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APPROVALS FOR THIS ISSUE

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Name	**Position**	**Signature**	**Date**
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HISTORY OF ISSUES / APPROVALS

REV	DATE	DESCRIPTION OF CHANGES	FILE NUMBER
0	10/03/22	Initial Issue	1206-RG-0002
1	28/04/22	Post-Issue Review	1206-RG-0002

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1.0 EXECUTIVE SUMMARY

This feasibility study investigates the possible development of Anaerobic Digestion (AD) plant in the Cavan and Monaghan border region to manage and decarbonise waste associated with the agricultural sector. The report consists of key sections:

- Feedstock Analysis
- Technological Pathway
- Basis of Design
- Sustainability
- Financial Assessment

The feedstock analysis consists of first assessing the availability of feedstocks in the border region; assessing a variety of feedstocks in addition to identifying suitable candidate co-substrates based on their geographic concentrations, digestion characteristics, availability and biomethane potential. Total biomethane potential from all feedstocks in the region is estimated to be ~700 GWh/a, the majority due to cattle slurry, grass silage and poultry waste contributing 280 GWh, 198 GWh and 176 GWh respectively.

A feedstock spatial analysis based on 13 no. candidate plant locations, based on their proximity to the nominated biomethane network entry facility (BNEF) and injection point, which is to be situated close to the existing gas infrastructure in the Border Region. Feedstocks within a 10, 20 and 30 km radius of the nominated sites were quantified and assessed.

Plant designs were considered, with continuously stirred tank reactor (CSTR) design being the most practical for the feedstocks considered, being the most common and widely available in the biogas industry in addition to having the lowest CAPEX. Mesophilic AD temperatures (35-45^{0}C) are found to be more suitable to this study due to their lower associated capital and operating costs, stability and robustness to changing feedstock composition, loading rates and environmental conditions.

Feedstock and digestate management will require that on-site storage for months where feedstock cannot be acquired (cannot be collected when pasture grazing) nor digestate disposed of (prohibited spreading winter period).

Three biogas end-use options were considered: Heat, Electricity & CHP and biomethane grid injection. Biomethane grid injection is the most suitable option given there is no adequate local heat load and other renewables technologies are more competitive than biogas in electricity generation. Biomethane grid injection can be facilitated either by virtual pipeline, where HGVs transport biomethane to the injection point, or by extending the gas pipeline with an injection point on-site.

Preliminary plant model in the 5-7 MW range (based on the available feedstock in the region) are considered. Plants are designed to be wet CSTR types, operate at mesophilic temperature conditions (38-40^{0}C), pasteurisation (Type 1 ABP rules), 25 day hydraulic retention time, 80% volatile solids destruction, 85% capacity factor (7,448 h/year operation), Carbon-Nitrogen (C:N) ratios of between 20-30:1, digestate separation into liquid and solid fractions.

Operating constraints and project risks were identified; feedstock security, digester loading and retention, temperature, ammonia inhibition and contaminants.

Environmental sustainability identifies sensitive areas in the border region where AD development would be impeded; 7 SAC sites, 4 SPA sites, 2 NHA sites and 38 pNHA sites were identified in the region. EPA licencing will be required for any significant AD plant development as more than 10,000 tonnes of waste per annum is to be processed.
A financial assessment determines that for the development of an AD plant in the 5 -7 MW range would require a CAPEX of €16-19m with OPEX of €2.6- 4.3m. Revenue streams are identified, namely support for biomethane production allocated under the Renewable Heat Obligation scheme (still under review) and revenue from fertiliser sales, derived from both extracted ammonia and digestate.

A financial analysis was done on three plant configurations most suited to the region over a 15 year plant lifetime, using the proposed Renewable Heat Obligation scheme (RHO) support as revenue in conjunction with CAPEX and OPEX estimates from biogas equipment supplier quotes. The analysis shows that the higher end of the proposed RHO rates (8 to 12 c/kWh) are necessary to ensure the viability of these plants.

To conclude, although technically feasible to develop large biogas plants and to decarbonise the agricultural sector in the Border region due to large quantities of feedstocks available, the economic viability is fundamentally dependent on adequate government support to promote and incentivise biomethane production, specifically via the RHO.

2.0 INTRODUCTION

The European biogas industry has developed into a mature industry over the past 20 years; the EBA reports 18,943 biogas plants and 725 biomethane plants in operation across mainland Europe at the end of 2019, producing 192 TWh gas in aggregate. In the Republic of Ireland however, there are less than 40 biogas plants in operation (majority of which are incorporated into waste-water treatment plants and a further 11 recover landfill gas). This is despite the excellent potential for anaerobic digestion (AD) given Ireland's strong agriculture and agri-food sectors, and the important role that biogas can play in helping meet critical decarbonisation targets as set out in EU Directives and national legislation. Ireland has the highest potential for biomethane production per capita in the EU. The relatively slow deployment of AD projects in the Republic of Ireland is attributed to a lack of government support that is required to stimulate an indigenous biogas industry. The potential of AD remains largely untapped throughout most of the Republic of Ireland, resulting in opportunities to investigate its current viability through feasibility studies.

The Border Region, in particular Counties Cavan and Monaghan, is home to a very strong agriculture and agri-food sector that yields significant quantities of biological waste material that can be harnessed in localised Anaerobic Digestion (AD) projects. Fingleton White, through a preliminary analysis of feedstocks nationwide, recognised the potential of AD in the Border Region, and subsequently engaged several organisations to mobilise a feasibility study in this area. The feasibility study described in this report is supported by Gas Networks Ireland (GNI) through the Gas Innovation Fund, which is committed to funding innovative projects that are concerned with the future development of the gas network. The feasibility study is also supported by Lakeland Dairies, Carton Bros, and Silver Hill Duck, local food producers in the region.

2.1 Anaerobic Digestion

AD refers to a collection of sustainable renewable energy technologies that exploits a naturally occurring biological process in which micro-organisms break down biodegradable feedstock material in the absence of oxygen to yield a methane-rich biogas. The biogas typically contains 50-70% methane by volume (CH_4), with the remainder comprised mainly of carbon dioxide (CO_2) and trace quantities of other impurities. The biogas can be used to generate electricity via a gas turbine or reciprocating engine (using a CHP unit if there is an adequate localised heat load) or upgraded to biomethane (~96-99% pure CH_4) for use as a vehicle fuel or injected directly to the gas network. Given the planned renewable energy support schemes, biomethane injection to the gