these intensive systems and pasture-based manure will not be considered further in this report.

Australia houses approximately 90 % of its pig herd indoors (Tucker, 2018). Housing is either in conventional sheds with slatted flooring (70 % of herd), or in deep litter sheds (20 % of herd). Slatted flooring allows excrement and spilt feed to pass through the slats to a concrete floor below. From here, waste is flushed with water into an adjacent anaerobic lagoon for treatment before being recycled as flush water or irrigation onto nearby agricultural land (Tucker, 2015). By contrast, deep litter sheds provide bedding in the form of various straws, husks or saw dust, and this combines with manure, urine and spilt feed to form litter (Tucker, 2015). While spent bedding has a good methane potential, spent bedding is currently spread onto agricultural land as fertiliser (Tucker, 2015).

Manure production from layer hens varies between caged, barn-laid and free-range facilities. Caged and barn-laid facilities represent 40 % and 10 % of egg production (Australian Eggs 2020a, 2020d). In these facilities, hens are raised on flooring which allows for manure to pass through to collect on a conveyor belt.

Meat chickens are typically raised in barns with the flooring covered in bedding (such as straw, husks or saw dust), though some barns use slatted floors (Federation, 2020).

2.2.3 State of the art manure utilization

Only pork manure is utilised for biogas production to any large extent in Australia due to the nature of housing of livestock and the ability to collect fresh manure. The following summarises each industry's manure collection system and degree of biogas uptake.

To the authors' knowledge there are no feedlots currently operating biogas facilities in Australia. Due to the dry, batch-wise production of feedlot manure, a dry digestion system such as a leach bed reactor or plug-flow reactor may be more suitable for a feedlot to adopt. If feedlot throughput is reasonably staggered, it may be possible to operate an anaerobic lagoon or continuous stirred-tank reactor, though these would require significant water addition. If a slatted floor approach were adopted, recycled flush water may be utilised to accommodate this process. The practical and economical collection of fresh manure from beef feedlots would enable the best-case scenario for feedlot waste processing in both maximising energy recovery and minimising water consumption. Industry-wide fresh feedlot manure production is estimated (Table 5) at 12,279,168 t of fresh matter with a respective yield of 1,215,514 t of volatile solids and a corresponding biochemical methane potential of 218 $m^3 \cdot t^{-1}$ of volatile solids (MLA, 2017a). By contrast, where feedlot manure is not readily collected but instead is allowed to age for over 100 days, the biogas potential of the collected manure is significantly reduced. During the aging process both the volatile solids content and the biochemical methane potential deteriorate. The reduced theoretical national yield of volatile solids was calculated at 303,878 t (Table 5) while the biochemical methane potential from aged manure has been measured at 13 $m^3 \cdot t^{-1}$ VS (MLA, 2017a).

There are no commercial scale biogas facilities using dairy manure, however, there have been demonstration facilities in the past and there is renewed interest with new facilities under construction. While dairy manure is sometimes a dry-scraped semi-solid, dairy manure is typically collected as a liquid effluent as a mixture of wash water, faeces, urine, cleaning chemicals, spilt feed and bedding if applicable; this results in a dilute/low solids content, but may also be collected as a semi-solid from feed pads (Birchall, Dillon & Wrigley, 2008). Australian dairy effluent is commonly treated in uncovered effluent ponds, and the adoption of pond covers represents an incremental change from current practice (Batstone & Jensen, 2011). Treated effluent is typically irrigated back to agricultural land to recover nutrients (Dairy Australia, 2008). Australian dairy farms are transitioning toward feed pads in which the collection of dairy manure is more practical. Currently, only around 40 % of dairy manure is collectable, resulting in a yield of 9,820,512 t of fresh manure (Table 5) with a corresponding volatile solids component of 1,013,477 t.

Biogas uptake in the Australian pork industry as of 2018 was approximately 13.5 % of total Australian pork production (Tait, 2018). There are approximately 20 systems which use covered anaerobic lagoons to capture methane (IEA Bioenergy Task 37, 2018). While the Australian pork industry have been proponents of biogas technology in Australia, there remains significant potential for the industry to capitalise on. Assuming a collection potential of 90 %, corresponding to the pig herd housed indoors, the annual collectable fresh matter (Table 5) is around 2,210,279 t with a volatile solids yield of 223,659 t.

Anaerobic digestion of layer hen manure is currently conducted in Australia, though the degree of uptake within the industry is unknown. Manure from layer hens is collected from a conveyor belt that is scraped and deposited onto another conveyor belt which transports the manure to a truck or storage unit for subsequent removal from site. This manure is commonly applied to agricultural land as a fertiliser or sold as fertiliser. Conversely, free-range farms represents 47 % of egg production (Australian Eggs, 2020c). After egg laying, hens are allowed to roam freely. If hens are confined to a shed, straws, husks and saw dust may be used as bedding in which manure and spilt feed accumulate to form litter. Spent bedding is typically spread on agricultural land. Layer hens in Australia produce an estimated 1,016,711 t of fresh manure annually, with a volatile solids yield of 146,406 t (Table 5).

In terms of biogas production, spent bedding from meat chickens would be well suited for dry, batch-wise digestion in a leach bed reactor or plug flow reactor. While the authors are unaware of any currently active biogas facilities utilising meat chicken manure, there is active interest in this area (Energy Farmers Australia 2019). Meat chickens are typically raised in barns with the flooring covered in bedding (straw, husks or saw dust), though some barns use slatted floors (Federation, 2020). This bedding combines with manure and spilt feed to form spent bedding. Spent bedding is commonly collected using a front-end loader after every flock, though some farms may re-use partially composted old bedding mixed with new bedding. In cases where bedding is re-used, litter is cleaned out after every second or third flock. Manure collection is reduced in free-range farms where chickens also have access to land outside the barn. Spent bedding is typically spread over agricultural land (Wiedemann, 2015).

2.2.4 Lessons learnt and perspectives of manure utilization

Biogas energy potential using manure from the Australian agricultural industries is substantial. However, anaerobic treatment of manure in Australia is still in its infancy, albeit with increasing adoption, especially in the pork sector. Challenges faced by the biogas industry include lack of financial viability, poor policies supporting purchase agreements, complex project development and operation conditions, inconsistent state by state digestate regulations, difficult access to infrastructure, and climate. Of these the revenue gap is the primary challenge and due to a lack of green energy incentives which cannot be readily overcome under present policy. Secondly, access to feedstock is challenging but this is changing as the dairy sector modernizes. Also, the classification of digestate has implications on its economic value. When digestate is designated as a waste rather than compost, this further limits its revenue options.

Based on successes of the piggery model, opportunities exist to develop new projects in Australia's dairy sector using similar approaches to generate electricity when the cost-benefit analysis of projects is positive. New models for using dry manure need to emerge, particularly for feedlot manure and poultry manure, although it is noted that the use of poultry manure is limited due the high levels of nitrogen.

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2.3 AUSTRIA

2.3.1 Overall potential

During the last agricultural structure survey in 2016, Austria recorded the values in Table 8 which may be synthesised as follows; approximately 2 million cattle, 2.8 million pigs, 0.4 million sheep and 17.5 million poultry. Manure per livestock unit and specific methane yield is documented in Table 9.

In Austria the total annual amount of manure is about 31.6 million t FM. However, Stürmer (2020) quantified the theoretical and technical potential of manure as 3.1 million t FM with a total energy content of 6.2 $TWhCH_4$ (approx. $20m^3CH_4$/t FM) and 2.6 million t FM with a total energy content of 5.1 $TWhCH_4$, respectively. The authors Dißauer et al. (2019) and Lindorfer et al. (2017) were more optimistic with the available manure for biogas facilities (8.5 million t FM and 3.9 Million t FM respectively).

Table 8: Amount of livestock in Austria in 2016

Livestock	Number of animals
Cattle	1,932,748
Horses and other equines	88,288
Pigs	2,883,988
Sheep	399,621
Goats	91,663
Chicken	16,745,159
Turkeys	590,219
Ducks	44,744
Geese	44,959
Ostriches	526
Other poultry	35,152
Other farm animals	41,176

Table 9: Mean value and standard deviation for the annual amount of farm manure in tonnes of fresh matter per livestock unit (LU) and the specific methane yield in cubic meters of methane per ton of dry matter (Stürmer, 2020)

	Mean Value [t_{FM} per LU *yr^{-1}]	Standard Deviation [t_{FM} per LU *yr^{-1}]	Specific Methane Yield [$m^3_{CH_4}$*$t_{DM^{-1}}$]
Cattle	18.5	1.53	167
Pigs	5.5	1.03	186
Poultry	7.4	1.31	225
Sheep and Goats	6.7	0.81	330
Other livestock	6.3	3.77	125

2.3.2 Structure of agriculture and spatial distribution of manure

The number of animals per farm varies strongly (Figure 10 and 11). Small family farms still account for a large number of farms. But their number is constantly decreasing, while the area farmed and animals kept per farm are increasing. In 1995, 115,700 farms kept an average of 20 head of cattle. This number increased to 32 animals on about 60,000 farms by 2016. During the same time, the number of animals per farm more than tripled for pig farming, from 35 animals per farm to 109 while the number of farms quartered from 106,900 to 26,000 farms. In the western part of Austria, loose housing predominates, and in the eastern part, tethered housing. The 3 main regions for animal breeding are Lower Austria, Upper Austria and Styria; 68 % of Austrian cattle production and 93.5 % of the pig production takes place in these regions.

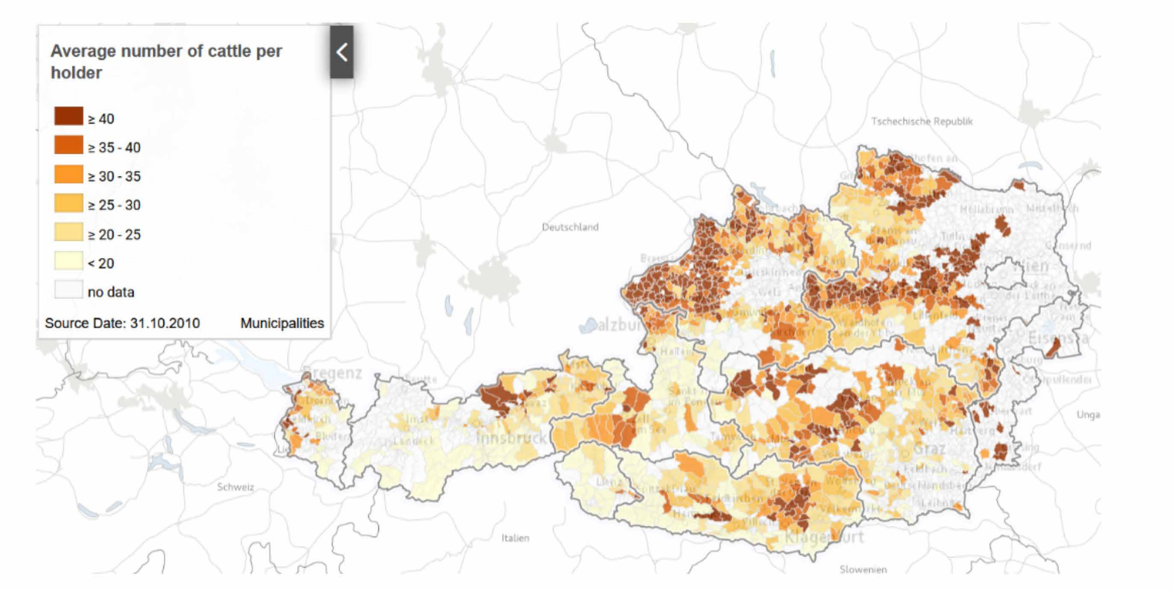

Figure 10: Average number of cattle per holder in Austria in 2010 (Statistik, Austria)

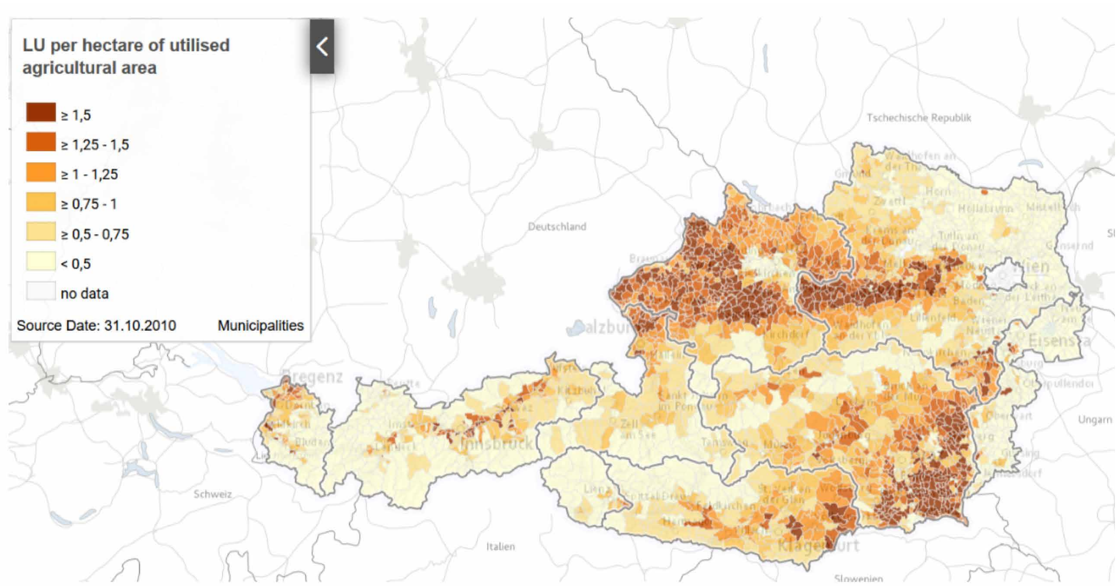

Figure 11: LU per ha of used agricultural land in Austria in 2010 (Statistik, Austria)

Detailed numbers are for available for animal husbandry of cattle and pigs from 2010 as per Table 10 and 11.

Table 10: Structural features of animal husbandry for cattle in Austria in 2010 (www.statistik.at)

Structural features				Animal husbandry for cattle		Type of housing				
						Tie stall		Free stall		Further animal hus-bandry
						Bedding (solid manure)	Liquid manure	Solid manure	Liquid manure	
				Farms	Total capacity	Total capacity				
Size classes lifestock units (LU)										
<		5	LU	9,782	77,471	54,018	3,630	9,897	2,398	7,528
5	to	10	LU	13,757	179,485	117,931	9,069	26,120	6,692	19,673
10	to	20	LU	20,175	481,111	245,780	37,289	99,818	44,857	53,367
20	to	30	LU	12,354	455,584	188,717	44,489	107,773	74,742	39,863
30	to	50	LU	10,801	606,736	162,543	50,217	159,243	178,101	56,632
50	to	100	LU	5,333	469,513	61,829	20,454	140,579	216,298	30,353
100	to	200	LU	820	101,076	6,621	2,297	33,234	53,375	5,549
200		LU >		95	18,595	1,119	286	10,106	6,498	586
Total				**73,117**	**2,389,571**	**838,558**	**167,731**	**586,770**	**582,961**	**213,551**

Table 11: Structural features of animal husbandry for pigs in Austria in 2010 (www.statistik.at)

Structural features				Enclosures for pigs		Type of housing			
						Partially slatted floor	Fully slatted floor	Straw (deep litter or slo-ping floor)	Other housing method
				Farms	Total capacity	Total capacity			
Size classes livestock units (LU)									
<		5	LU	6,291	49,091	8,446	5,972	25,254	9,419
5	to	10	LU	5,702	48,857	6,826	3,138	26,793	12,100
10	to	20	LU	8,521	98,953	20,808	7,428	44,591	26,126
20	to	30	LU	5,680	123,971	34,660	19,701	39,849	29,761
30	to	50	LU	5,443	280,448	88,820	70,485	66,880	54,263
50	to	100	LU	4,367	875,619	271,023	419,988	106,774	77,834
100	to	200	LU	2,487	1,352,995	285,728	960,092	71,820	35,355
200		LSU >		669	732,196	139,938	567,540	18,939	5,779
Total				**39,160**	**3,562,130**	**856,249**	**2,054,344**	**400,900**	**250,637**

2.3.3 State of the art of manure utilization

In 2018 in Austria the share of manure within total feedstock of biogas facilities (expressed in percentage energy content) is 5.9 %. Table 12 shows the fraction of manure from each animal species. Traditionally manure is used as fertiliser on farmland and this is still the dominat use of manure. The amount of manure treated in biogas facilities is low for economic reasons. Manure contains a high percentage of water. Thus, biogas facilities require large digester volumes and show relatively low specific gas yields per m^3.

The goal of the Austrian government is to increase the amount of manure in anaerobic digesters. The last amendments of the renewable energy law (Ökostromgesetz, 2020) mandated the use of manure in anaerobic digestion systems. It is required that at least 30 % of manure is used as feedstock to receive the feed-in tariff. A specific tariff for manure like in other countries does not exist.

Table 12: Share of manure used in biogas facilities related to the energy content of the input material (Ökostrombericht, 2020)

Animal	Percentage of energy content of total feedstock (share energy content of total manure utilized)
Cattle slurry & dung	3.2% (54%)
Chicken manure	0.8% (14%)
Pig manure	0.9% (15%)
Sheep, Goat, hoarse and undefined	1.0% (17%)

2.3.4 Lessons learnt and perspectives of manure utilization

The biogas industry in Austria has been challenged with low feed-in tariffs for a number of years. Very few new facilitiess are built, or biogas facilities are not expanded even though the aim of the ministry is to increase the amount of manure used in biogas facilities. An additional incentive is not given nor is planned. One aim for the future will be the implementation of a green gas directive. How this directive will influence the anaerobic manure treatment is unclear?

A national strategy for manure treatment does not exist. In Austria, the agricultural structure is still based more on small scale farms with small numbers of animals and not with high animal density compared to other regions such as in Lower Saxony/Germany, Brittany/France or the Netherlands. The biggest challenge for farmers in some regions with higher animal numbers is the reduction of manure caps and reduction of the period where manure may not be applied to land. Larger storage capacity on farms or treatment in surrounded biogas facilities would be an option. Application of manure in existing biogas facilities is limited due to the amount and the distribution of existing biogas facilities in Austria. New and economic facilities for manure treatment are required to tackle this obstacle.

2.3.5 References Austria

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2.4 NORWAY

2.4.1 Overall potential

In Norway there are about 26,000 animal farms (holdings), and the number of cattle and pigs was 863,000 and 83,000 respectively in 2019 (Statistics Norway, 2020a). The theoretical amount of manure from cattle and pig available for biogas production has been estimated to be 6.9 million tonnes per year (Lyng et al., 2019a). This amount excludes manure produced during grazing. The realistic potential of biogas produced from livestock manure is estimated to be 796 GWh in 2030, which is about 32 % of the potential of biogas from all feedstocks, which was estimated as 2.5 TWh by Isakova et al. (2019).

2.4.2 Structure of agriculture and spatial distribution of manure

The average number of animals on each farm in Norway is relatively small compared with countries such as Denmark and Germany. For example, the average number of beef cows per holding in 2020 was 18 and the number of dairy cows averaged 30 animals per holding. For pig farms the average number of breeding pigs per holding was 79, while the number of pigs for slaughtering was 250 per holding (Statistics Norway, 2021). Manure can only be spread on approved land, and the number of animals on each farm is restricted by the area of land available for spreading manure.

Figure 12 shows the spatial distribution of manure resources available for biogas production and the location of biogas facilities treating manure; these maps were created based on data from (Lyng et al., (2019a and 2019b). This shows that the largest amounts of manure resources are situated in mid-Norway and in South-West Norway, while existing biogas facilities treating manure are located in Eastern Norway. Several new biogas facilities under planning, construction and start-up period are, however, planning to treat livestock manure in combination with industrial and marine wastes (Lyng et al., 2019b).

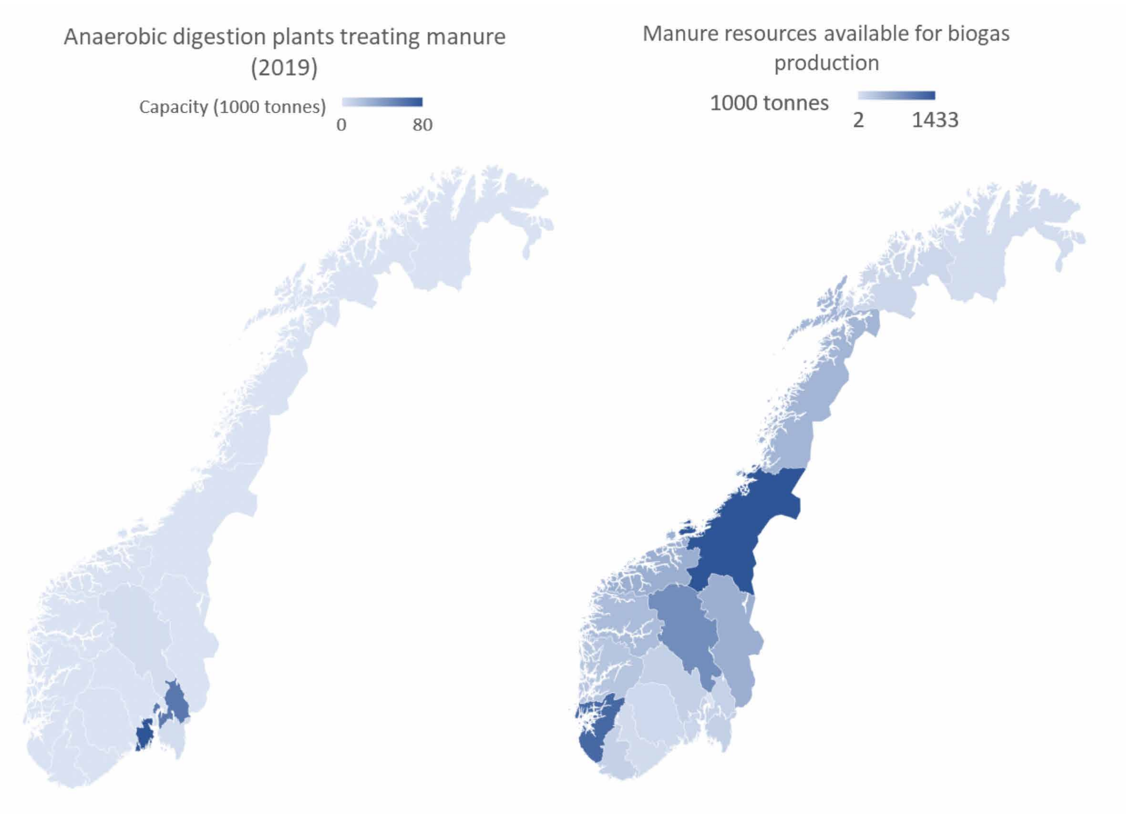

Figure 12: Spatial distribution of manure resources and biogas facilities treating manure (Lyng et al., 2019 a & 2019b)

2.4.3 State of the art of manure utilization

The driver for using manure resources for biogas production in Norway is primarily reduction of greenhouse gas emissions from manure management in the agricultural sector. Agriculture was responsible for 9 % of the national greenhouse gas emissions in 2019 (Statistics Norway, 2020b). The agricultural sector has committed to reducing their emissions by 381,000 million CO_2 equivalents from 2021 to 2030 (Teknisk arbeidsgruppe, 2018). Biogas production from manure has been identified as one of the most important measures to achieve this commitment.

A white paper for agriculture in 2009 presented a national goal of 30 % of manure for biogas production by 2020 (Norwegian Ministry of Agriculture and Food, 2008). From 2013 to 2017 the amount of manure treated in biogas facilities increased from 3,000 tonnes to 70,000 tonnes (Figure 13), but the estimated share of manure for biogas production in 2020 was still only 1 %.

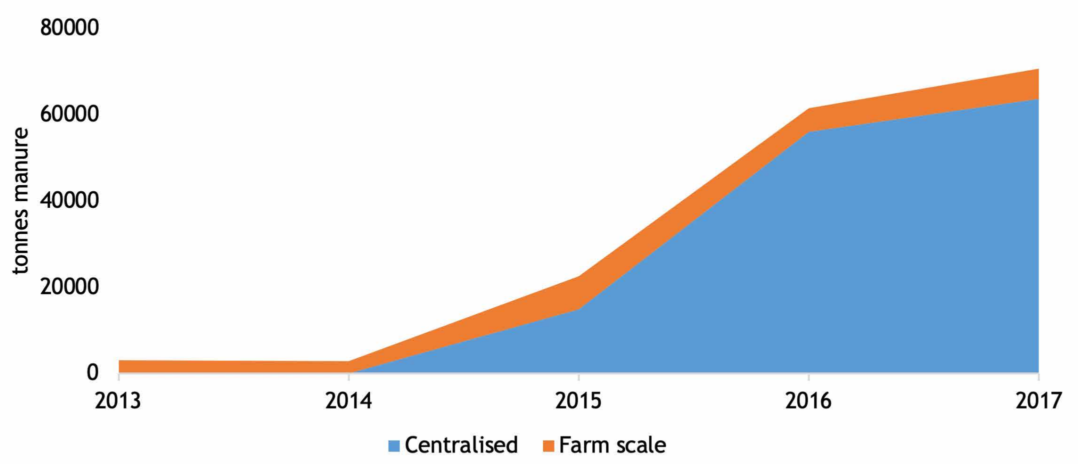

Figure 13: Livestock manure used for biogas production in Norway, based on data from Norwegian Agriculture Agency

As an instrument to increase the amount of manure used for biogas production, a support system for manure used for biogas production was introduced in 2012 (Lyng et al., 2019c); 42 farms applied for the support in 2020 (Norwegian Agriculture Agency, 2020). Most of those were farms who supplied manure to a centralised biogas plant and received liquid digestate to be used as biofertilizer in return. Until 2020 the only large-scale biogas plant using manure as one of the main inputs was The Magic Factory, which co-digests manure with food waste from households and industry. As the dry matter content in manure is low, the plant regards the manure simply as process water, reducing the need for adding fresh water to the treatment of food waste.

Only 5 of the applicants for the support for manure used for biogas production in 2020 were farms with small scale biogas production (Norwegian Agriculture Agency, 2020). The farm scale biogas facilities are mainly pilot or research facilities and the amount of manure treated is between 2000 and 3000 tonnes of manure per year.

2.4.4 Lessons learnt and perspectives of manure utilization

One of the most important barriers has been identified as lack of economic profitability. For farm scale biogas facilities the lack of profitability can be explained by small volumes of manure on each farm and insufficient income to cover the investment and maintenance costs. The volumes produced at the farm scale facilities are too small for upgrading of biogas to be profitable, and thus the end product from the farm biogas facility is heat and/or electricity. Norwegian farms generally have access to renewable and relatively cheap energy, which means that the alternative costs for heat and electricity are low.

There are no examples of centralized agricultural facilities treating manure from several farms. This may be explained by the spatial distribution of farms and by the small volumes, leading to large transport costs.

For centralized, large scale biogas facilities in Norway the largest costs associated with using manure as input are transport costs and the costs associated with investing in a pre-storage tank on each farm (Lyng et al., 2019c). Manure must compete with other feedstocks which have higher biogas yields. For most biogas facilities in Norway, the service of treating food waste or sewage sludge (which derive a gate fee) represents a large share of the income (Lyng et al., 2019d), which makes manure less competitive. Cost estimations for the existing co-digestion facility treating manure showed that the operation of the plant in general is profitable (Stensgård et al., 2017), but the use of manure as input generates more costs than income (Lyng et al., 2019c). This indicates that the centralized facilities' motivation of using manure as input is not primarily economic. Cost estimations have shown that the arrangement seems profitable for the farms that supply manure to the facility and receive digestate in return (Lyng et al., 2019c).

The positive aspects of manure as feedstock is that it can contribute to a more robust and stable production and that it is a feedstock that is available all year (Lyng et al., 2019c). Lab scale tests also indicate an increase in production when co-digesting food waste with manure, larger microbial diversity and a more balanced C/N ratio (Zamanzadeh et al., 2017).

Co-digestion of manure in a centralised facility with other substrates such as food waste can in addition result in larger reductions of greenhouse gases than farm scale biogas production if the large-scale facility upgrades biogas to fuel quality and the biogas substitutes for diesel. This is because the heat and electricity mix in Norway is relatively renewable, and thus the substitution effect and reduction potential are lower than that in the transport sector.

Despite political ambitions to increase the share of manure used for biogas production, only 1 % of the total amount is presently treated in anaerobic digestion facilities. In 2020 there was only one large scale biogas facility and a few farm-scale biogas facilities using manure as one of their main feedstocks. The establishment of the large-scale plant has, however, resulted in a significant increase in manure used for biogas since 2013. The support scheme per tonne of manure used for biogas production has been a driver and can be expected to increase the amount in the coming years. The support is calculated based on the dry matter content in the manure and has increased each year from 1.5 Euros (15 NOK) per tonne manure in 2012 (Norwegian Environment, 2013) to 9.7 Euros per tonne (100 NOK) in 2021 (Agricultural agreement, 2020). The support system changed status from a pilot scheme to a permanent scheme in 2020. As there are several biogas facilities that are considering using manure as input, the amount of manure treated in centralised biogas facilities can be expected to increase the coming years.

2.4.5 References Norway

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2.5 CANADA

2.5.1 Overall potential

Canada's total livestock production in 2018 is estimated to have generated 21.4 million tonnes of dry manure or 19.8 million tonnes of volatile solids (VS). Table 13 highlights the 12 largest animal groups according to manure volumes, along with their respective populations and average VS contents. Only a portion of the total manure is collectable and available for anaerobic digestion. For example, beef cows can spend 5 to 7 months of the year grazing, while dairy cows are usually housed in barns where manure is washed out into storage tanks.

Table 13: Animal Population and Manure Production in 2018 (ECCC, 2020)

Animal Group	Population in 2018	Dry Manure (t DM*yr^{-1})	Volatile Solids (kg VS*(head*day)$^{-1}$)
Beef Cow	3,704,400	8,965,455	6.100
Calf	3,856,750	3,387,117	2.214
Dairy Cow	971,000	2,404,427	6.241
Beef heifer-bred	615,750	1,055,770	4.322
Poultry: Broiler	109,531,538	829,964	0.020
Hog (> 60 kg)	4,517,500	696,502	0.400
Steer	1,381,800	681,699	1.243
Dairy heifer	434,400	618,274	3.587
Bull	218,900	556,658	6.410
Beef heifer-slaughter	807,000	445,951	1.393
Horse	291,561	393,554	3.550
Turkey	8,423,900	257,047	0.075

The primary types of manure that are considered to be most amenable to anaerobic digestion are found in confined operations of the following four animal groups:

- Dairy cattle – milking cows and replacement heifers;
- Hogs – growing and finishing pigs, and sows;
- Beef cattle at feedlots – steers and heifers for slaughter; and
- Poultry: broilers, laying hens and turkeys.

Today, most collected manure is land applied as fertilizer to agricultural soils, with a small percentage undergoing composted before application. Approximately one percent of total manure (456,000 tonnes FM) is converted into biogas and digestate. While the theoretical feedstock potential appears very large, the technical potential depends on the collectability of the manure, its composition including sand and stone contaminants, and the availability of suitable co-substrates to provide good biogas yields. The economic potential is a function of the concentration of manure and co-substrates in a given location, and proximity and access to energy users. The size and certainty of the revenue streams, namely the value of the energy from biogas, digestate nutrients and other environmental and social benefits, including carbon credits, determines the financial viability and project rate of return. To date, provincial government policies and feed-in-tariff (FIT) programs have been essential to adopt for on-farm anaerobic digestion.

Currently (2021), Canada has 46 digesters operating with some manure input. Of these, 74 % are based on dairy manure and the remainder are based on beef manure (2 digesters), hog manure (1 digester) and mixed manures. Dairy manure, mostly in liquid form, is readily collected from barns, relatively free of contaminants and has a relatively high VS content on a per head basis.

As economies of scale are achieved with larger farm sizes and co-digestion with off-farm feedstocks, work is underway to estimate the manure potential by farm size and complete GIS-based mapping of feedstocks and infrastructure in selected regions of the country.

In Canada, farm size varies significantly between dairy, hog and poultry farms and beef cattle feedlots. Farm sizes in supply-managed industries, such as dairy, egg and poultry have remained fairly stable as there is a fixed limit to production. For other livestock groups, such as hog and beef production, the trend has been towards larger farms and consolidation.

Table 14 presents the total number of farms and average number of animals per farm for these four animal groups, on a national basis. The farm size distribution differs for these animal groups. The dairy farm distribution, shown in Figure 14, reveals the many small to medium sized farms that are characteristic of a supply-managed industry, while the distribution of farms housing grower and finishing hogs, shown in Figure 15, shows significantly more large sized farms.

Table 14: Number of Farms and Animals on Canadian Dairy, Hog, Beef and Poultry Farms in 2016 (Statistics Canada 2016)

Animal Groups	Total No. farms	Number of Animals per farm National average
Milking Cows	12,895	73
Replacement heifers for dairy*	12,049	36
Grower and finishing pigs	5,464	1,394
Sows and gilts for breeding	3,716	326
Steers	23,613	67
Heifers for slaughter or feeding	14,971	60
Laying Hens	18,664	1,301
Broilers	7,249	14,195
Turkeys	2,690	3,132

*Milking cows and replacement heifers are typically located on the same dairy farm.

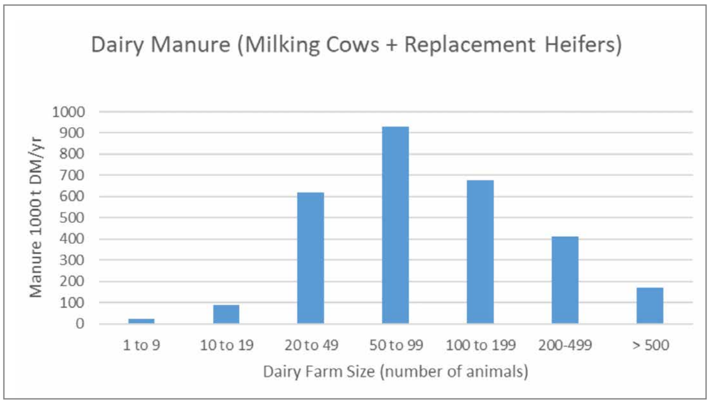

Figure 14: Distribution of Dairy Manure by Farm Size in 2016 (VanderZaag, 2021)

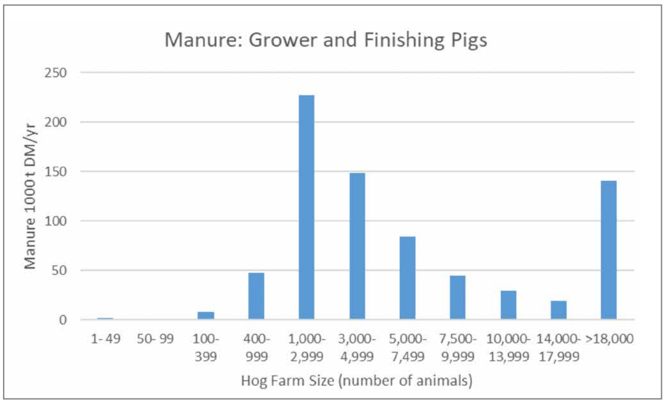

Figure 15: Distribution of Grower and Finishing Hog Manure by Farm Size in 2016 (VanderZaag, 2021)

Therefore, policies and programs targeted to increase adoption of anaerobic digestion need to take into account both the different industry structure of the animal groups, and the VS content or methane potential of the manure type. As shown in Table 15, if a target of 50 % manure conversion into biogas were set for these four animal groups, this would require approximately 2,600 dairy farms (20 % of total farms) to feed into digester systems but only 660 hog farms with grower and finishing pigs (12 % of total) to feed into digester operations. However as per Table 15 the total VS content of the dairy farms is more than double the VS content of farms producing grower and finishing pigs. It is interesting to note that for some animal groups, less than 10 % of the total farms account for 50 % of the total manure. These larger farms could be good candidates for future AD systems.

Table 15: Number and Size of Farms Representing 50% of the Total Volatile Solids in each Animal Group

Animal Groups	50% of total VS of the animal group (tonnes VS*yr^{-1})	No. farms	% of farms
Milking Cows	1,106,036	2,600 farms with 100 or more milking cows	20.2%
Replacement heifers for dairy*	284,406	2,444 farms with 50 or more replacement heifers	20.3%
Grower and finishing pigs	434,223	660 farms with 3,000 or more grower and finishing pigs	12.1%
Sows and gilts for breeding	69,976	293 farms with 1,001 or more sows and gilts for breeding	7.9%
Steers	313,581	214 farms with 1,001 or more steers	0.9%
Heifers for slaughter or feeding	205,137	138 farms with 1,001 or more heifers for slaughter or feeding	0.9%
Laying Hens	394,233	348 farms with 20,000 or more birds	1.9%
Broilers	122,284	764 farms with 45,000 birds and over	10.5%
Turkeys	115,671	124 farms with 20,000 or more turkeys	4.6%

*Milking cows and replacement heifers are typically located on the same dairy farm.

Today, manure-based digester systems range from 20 to 2,800 kW with the majority having a name plate electrical generation capacity of 500 kW. This was the size supported by most feed-in-tariff programs to encourage economy of scale. Given the predominance of smaller farm sizes, this meant that co-digestion with off farm materials would be needed. On average, manure represents 59 % of the substrate in manure-based digester systems. The other substrates depend on what is locally available and typically include fats, oils and greases and food processing residues. To date, only four digesters operate solely on manure.

2.5.2 Structure of agriculture and spatial distribution of manure

The spatial distribution of manure and other substrates is important from both technical and economic perspectives as they dictate the amount of biogas that can be generated and the quality of the digestate. There must be sufficient volumes of collectible substrate available on a consistent basis within a relatively short radius for a digester system to be viable.

Census of Agriculture data provide a general idea of the location of livestock operations across the country and a starting point for site location. The information is available by census unit which is still relatively large. More detailed GIS based work is needed to identify not only livestock farms but other sources of feedstock and proximity to local energy users or natural gas infrastructure.

The most recent manure mapping study was conducted by Torchlight Bioresources in 2020. It estimated 40 PJ*yr^{-1} as the theoretical potential for energy from manure (based on a recovery rate of 82 %), and a more realistic (feasible) potential to be 9.4 PJ*yr^{-1}. The work mapped the major production areas for dairy, hog, beef cattle (in feedlots), poultry and turkeys by census zones, and included information on potential landfill gas and biogas from urban waste and municipal and industrial wastewater treatment in each zone. The darkest areas in Figure 16 indicate the areas of greatest total theoretical potential for renewable natural gas production. (Torchlight Bioresources, 2020)

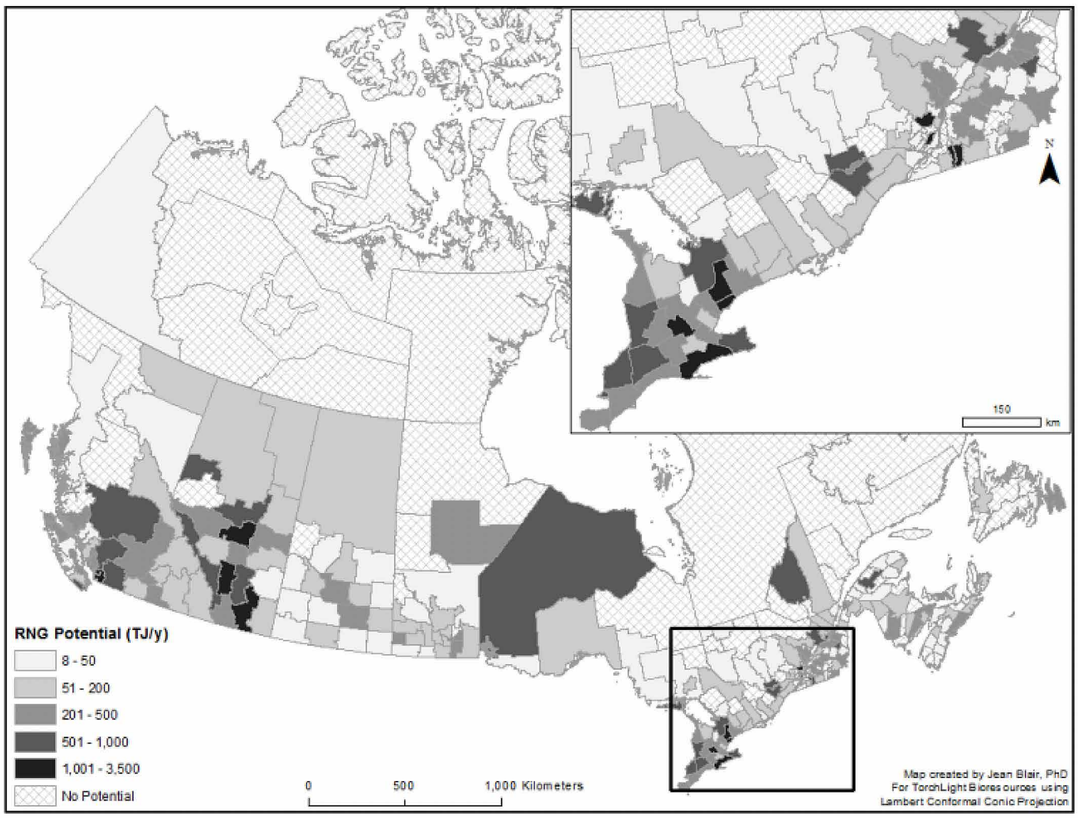

Figure 16: Theoretical potential for Renewable Natural Gas in Canada. Production by Census Zone (Torchlight Bioresources, 2020)

Anaerobic digestion of crop residues is not practiced to a significant extent in Canada. Given the large amount of available residue, Torchlight Bioresources estimated that the digestion of crop residues could provide an additional 10.6 PJ of energy, increasing the feasible potential to 20 PJ*yr^{-1}. To date, crop residue removal has not been strongly promoted because of its important role in reducing soil erosion and protecting soil health. However, there are areas with heavy biomass accumulation where partial residue removal can be considered for biogas production provided the digestate nutrients are returned to the harvested fields (Bentsen et al., 2017).

In addition to proximity to feedstock supply, the digester's location should allow easy distribution of its outputs – biogas and digestate. As on-farm digester systems produce more energy than is typically needed by a farm operation, other local energy users need to be found or the energy needs to be sold to electricity or natural gas utilities. Most on-farm digester systems operating in Canada today convert their biogas into electricity that is sold to the utility for a premium.

With the ending of the provincial feed-in-tariff programs, the main opportunities for energy sale appear to be as upgraded biogas that is sold to a local user or a natural gas utility. Not surprisingly numerous gas utilities and project developers have carried out more detailed mapping of feedstock sources in relation to the existing natural gas infrastructure. With the federal government's recent release of a hydrogen strategy (Natural Resources Canada, 2020), regional hydrogen blueprints are being developed. Biogas production, natural gas pipelines and future hydrogen infrastructure should all be included in the renewable gas vision.

With respect to digestate nutrients, in most parts of Canada, manure and digestate are land applied to the fields of the livestock farm and neighbouring farms, replacing a portion of the fertilizer required for crop production. Depending on the type of substrate, some digester systems will require pasteurization to ensure the destruction of harmful organisms before being land applied. However, in a few areas of the country, such as the Lower Fraser Valley of British Columbia, nutrient loadings are already high and livestock production is therefore limited. Here anaerobic digestion combined with nutrient recovery from the digestate avoids nutrient overloading. The concentrated nutrients can be applied to more distant farmland or be sold for fertilizer applications outside of the region.

2.5.3 State of the art of manure utilization

Canadian Biogas Association has estimated that 456,000 tonnes of manure were treated in on-farm digesters in 2020. Almost all of these systems co-digested manure with off-farm material such as fats, oils and greases from local abattoirs and restaurants, and food processing residues. It is therefore not possible to strictly separate out the amount of energy that is derived strictly from manure. In 2020, 779,000 tonnes of manure and other material produced approximately 67 million m^3 of biogas (86m^3/tFW). Today, most (78 %) of the biogas from manure-based systems is converted into electricity, 20 % is used for heat or upgraded to renewable natural gas (biomethane), and 2 % is flared. Manure-based digesters account for 17 % of the total biogas production in Canada, with the remainder being derived from wastewater treatment plants (municipal and industrial) and the digestion of source-separated organics, (Canadian Biogas Association, 2020)

On-farm digestion of manure began in the 2000s, supported by feed-in-tariff (FIT) programs that were established in several provinces to increase renewable electricity production and derive value from wastes. The Province of Ontario offered the highest rates, and not surprisingly this is where most of the manure-based digesters exist today. The FIT programs encouraged the development of 500 kW systems that necessitated changes in provincial legislation to allow farms to receive off-farm material. A micro-FIT program was also put into place in Ontario, and it supported one small (20 kW) system. These programs have now ended in most provinces as less costly sources of renewable electricity have become available.

It is important to note that several manure-based systems closed over the last decade mainly because they were not financially viable. At least four of these were installed at hog farm operations in the Provinces of Quebec, Saskatchewan and Alberta. One system operating on a large beef feedlot was shut down due to operational difficulties created by the sand and stones entrained in the cattle manure and a complicated integration with an ethanol plant. Given these fairly recent experiences, hog and beef producers have not been overly keen to consider new investment in capital-intensive anaerobic digestion systems when comparing these to other investment opportunities that could more directly improve their competitiveness. There needs to be a good business case or another compelling reason for agricultural producers to consider adopting these systems.

With many on-farm AD facilities now being past the mid-point of the facility lifespan, the existing industry will soon stand at a crossroads. New opportunities appear to have emerged for large farms or feedstock supplies that are close to a natural gas pipeline. At present, two provinces are offering a premium for renewable natural gas, and they can purchase the Renewable Natural Gas (RNG) from facilities in other provinces. Feedstock cluster configurations are being considered with third party operators coordinating feedstock collection and day to day operation of the digester. Going forward, the main drivers for biogas production include organic waste diversion and climate change mitigation. Provincial RNG mandates and premiums paid for RNG, rising carbon taxes, federal clean fuel regulation and greenhouse gas reduction requirements imposed on the agriculture sector are expected to create pressure to reduce GHG emissions from manure management and opportunities to convert manure into renewable energy while recovering its nutrients.

The main challenge continues to be financial with a weak business case and difficulty obtaining a long-term supply contract for off-farm feedstock, making it difficult to obtain financing. Upgrading of biogas to RNG is costly and requires a minimum scale to be considered. Even with a good offtake agreement for the RNG, on-farm systems struggle to raise capital and have sufficient revenue. For this reason, new business models are being explored to share both the capital and operating risks.

Finally, as not all parts of the country have access to a natural gas pipeline, other opportunities would benefit exploration including more local uses of the biogas or RNG in stationary or mobile applications and producing other products from biogas such as single cell protein that could be used as animal feed.

2.5.4 Lessons learnt and perspectives of manure utilization

Given the abundance of smaller farms and distances between many farms, to date AD systems have only been viable with co-digestion of off-farm material and a premium paid for energy sales. While often mentioned, the other benefits of AD such as nutrient recovery, odour reduction, pathogen reduction, groundwater protection, contribution to a more circular economy and SDG goals, are not monetized and no framework exists to guide decision-makers on how to include these benefits in project decision-making.

Reducing GHG emissions from manure management is mentioned more frequently as an area requiring attention in the country's national and provincial environmental plans. In 2018, 7.9 Mt CO_2e of GHG emissions were attributed to manure management. A portion of these emissions could be avoided with anaerobic digestion, however not all manure can be easily collected, and AD of manure is a relatively expensive option. When seen strictly from a mitigation perspective and co-benefits of AD are not taken into account, other, less costly measures such as covering manure storage and acidification could be preferred measures for many agricultural producers.

Also, it is not yet clear how GHG emission reductions from agricultural AD systems will be calculated and attributed in Canada. While the market appears to be emerging for carbon credits to be generated from manure digestion, it is not yet there, making it difficult to speculate what level of revenue might be contributed from the sale of such credits.

Some believe that the opportunity for using agricultural biomass, such as crop residues, perennials and cover crops, to produce bioenergy via combustion or anaerobic digestion could be very large. What impacts biomass removal might have on soil sustainability and biodiversity need to be clearly understood before embarking on biomass harvest. Greater use of cover crops and small harvests of agricultural biomass to supplement AD systems, with digestate nutrients returned to the soil, could support AD development as well as sustainable agriculture.

The agri-food industry, globally, is doing a lot of work to improve the environmental and social sustainability of their supply chains. This ambition could in turn lead to some new investment in anaerobic digestion systems on farms and feedlots. Consequently, the agri-food industry must be made aware of the size of the opportunity and the multiple benefits that agricultural AD systems could bring to the supply chain.

Finally, the announced strategies for greater electrification and hydrogen in Canada raise questions as to where and how biogas and RNG production fit into the clean energy transition. This reiterates the point that the development of AD systems needs to find a home within a multi-agency context that integrates clean energy, climate change mitigation, organic waste reduction and sustainable agriculture. Without dedicated policies or specific support for biogas production and use, and nutrient cycling, development of manure-based systems will likely be limited to very large farms near industrial gas users or existing pipelines, and/or to opportunities that provide food and beverage manufacturers with a significant competitive advantage.

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2.6 IRELAND

2.6.1 Overall Potential

The total number of livestock in Ireland in 2018 was 32,719,460 (Table 16). Approximately 19.67 % of cattle are dairy cows owing to the large dairy farming sector in Ireland. The total population of sheep in Ireland in 2018 was 5,139,824. The population of pigs in Ireland was primarily comprised of pigs greater than 20kg in mass (63 %) and pigs less than 20kg in mass (28 %). Poultry in Ireland were mainly broiler chickens (69 %) and layer hens (21 %). Table 17 outlines typical manure properties in Ireland.

Table 16: Livestock population in Ireland 2018

	1,000 Head	Share (%)
Total Cattle	7,243.60	100
Dairy Cows	1,425.00	19.67
Total Sheep	5,139.82	100
Total Pigs	1,597.05	100
Total Poultry	17,313.99	100

Table 17: Manure properties in Ireland.

	TS (%FM)	VS (%FM)	BMP (LCH_4*kgVS^{-1})	Methane Yield (m^3CH_4*tFM^{-1})	Source
Dairy Cow Slurry	6.5-8.75	5.10-6.69	175-239	8.95-16.02	(Allen et al., 2016)
Beef slurry	8.44	6.76	310	21	(Allen et al., 2016)
Sheep Manure	35	22.6	171	39	(Allen et al., 2016)
Pig Slurry	3.7	2.6	292	8	(O'Shea et al., 2016a)
Poultry Manure	51.46	29.72	28	68	(Allen et al., 2016)

TS: Total solids, VS: Volatile solids, BMP: Biochemical methane potential, FM: Fresh matter

2.6.2 Structure of agriculture and spatial distribution of manure

The population of livestock in 2010 (based on the most recent Census of Agriculture) at a county level in Ireland is illustrated in Figure 17. The greatest concentration of cattle is located in the south of Ireland. The sheep population is concentrated in the west of Ireland. The population of pigs in Ireland is primarily in Cavan (22 %) and Cork (17 %). Poultry in Ireland are predominantly farmed in Monaghan (54 %), Limerick (12 %), and Waterford (8 %).

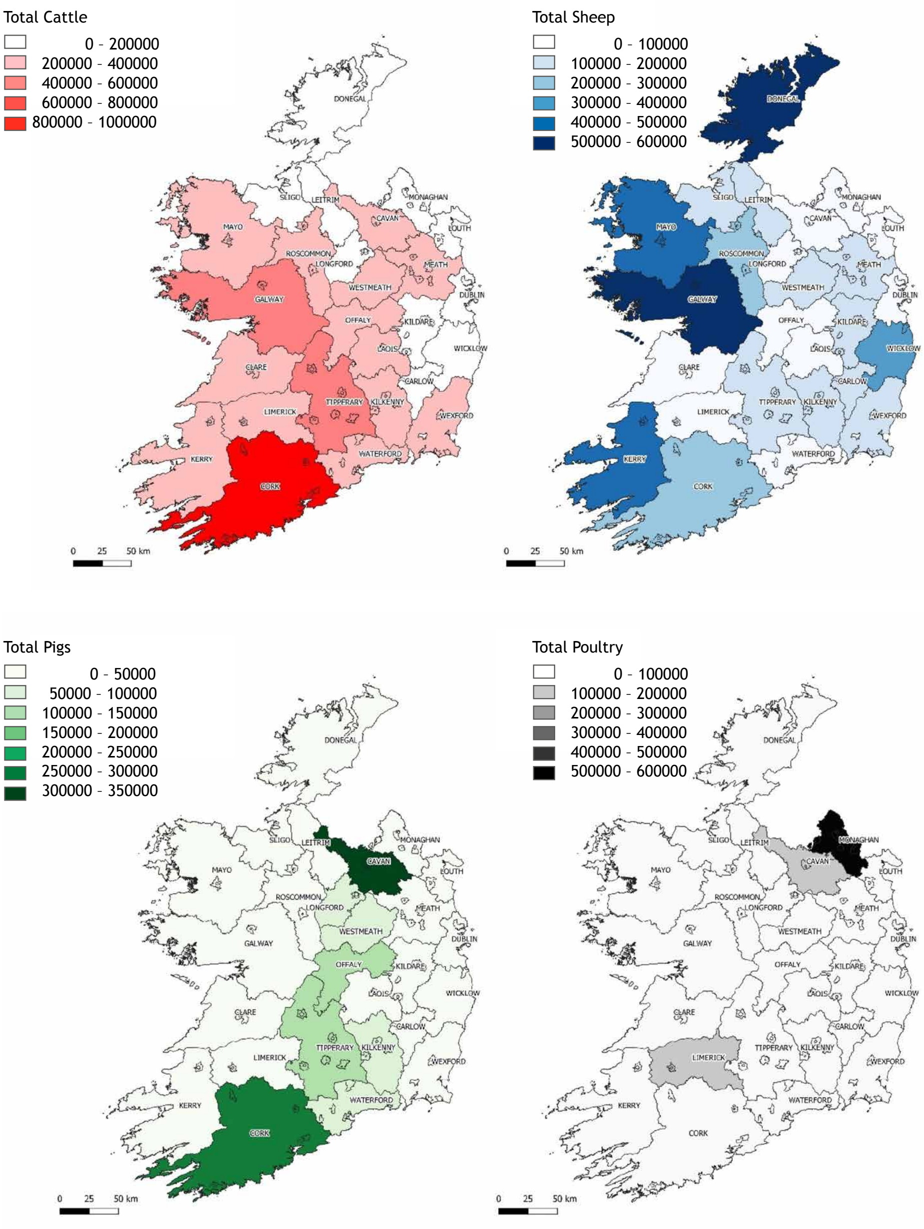

Figure 17: Livestock population by county in Ireland 2010

Characteristics of husbandry (indoor housing and on pasture)

Cattle

There were an average of 66 cattle per farm in Ireland in 2016 (Central Statistics Office, 2018). Cattle in Ireland are farmed on pastureland for the majority of the year in order to maximise the use of grass. During winter months cattle are housed indoors, the volume of manure storage over the winter period must cover housing for a period of 16 to 22 weeks (Government of Ieland, 2017), (Buckley et al., 2020). Data for 2018 (Duffy et al., 2020) indicates that cattle spend 58 % – 98 % of their time grazing pasture. When cattle are housed indoors 81 % of manure was sent to a pit storage system in the form of slurry (Buckley et al., 2020). Only the manure which is collected during the winter months as slurry when cattle are housed indoors can be used in biogas plants.

Sheep

The average sheep herd size in Ireland was 140 in 2016 (Central Statistics Office, 2018). Approximately 89 % of lowland ewes and other sheep older than 1 year are housed for 28 – 85 days during the winter (Duffy et al., 2020). The majority of remaining sheep are not housed indoors during the winter. Only manure collected when sheep are housed could be used in AD plants.

Pigs

The majority of pigs in Ireland are farmed in a small number of intensive farms (Central Statistics Office, 2018). In 2016 there were 1,300 pig farms in Ireland with an average herd size of 1,234 pigs (Central Statistics Office, 2018). The majority of pigs in Ireland are housed indoors year-round and manure produced by pigs is managed as slurry using pit storage (Duffy et al., 2020). The intensive farming of pigs in Ireland at a relatively small number of farms, coupled with the year-round collection of pig slurry could make pig slurry a viable resource for biogas production.

Poultry

Poultry are also farmed in an intensive manner by a small number of specialised farmers. In 2018 there were 17 million poultry in Ireland, the average flock size ranged from 681 to 4,720. The majority of poultry are housed indoors year-round (Duffy et al., 2020). Manure storage systems used for poultry manure consist of litter-based systems along with pit storage systems. Intensive farming of poultry and year-round manure collection could make poultry manure a viable resource for biogas production.

Size distribution of farms and spatial distribution within country

The number of beef farms for a given herd size (total cattle) was evenly spread across the different herd sizes (Figure 18A). Most beef farms had between 50 – 99 cattle (20 % of specialist beef farms), The average number of total cattle on specialist beef farms in 2010 was 44 (Central Statistics Office, 2012). The number of specialist dairying farms for a given herd size is skewed toward higher herd sizes (Figure 18B) with the majority (62.9 %) having more than 100 livestock. The average number of total cattle (cows used for milk production, as well as heifers, calves, and bulls) on specialist dairying farms in 2010 was 143. The average number of dairy cows per farm in 2010 was 63. The majority of specialist sheep farms in Ireland are skewed toward larger flock sizes. In 2010, most specialist sheep farms had more than 100 head of sheep (Figure 18c). The average number of sheep on specialist sheep farms 2010 was 185. Most pigs in Ireland are farmed by large scale intensive pig famers. The majority (29.8 %) of pig farms in Ireland have a herd size of 500 – 2,999 (Figure 18d). The average number of pigs in a herd on a specialist pig farm in Ireland was 3,099 in 2010. Poultry farming in Ireland is dominated by a small number of specialist intensive poultry farmers. In 2010 67 farms (9.6 % of farms) with flocks larger than 50,000 birds accounted for the majority of birds (Figure 18e). Most (25 %) poultry farms had a flock size of 10,000 - 49,999. The average flock in 2010 was 15,406; 67 farms had 50,000 birds or more.

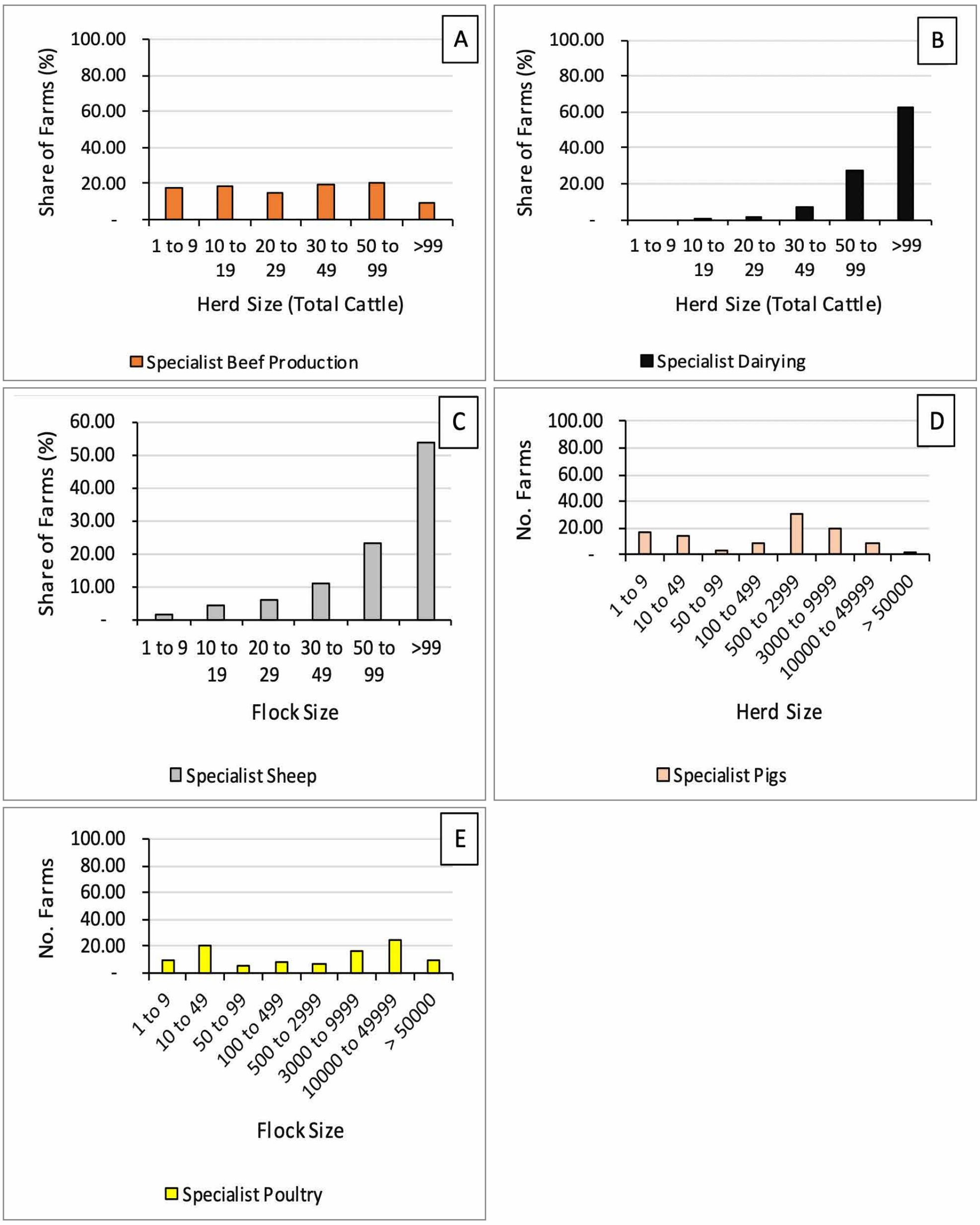

Figure 18: Farm size distribution based on herd or flock size in Ireland in 2010. A) Specialist beef. B) Specialist dairying. C) Specialist sheep. D) Specialist pig. E) Specialist poultry.

Effect on biogas systems

The biogas industry in Ireland is nascent and relatively underdeveloped compared to Germany, The United Kingdom, Austria, and Italy. O'Shea et al. estimated the gross potential biogas resource associated with cattle slurry to be 9.6 PJ*yr^{-1} from ca. 28,500 ktFM of slurry (O'Shea et al., 2016b). The spatial resource of biogas from cattle slurry is concentrated in the south of Ireland, where most dairy cows are farmed. The gross resource from sheep manure was 0.58 PJ*yr^{-1} from ca. 418 ktFM of manure (O'Shea et al., 2016b). The sheep manure resource is located along the west of Ireland and one region in the east. To estimate the potential gross biogas resource associated with pig and chicken manure O'Shea et al. used data from large intensive pig and poultry farms (O'Shea et al., 2016b). Pig slurry produced was ca. 939 ktFM with a gross biogas resource of 0.26 PJ*yr^{-1} (O'Shea et al., 2016b). The pig slurry resource is concentrated in Cavan and Cork (highlighted dark green and light green in Figure 19C respectively). Pig slurry is produced in a small number of large intensive farms, this could enable easier collection and utilisation in AD plants compared to the distributed resources of cattle slurry and sheep manure. The mass of poultry manure produced by large intensive poultry farms was 137 ktFM with a gross biogas resource of 0.11 PJ*yr^{-1}. The majority of the chicken population and potential biogas resource is located in Monaghan (Figure 19D). Similar to the farming of pigs, the centralised farming of poultry in a small number of geographically concentrated facilities could facilitate the collection and use of chicken manure in AD plants, however the mono-digestion of chicken manure can be difficult owing to the high nitrogen content which can lead to ammonia inhibition. This can be alleviated through co-digestion with carbon rich substrates, or by the removal of nitrogen in the poultry manure prior to anaerobic digestion (IEA Bioenergy Task 37, 2019).

A potential reason for the low utilisation of livestock manure in AD plants is the small herd sizes on cattle farms and the fact that cattle are only housed indoors for a fraction of the year. In the case of beef cattle, for an average herd size of 44 cattle, an annual indoor housing period of 141 days (20 weeks), and a slurry storage capacity 0.29m^{3}per week per cow would yield 257tFM*yr^{-1} of slurry. Thus, an average herd of beef cattle could produce 53.562MWh of methane (gross) in the form of biogas. Assuming 8760 hours of operation of an AD plant, the gross power output would be 6.11kW. If the biogas was used in a combined heat and power (CHP) unit with an electrical efficiency of 35 % the gross electrical power output would be 2.14 kW$_e$. Table 18 presents results for dairy cows, sheep, pigs, and poultry.

For average sized farms a combination of low herd or flock size, and the short periods housed indoors (for cattle and sheep) result in a low gross biogas resource. The largest biogas resource for an average sized farm is associated with poultry farms owing to their relatively large flock sizes and indoor housing year-round. When assessing the gross biogas production from the largest herds and flocks, the intensive farming of pigs and poultry present the greatest biogas resource from single farms. Farms of this scale are not common. The use of manure arising from one farm in an AD plant is limited to small scale applications owing to small herd or flock sizes, and the limited time livestock are housed indoors.

The combination of manure with other feedstocks suitable for biogas production is possible. Smyth et al. determined that grass silage from land used for beef farming could provide additional feedstock for a biogas industry and supplementary revenues for beef farmers (Smyth et al., 2011) in a co-operatively owned AD plant (Smyth et al., 2010). The synergistic impact of co-digesting cattle slurry with grass silage in Ireland has been well researched. Wall et al. found that the co-digestion of cattle slurry and grass silage can allow AD to operate at a higher organic loading rates (Wall et al., 2014). Xie et al. found that the co-digestion of pig manure and grass silage enabled higher specific methane yields compared to the mono-digestion of either (Xie et al., 2011). Owing to the small herd and flock sizes in Ireland (with the exception of the largest pig and poultry farms) AD plants processing manure from a collective of farms may be the best option to maximise manure utilisation. These communal digesters could also co-digest additional feedstocks with a high biomethane yield such as source segregated food waste, by-products from food processing, or grass silage with the manure.

Table 18: Biogas resource from livestock herds or flocks in Ireland

	Herd/ Flock size	Indoor period	Weekly Manure	Annual Manure	VS	BMP	Gross biogas output*	Gross electrical output**
	head	days	m³	m³	%FM	LCH$_4$*kgVS^{-1}	kW	kW$_{el}$
	Average Herd / Flock Sizes							
Beef	44	141	0.29	257.02	6.76	310	6.11	2.14
Dairy	63	117	0.33	347.49	6.90	239	6.51	2.28
Sheep	185	85	0.03	67.39	22.60	171	2.96	1.03
Pigs	3,099	365	0.04	6,302.04	2.60	292	54.31	19.01
Poultry	15,406	356	0.81x10^{-3}	650.68	51.46	228	86.67	30.33
	Largest Average Herd / Flock Sizes***							
Beef	110	141	0.29	642.56	6.76	310	15.29	5.35
Dairy	143	117	0.33	788.75	6.90	239	14.77	5.17
Sheep	253	85	0.03	92.16	22.60	171	4.04	1.42
Pigs	50,000	365	0.04	101,678.57	2.60	292	876.32	306.71
Poultry	50,000	356	0.81x10^{-3}	2,111.79	51.46	228	281.27	98.45

Density of methane: 0.716kg(m^3)$^{-1}$. Energy content of methane: 50MJ*(kg)$^{-1}$. Operational hours of biogas plant: 8760
Electrical efficiency of combined heat and power unit: 35%. * Larger herds and flock than this do exist but are not common.

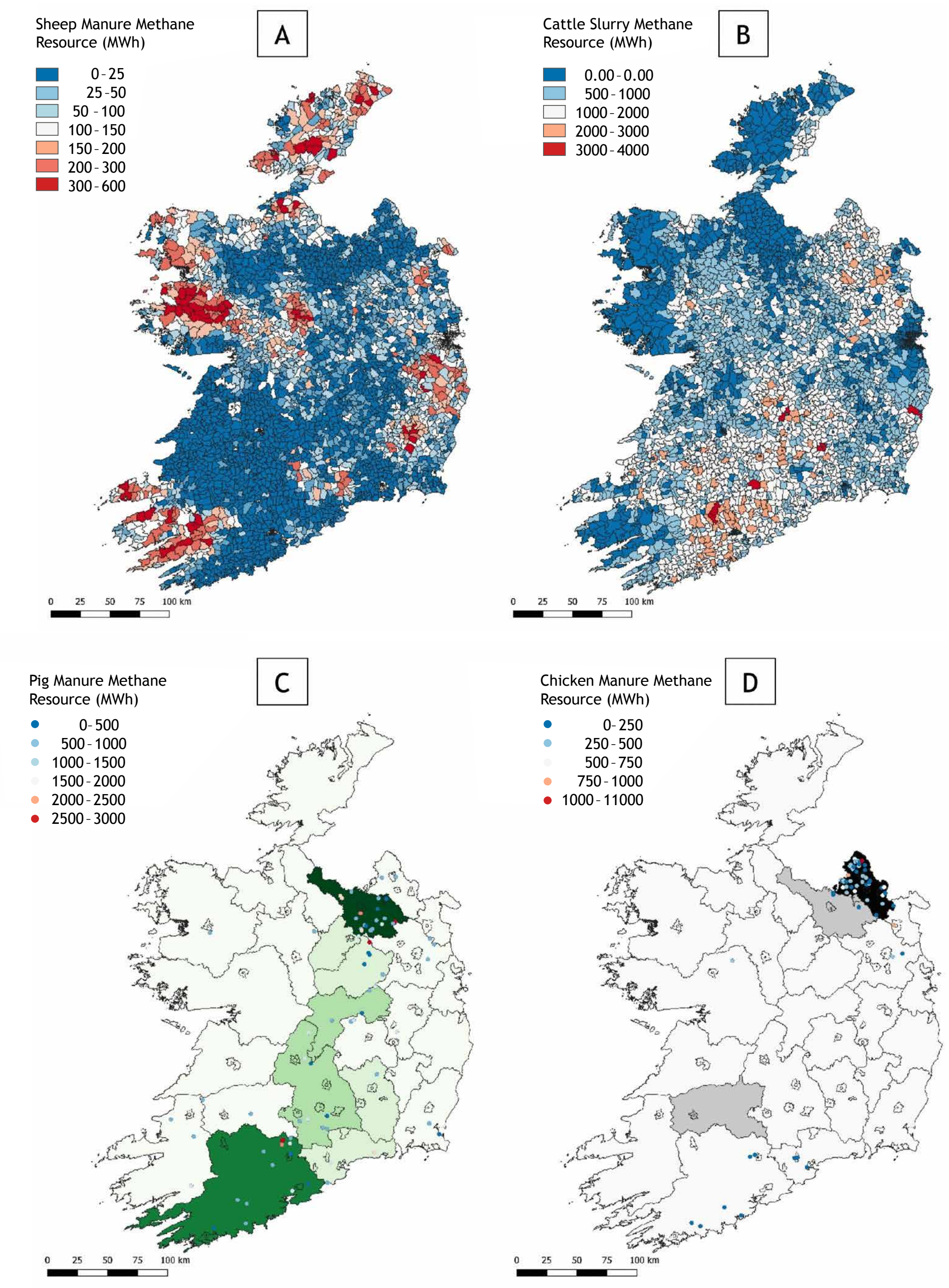

Figure 19: Spatial distribution of biogas resource in Ireland 2010

2.6.3 State of the art of manure utilization

Utilisation of manure in AD in Ireland is limited. Most manure generated is handled using pit storage systems, deep bedding, or litter followed by land application. There are 12 AD plants which digest manure along with other feedstocks. Most of these plants are mesophilic continuously stirred tank reactor type plants. The biogas is used for the generation of electricity, thermal energy, and biomethane.

Plants use animal manure (sourced on site and off site) as well as additional feedstock (abattoir waste and food waste) which have higher methane yields. This improves the financial viability of plants. The co-digestion of manure with additional waste streams requires pasteurisation of the feedstock prior to use in the AD plant (DAFM, 2014a)(DAFM, 2014b). All of the 12 AD plants identified which use animal manure as a feedstock co-digest animal by-products (ABPs) or manure from more than one source.

Incentives for the use of manure in anaerobic digestion in Ireland

There are no specific incentives in place which promote the use of animal manure in AD in Ireland. Incentives which aimed to support AD plants were available under ReFIT-3 for the production of electricity from biogas. ReFIT prices in 2020 for electricity are as follows: >500 kW_e (Non CHP systems) 106.978 €*$MWhe^{-1}$, ≤500 kW_e (Non CHP systems) 117.675 €*$MWhe^{-1}$, >500 kW_e (CHP system) 139.071 €*$MWhe^{-1}$, ≤500 MWe (CHP system) 160.466 €*$MWhe^{-1}$ (Department of Communications Climate Action and Environment, 2020).

Incentives promoting renewable heat production are proposed under The Support Scheme for Renewable Heat (SSRH), available to projects for 15 years. Eligible projects include biogas use in boilers for the production of heat, or biogas used in high efficiency CHP systems. Systems producing less than 1000 $MW_{th}h$*yr^{-1} receive 29.5 €*MWh^{-1}, and systems producing 1000 – 2400 $MW_{th}h$*yr^{-1} receive 5€*MWh^{-1}. Only projects which are developed at sites not covered by the European Union Emission Trading Scheme (EU-ETS) are eligible for support. Biogas must be used in boilers with a minimum efficiency of 90 %. Incentives for the heat produced from high efficiency CHP systems fuelled by biogas are also available. Biogas must have lifecycle GHG emissions ≤24gCO_2eq*MJ^{-1}. Without feedstock certification a maximum of 20 % grass silage or other harvested energy crop can be used (SEAI - Sustainable Energy Authority of Ireland, 2018)(SEAI, 2018).

Major drivers and obstacles for industry

The major barrier to the development of AD in Ireland has been the relatively low level of financial support available which resulted in unfavourable economics (Composting and Anaerobic Digestion Association of Ireland, 2018). Ranjendran et al. indicate that incentives to promote biomethane in Ireland could include for a biofuel obligation scheme for gas suppliers, a feed in tariff for biomethane producers, and/or vehicle tax reductions for natural gas fuelled vehicles (Rajendran et al., 2019). A perspective on the fiscal support to aid in the establishment of an AD industry in Ireland indicates that a initial budget of €40 Million could be required to develop 25 AD plants producing 1.6TWh of biogas (200 MW biomethane) (IrBEA and CRE, 2019).

Non-fiscal barriers to the AD industry are the small cattle herd sizes and short periods of time during which manure can be collected throughout the year. The small quantities of manure produced at most Irish cattle farms means that AD of manure and grass silage at an individual farm scale is unlikely to be viable. Farms with larger herd sizes or more intensive farming operations may be viable sites for AD plants owing to the larger mass of manure available.

Several large AD plants were denied planning permission for construction as a result of public opposition. The reasons varied from concerns regarding; odour, impact on water quality, Not in My Back Yard (NIMBY), potential impacts on the health of livestock, potential impacts on human health, and the increase in traffic volumes associated with AD facilities. There is clearly significant public concern regarding the safety of large-scale AD plants processing manure and other ABPs which must be satisfied in order for the industry to develop in Ireland.

A final obstacle to the development of an AD industry using manure is the spatially distributed nature of the resource. There is a significant manure biogas resource, however, connecting to the electricity network has been expensive and difficult. The injection of biomethane into the gas grid in Ireland, or transportation of biomethane in gas cylinders, only commenced recently. As such, linking AD plants in rural areas to energy users requires novel solutions.

2.6.4 Lessons learnt and perspectives of manure utilization

The gross theoretical resource of biogas associated with animal manure in Ireland is substantial. However, the largest share of this resource, manure from cattle, is only available in small quantities at individual farms owing to the small herd sizes and the short period of time for which cattle are housed. This means that the use of manure for biogas production can only occur at an appreciable scale at the largest dairy or beef farms, or at pig and poultry farms (which are in general a more intensive agricultural practice in Ireland).

Larger community style AD plants which process manure from a number of farmers, along with higher energy feedstock such as grass silage may be a solution to the issue of small herd sizes. The use of manure from multiple herds necessitates pasteurisation to limit the spread of disease which can present an added cost to such communal style AD plants.

Novel methods of linking AD plants to energy users have been demonstrated in Ireland. Two AD plants processing manure and other ABPs have upgraded the biogas to biomethane and transported this by road to an industrial energy user, or an injection point to the gas network. This model is to be implemented in the GRAZE project under development by the Irish gas grid operator Gas Networks Ireland; this consists of a large centralised injection facility located on the gas network which is to be supplied with compressed biomethane from up to 20 AD facilities via road. The project is located in the southern region of Ireland where the majority of dairy cows and dairy farms are located, and where the size of cattle herds is the highest in the country, thus facilitating the use of manure from dairy cows (amongst other feedstocks) in the AD plants.

2.6.5 Conclusion

There is a significant potential resource of biogas from animal manures in Ireland. The majority of this resource is associated with manure from cattle. However, cattle herd sizes are small, and cattle are housed indoors for a fraction of the year. Therefore, the large cattle manure resource actually consists of a multitude of small amounts of manure distributed throughout the country. The small herd sizes and limited indoors housing period means that only the largest cattle herds, most likely associated with dairy farms, can be seen as a viable resource of manure for on farm biogas production. The more intensive farming practices associated with pig and poultry farming in Ireland make manure from these farms a more likely candidate for initial use in biogas production owing to the larger amount of manure available, and the availability year-round. Communal AD plants which process manure from multiple farms along with other feedstocks such as grass silage or food waste may be a viable method of utilising the distributed manure resource in Ireland. The use of manure from multiple sources results in the mandatory pasteurisation of incoming feedstock or digestate in order to limit the potential spread of disease. The current utilisation of manure for biogas production in Ireland is limited, primarily due to the unfavourable economics of AD in Ireland at present, the aforementioned small herd sizes, and concerns from the public regarding the safety of AD. Planned projects such as the GRAZE project which aims to use biomethane from a number of farm based AD plants using manure, grass silage, and food waste indicate that innovative and novel methods of utilising the significant biogas resource available in Ireland are being developed.

2.6.6 References Ireland

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2.7 UNITED KINGDOM

There are 212,000 farms in the UK of which about 15 % hold livestock. These farms produce of the order of 225 to 250 million tonnes per year of manure as slurry, Farm Yard Manure (FYM) where excreta is dropped onto straw, as chicken manure on litter from chickens and turkeys for the table, and manure from laying hens.

2.7.1 Livestock numbers in the UK

The amount and characteristics of manure is dependent on the type of animals, housing, feeding regime, if it is for breeding, for meat/milk/egg production and last but not least simply the number of animals.

There are 224,629 million farm animals (Annual Agricultural Census for the United Kingdom, Defra, 2020), which have a theoretical output of approximately 248,338,167 million tonnes of manure a year (Table 19). This is likely to have different characteristics dependent upon feed rations and water intake. The amount which can be collected and over what period it is practical to collect it varies from farm to farm and the type of surface on which it is deposited. It must also take into account the how long the animals are on pasture. Available data on storage is included in Table 20.

Table 19: Amount of manure per animal and relevant characteristics

Type of livestock	Total number of animals	Manure	Total Manure	Volatile solids	Methane	No of animals to produce 100 kW electricity
	(000's)	$t*(unit*yr)^{-1}$	$t*yr^{-1}$	$t*yr^{-1}$	$m^3(CH_4)*yr^{-1}$	
All female cattle	7,077	19.345	136,904,565	10,226,771	1,891,952,636	998
All male cattle	2,662	16.425	43,723,350	3,266,134	604,234,835	1,175
Breeding pigs	509	4	2,036,000	89,584	22,396,000	6,063
Fattening pigs	4,569	2	9,138,000	438,624	109,656,000	11,116
Sheep and lambs	33,580	1.533	51,478,140	nd	nd	nd
Poultry Egg layers	54,732	0.0438	2,397,262	539,384	175,299,755	83,297
Poultry broilers	121,500	0.0219	2,660,850	1,197,383	359,214,750	90,238
	224,629		**248,338,167**	**15,757,990**	**3,162,753,976**	

Source: Defra (2019) Agricultural Census: Calculated from data for livestock numbers

Table 20: Storage preferences in animal husbandry

Animal type	% manure incine-rated	% slurry spread fresh	% slurry stored	% slurry stored in lagoon	% slurry stored in slurry tank	% stored in weeping wall	% stored covered or crusted	% slurry stored but not covered or crusted	% to anaerobic digesters
Dairy		16	84	39	39	22	80	20	?
Beef		25	75	39	39	22	80	20	?
Pigs		27	74	47	53	0	3	97	?
Poultry Broilers	35	50	50						
Poultry layers		50	50						
Sheep		-	-	-	-	-	-	-	-

Sources: Nicholson, F. *et al* (2010) National Inventory and map of livestock manure loadings to agricultural land

Manure which drops on straw, or a similar type of bedding is referred to as farm yard manure. The total solids content of such material would be over 20 % as compared with slurry at 6-8 % dry matter. Only 34 % of dairy manure is deposited onto straw or similar bedding during housing and of this 69 % is stored in heaps usually close to fields where it is likely to be used later in the year. The remainder is spread fresh. In contrast during winter housing 82 % of beef cattle manure is dropped on straw bedding, with 25 % and 75 % respectively spread fresh or stored. A similar situation applies to pigs where 65 % of manure falls onto straw.

Organic farming is a growing are of interest and is especially suited to anaerobic digestion. Statistics on organic farming data used here is derived from the UK Certification Bodies and further checked by Defra's own statisticians,(Defra, 2020 Organic Farming Statistics). Organic farms in the UK manage 485,000 hectares of land which accounts for 2.7 % of the usable agricultural area. Sixty three per cent of this land is permanent pasture, 20 % temporary grass, 8 % cereals and the remainder a mix of uses including field horticulture, potatoes, etc. Mineral fossil fuel based fertilisers are not permitted for use on organic farms. These farms however may purchase a range of commercial fertilisers made from fish manure, guano, sorghum meal and a number of other natural products to supplement nutrient needs provided by the farm's own manure and cover crops.

The manure from dairy, pig and poultry farms generally and organic farms in particular which have sufficient cropping or grassland areas of their own can secure the best nutrient/cost benefits. Cost advantages over mineral replacement amount to about £4.50 per hectare. Where either organic or non-organic farms have manure surplus to requirements, it will be necessary to find an alternative user. For manure with low total solids content the costs will reflect the capacity of the tankers, the distance to the recipient farm and equally the distance travelled during field application. On a 3,000 ha farm for example, where the digestate is separated, it is distributed through the farm's existing layout of pipes for irrigation to tanks to distant fields and thereafter tanker spread. This is the least cost option (Lukehurst, 2019)

2.7.2 Manure potential and utilisation.

Figure 20 illustrates the percentage of the national herd for each type of livestock in England. The concentration of pigs and poultry in the Eastern regions is in marked contrast to the large number of dairy and beef cattle as well as sheep along the Western half of the country.

Typically, cattle are housed on deep straw litter bedding which is replaced when soiled to become FYM. Eighty percent of dairy cow manure is stored as slurry in covered tanks (not specifically airtight) or lagoons compared with 97 % of pig manure which is stored uncovered. Similarly deep litter is preferred for pigs. Poultry manure is also stored in uncovered heaps.

If the theoretical totals of collectible manure can be realised (as described in Table 21) then this would lend itself to calculation of the theoretical amounts of retrievable manure in Table 22 based upon the mount of manure per animal and animal numbers from Table 19.

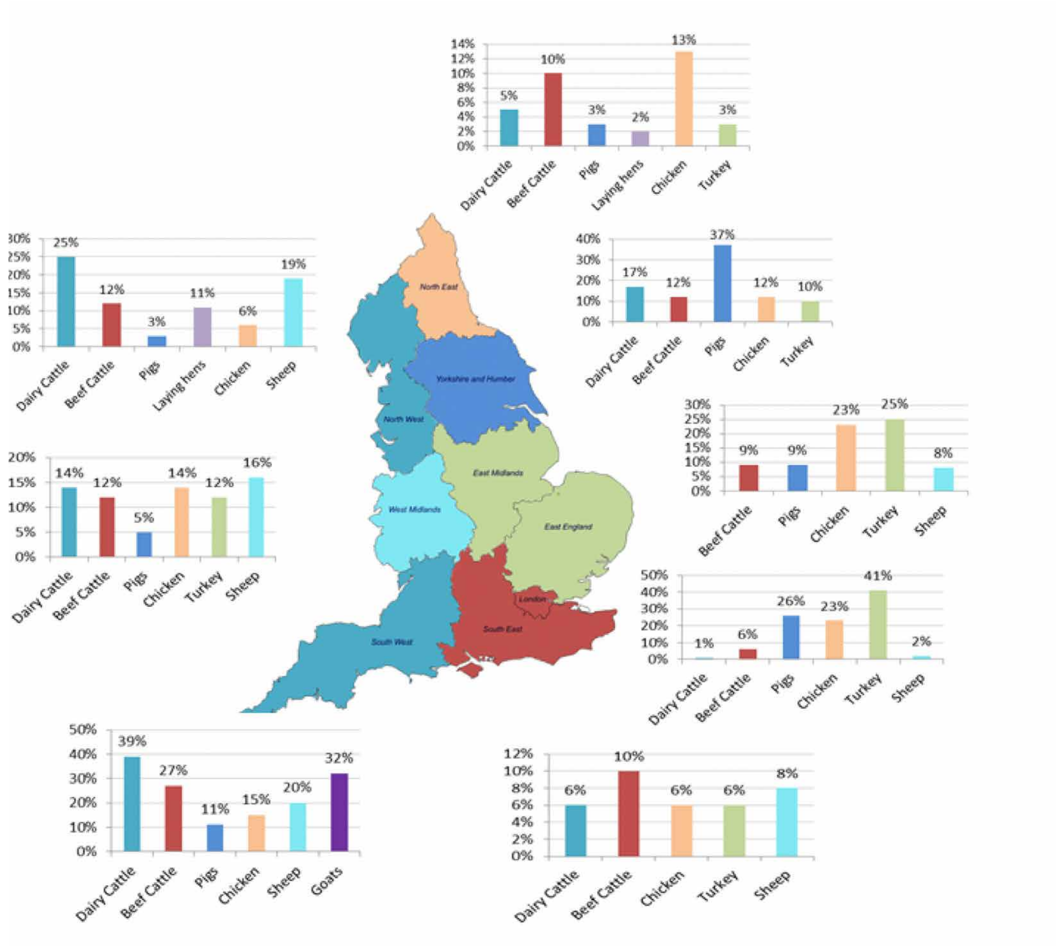


Figure 20: Percentage of the national herds in each English administrative region

Source: Defra (2020) Defra Statistics: Agriculture Facts: England Regional Profiles

Table 21: Percentage of annual fresh manure from gathering yards during housing

Surface	Dairy cattle	Beef	Sheep	Pigs	Poultry layers	Broilers
Grazing	38	62	93	32	20	2
Housing summer	7			Year round	100	100
Collecting yards summer	12			Year round	-	
Housing winter	31	31	7	Year round	100	100
Feed yards winter	3	7		-	-	
Collecting yards winter	9			-	-	
percentage manure theoretically collectible	62	38	7	78	80	98

Source: Nicholsen, F. *et al* (2010) National Inventory and Map of Livestock Manure loadings to Agricultural Land

Table 22: Theoretical quantities of retrievable ($t*yr^{-1}$) manure

Animal type	Total manure produced [1]	Theoretical % collectable manure [2]	Theoretically retrievable
Dairy herd as slurry	136,904,565	62	84,880, 830
Beef Cattle as FYM	43,723,350	38	16,614,873
Pig as FYM	9,128,000	78	7,119,840
Laying hens	2,397,262	80	1,917,810
Broilers	2,600,850	98	2,548,833

1.data from Table 19. 2.data from Table 21
Source: Nicholson, F *et al* (2010) National Inventory and Map of Livestock Manure Loadings to Agricultural Land

In all, there is the potential for a 113 million tonnes resource with a significant portion likely to be FYM with a high proportion of bedding material. It is asserted that this quantity of high solid material will need to be considered when assessing the types of digesters and processes best suited to it.

There are various ways to illustrate the size and distribution of farms but for present purposes two have been selected:

1. The number of livestock in each size category as defined by the Agricultural and Horticultural Development Board (ahdb.org.uk>uk-en-cow-numbers)
2. A cartographic representation of regional specialisations of the livestock enterprises based on the Defra's (2020) Farm Business Statistics (Figure 20)

The average dairy herd size for England alone, is 143 cows and their distribution between the number in each category is illustrated in Table 23.

Table 23: Distribution of dairy cows in relation to herd sizes in England.

Herd Size	<9	10-49	50-99	100-149	150-249	250-499	500-999	>1000
Cow numbers in each category	11,241	30,483	124,075	193,165	306,256	309,984	110,467	30,436

The literature from WRAP indicates at least 1,604,000 tonnes of primary produce with a commercial value of £650 million is wasted each year. This consists of agricultural surpluses or damaged produce which is usually suitable for co-digestion with the manure. If these 'wastes' can be co-digested with the manure it can lay the foundation for future biogas development planning and as aid for the types of digesters that could be appropriate at the local level.

State of the art of manure utilization

It could be claimed that the low methane potential of animal manure poses a significant barrier for its use in the renewable energy sector where high rates of internal return up to 15 per cent are expected.

The second group of factors relates as to how the plants are funded and the purpose for which they were installed. Table 24 below summaries the legislation which has had both a positive and negative impact on the adoption and growth of the industry.

The main obstacles to the development of the UK industry have been the Governments' lack of a continuous policy and the stop /start nature of the support mechanisms. Support for electricity has ceased and farmers (and others) must negotiate with the power purchasers to secure a wholesale price. However, since the Government's adoption of a Net Zero GHG emission target for 2050 emphasis has switched to the support of biomethane as opposed to combined heat and power facilities. Both biomethane facilities and digester CHP systems must optimise use of heat. The surplus from process use is frequently used on site for example in dairies or for holiday cottages.

Costs and/or cost structure of manure based biogas

Any attempt to demonstrate the costs of manure based biogas, breakeven points and internal rates of return (IRR) is fraught with danger. Plant designs are usually specific to the farm and can take into account existing structures such as a lagoon store for the separated liquid fraction of the digestate. An existing barn or bunker may be suitable to store the separated dry matter which is applied to meet phosphates needs of the crops. The slurry can contain large volumes of water which in turn require large digester tanks and a considerable amount of heat to maintain the process even at mesophilic temperatures usually between 37 – 45° C. This all contributes to the capital cost especially as manure has a very low biogas potential. Farmers are acutely aware of costs and especially those which are unnecessary such as the inclusion of parlour and yard washing at any time but especially after an investment in a digester.

It is so often assumed that the economies of scale influence the viability of the digesters especially for those farms with fewer than 100 cows. However, care needs to be taken not to make generalisations as to

Table 24: Incentives and disincentives to biogas industry development.

Legislation	Incentives	Impact on the industry	Positive impact
1985	EC Council Regulation 797/85 on improving agricultural structures	1. Capital grants to increase productivity of the farm including production of heat and electricity	Yes
1991	European Commission EEC Regulation 2328/91 on improving agricultural structures	2. Grants to reduce diffuse pollution, odours droplet reduction, improve manure storage, cover tanks, etc.	Yes
1990-1994	Environmental Pollution Acts (UK)	3. Steady adoption of digesters at rate of 30 $*yr^{-1}$. Very small scale mainly on dairy farms with up to about 100 cows.	Yes
1996	All discontinued	Industry came to a standstill	
1990 - 1998	Non Fossil Fuel Obligation (NFFO)	Blind bidding process, virtually guess work, as to what price per kWh could be charged to power generating companies. Designed to support nuclear but wind, solar, hydro found a loop hole. One contact awarded to AD under option but at unrealistic price of £0.7p$*kWh^{-1}$. Never built. Government excluded AD. In 1997 contracts awarded for seven plants but only one built - Hoslworthy a Danish style centralised plant to process 146,000 tonnes manure $*yr^{-1}$. This project proved challenging. NFFO was not positive for the AD industry and farms - industry at a standstill	No
2002 - 2017	Feed in Tariffs for small scale plants (<3MW_e)	Stimulus for industry growth with construction of up to 40 plants$*yr^{-1}$. Mix of feedstocks including food waste, mixed crops and manure to solve waste management problems but with effect of increased productivity. Stopped 2017	Yes
2016		AD Industry came to standstill	
	Renewable Transport Fuel initiative	Levy per litre on all transport fuel purchasers - stimulus to encourage compressed biomethane, conversion of HGV fleets and on site filling stations.	Yes

what makes such an enterprise desirable to farmers especially in dairying. The key decision rests on the role of the digester in the whole farm and the farm's productivity when it is fully integrated into the farming system (Lukehurst, C. and Bywater, A., (2015); McCabe et al. (2020)). Payments for electricity are just one part of the equation. Table 25 gives examples of the funding /cost structures in the UK.

The cumulative total of the emissions reduction represents the value of a fully operational proven enterprise rather than the actual cost of the plant when it was built. The owners of each plant must submit details of sustainability to be eligible for the Renewable Heat Incentive (RHI). These are calculated for all operations from planting to harvesting and include any transport for both feedstock and digestate delivery. An example is illustrated in Figure 21 for Icknield Biogas plant which was certified to have an 85% reduction in CO_2 equivalent emissions (as compared to grid electricity from natural gas) and 77% for biomethane (Aardvark Certification Ltd., 2019).

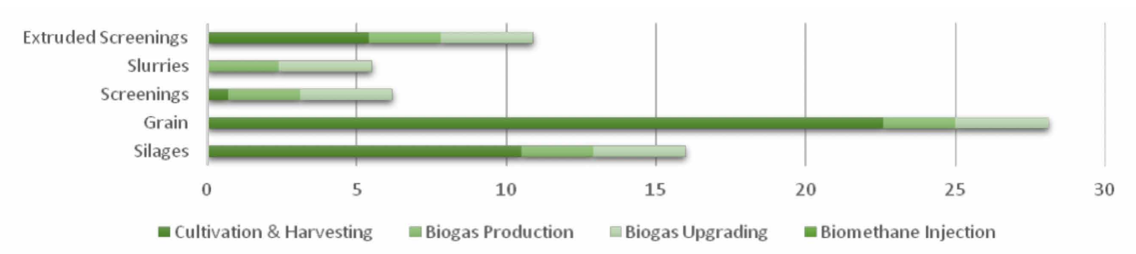
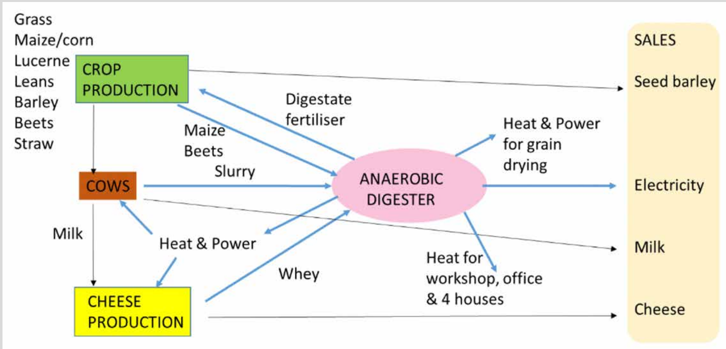


Figure 21: GHG Emissions per Feedstock (gCO_2eq*MJ $biomethane^{-1}$)

Source: reproduced with permission from Aardvark Certification Ltd (2019)

IEA Bioenergy have previously published on Methane Emissions from Biogas Plants (Liebetrau et al., 2017); this work highlights the positive impact of slurry digestion in terms of saved fugitive methane emissions from open storage of manure/slurry. This manure credit can generate a GHG negative result for biogas produced from manure.

Table 25: Examples of investment strategies on UK farms
Sources: Information provided by individual farmers, biogas companies and investors.

<table>
<tr><td>1. Fully self-funded digester system on 230ha organic farm with 126 Brown Swiss cows, 170 kW CHP and back up198 kW boiler</td><td>The plant is designed to meet the specific needs of the farm for example:
Copys Green Farm: 230 ha mixed dairy & arable


To optimise value of exiting products such as slurry, whey from cheese making, any poorer grade silage from the sides & top of clamp
To reduce operating costs for energy & fertilisers
Prevent nutrient losses through leaching and emissions
Provide new income streams and financial security</td></tr>
<tr><td>Partly self-funded +capital grant</td><td>As above but the burden of mortgage repayments is reduced by capital grants. Pollution Control Grants were discontinued in 1996. Ended development of small plants especially on dairy farms. Sizes range from 6kWe for beef manure and silage for on-site heat only to 125 kW_e for slurry and chicken litter on site CHP use. Major capital grants became available under EC funding for areas lagging behind in the development. Holsworthy secured £4m from Objective 5b Regional funding with additional funding made up by local private investment</td></tr>
<tr><td>Part self-funded + outside investment</td><td>Investors can include the biogas plant suppliers who take on the responsibility for remote AD management and monitoring but farmer is wholly in control of his own business and husbandry</td></tr>
<tr><td>100% investment for an external source</td><td>Farm leases the land (approx. 2 ha) for the plant, grows the crops and supplies a guaranteed quantity of high quality feedstock per year on contract for predetermined price for the lifetime of the plant. New crops such as maize, rye, Lucerne are introduced. Regular, high quality advice from agronomists on crop production and digestate nutrient management and emissions control are provided. Optimise nutrient management – GIS field mapping, targeted digestate, fertiliser, manure application to increase whole field productivity, reduce nutrient cost and application costs. Standard 5 MW biomethane plants</td></tr>
<tr><td>Feedstock supplier/ digestate in return</td><td>Digestate storage tank supplied at no cost to farm, advice on crop husbandry and digestate use. Receives regular guaranteed income from the feedstock supplied. Benefits as above. Cow, pig and poultry manure also supplied</td></tr>
</table>

2.7.3 The way ahead

Spatial analysis of manure availability has highlighted regional variations as well as a potential need for different digestion processes to optimise the biogas potential of the feedstock. Biogas has a twin contribution to make to the fulfilment of Government policy: the production of biomethane for grid injection and as the centre piece for the Sustainable Farming Incentive currently being trialled with volunteer farmers and due to start in 2022 in England.

The Green Gas Certificates focus on the production of biomethane for injection into the gas distribution network as a renewable fuel alongside hydrogen (when that reaches commercial production). Currently, biomethane production is about to be supported by new Green Gas Support Scheme (GGSC) with the closure of the Renewable Heat Incentive. The GGSS is a valuable contribution to shippers of gas and may encourage the construction of large biogas plants based on food waste and other waste arisings which must be at least fifty per cent of the feedstock. The inclusion of manures with their low biogas potential leads to a lower gas output than forage crops but its inclusion adds additional microbes beneficial to the digestion process. It also helps to reduce the dry matter fraction in the digester.

Green Gas for grid injection as biomethane however, is just part of the much larger equation of farm biogas production including that from manure. It has a significant and key role to help meet the aims of the Government's policy – the Twenty Five Year Environment Plan and its Sustainable Farming Incentive from 2022. This Incentive seeks to increase the productivity of arable and grassland, reduce operating costs, reduce use of fossil fertilisers and GHG emissions from their production and application. Reduced odours, reduced nutrient run off into watercourses, reduced droplet pollution from some application techniques are significant co-benefits and make a significant contribution to the public good for which a graded system of capital payment will begin dependent on the public goods delivered. Ultimately all lead the way to reduced GHG emissions.

The new plan has six goals. These aim to create: (1) clean air; (2) thriving plant life; (3) reduced risk of harm from environmental hazards of flooding and drought; (4) enhanced beauty of the landscape; (5) engagement with the natural environment; (6) mitigation and adapting to climate change and a contribution to Carbon Net Zero. The optimum use of livestock manure and agricultural residues such as vegetable trimmings to produce biogas can contribute to those goals.

Biogas plants are much more than energy producers. They are the centre piece for a sustainable agriculture especially for livestock farms where the optimal use of all resources including manure underpins the increased productivity of grass, forage and arable land. This reflects the purpose for which they were installed with capital grants for pollution control between 1978 and 2002. The principal feedstock was slurry or arisings from cheese, yoghurt and other dairy products. The energy was mainly for on-site use and to protect farms from disruptions to oil supplies, high energy prices and fertiliser costs.

The modern plants bring new valuable and environmentally beneficial opportunities from the inclusion of catch crops including radish, legumes, grains and grasses, longer crop rotations, improved soil structure, aeration and drainage. These plants form part of a total package for environmental management wholly in the public good. The investment in a farm biogas plant and all the benefits which it brings to the environment and the business is enhanced with the use of digital mapping and precision farming practices. The totality of the concept culminates in a steady reduction of agricultural GHG emissions; wholly meeting a large number of the aims of what the Sustainable Farming Incentive is intended to support.

Manure to biogas in the whole farm context can offer government good value for money, all of it for the public good.

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National Inventory and Map of Livestock Manure Loadings to Agricultural Land (2009)

Nicholson, F et al (2010). National Inventory and Map of Livestock Manure Loadings to Agricultural Land

3 Conclusion

Manure can be a sustainable substrate for energy provision. The use of manure in anaerobic digestion facilities reduces greenhouse gas emissions otherwise resulting from manure management. However, there are different types of manure depending on animal type and method of husbandry, leading to differing characteristics and geographic specific availability which in turn result in a wide range of levels of technically available resource and costs of biogas produced from manure.

The technical availability of manures for utilization in a biogas system depends on the animal species and type of husbandry practiced at the farm. The major factors which define the suitability of manure for an economic anaerobic digestion process include: the biogas potential of the manure; the water content of the manure; unwanted and inhibitory materials in manure; the herd size where the manure is processed; and the resulting amount of manure available to the biogas facility. Cattle for instance produce easy digestible manure, whereas chicken manure is nitrogenous and as such requires either innovative technologies or additional substrates to achieve stable digestion conditions.

If the manure has a very high water content (such as liquid cattle slurry) this impacts greatly on the cost sustainability with increasing transport distance. Chicken manure on the other hand has a high solids content and is already transported in Europe for disposal over large distances. A herd of 50 dairy cows housed in barns may not produce enough manure for an economic biogas operation. Husbandry on pastureland (such as in Ireland) does not lend itself to collection of manure and as such is a major barrier to a viable biogas industry. The seven countries described in this report each have specific regions, where the farming of specific animals is concentrated and the potential for a viable biogas industry is high. In such regions the option of manure transportation to reach the necessary capacity for profitable operation of a biogas facility might be an option worthy of analysis.

Manure might require co-substrates for a successful biological digestion process. Energy rich co-substrates can also improve profitability. Waste materials (such as from food) are a sustainable addition but might come with different regulations for their treatment and subsequent land application. The use of energy crops can have a negative impact in the case of regions with a high animal density as they add to the quantity of digestate and nutrient load requiring application to, and assimilation by agricultural land and as such increase the potential for eutrophication.

Anaerobic digestion of manure requires incentives to be financially viable. Any measure or strategy needs to consider the structures of existing farms and characteristics of the produced manures to achieve a significant impact efficiently. Anaerobic digestion plants using manure as the main substrate typically have a small capacity and consequently high specific costs. Species of animals and the type of husbandry have a significant impact on the costs of digestion and the biogas yield. Support schemes need to reflect these factors to be effective. In most countries agriculture faces a constant trend of increasing facility size. Countries with historically small sized agriculture production, are observing an ongoing reduction in the number of farms and an increase in farm size. This trend may not benefit the family farm or rural society but however, may increase the potential for sustainable anaerobic digestion.

To optimise the benefits of incentives applied to biogas it is essential to maximise the potential impact on greenhouse gas emission reductions and minimise the cost of abatement. This would suggest that incentives should focus on the manure types with high emission reduction potential and the lowest cost to treat; an example of this is liquid cattle manure (or slurry). The biogas system should be designed to ensure the digester has sufficient retention time to optimise the potential for collectable biogas production and minimise the biogas potential in the digestate; the digester needs to be gastight to ensure minimisation of fugitive methane emissions through leakage.

Future support or state aid for animal husbandry should facilitate optimization and integration of anaerobic digestion into existing farming practices. The biogas facility should ensure easy collection of manure with minimal storage prior to the anaerobic digestion process to minimise fugitive emissions and to utilise as much of the biomethane potential in renewable energy provision as possible. The role of biogas in organic farming should be enhanced. The increasing share of organic farming requires increasing quantities of organic fertilizers. The potential to integrate the biogas facility into the organic farm model to supply organic fertiliser should be reflected in future policy and support developments. The biogas facility should be seen as an essential constituent in the circular economy agricultural system. Its output must not be focused on energy yield alone but also, as a source of valuable biofertilizer to be recycled back onto agricultural land which is the starting point for feed for animals which produce the manure.

To synthesise, the strategies for manure utilization need to reflect:

- Farming structure, in particular herd size and characteristics of animal husbandry to be targeted (say intensive dairy farms);
- Long term perspective for animal husbandry in the region;
- The particular target sector for biogas utilization (electricity, green gas, transport biofuel, district heating);
- Cost structure for utilization of specific manure type with particular end use of biogas;
- Potential co-substrates and the regional impact on the utilization of these co-substrates in AD facilities;
- Support mechanisms which reflect long term operation of agricultural facilities which will have a lasting positive impact;
- Development of animal husbandry (renovated or newly constructed dairy farms) which optimizes manure handling for usage in AD facilities;
- Impact of the measures on greenhouse gas reduction.

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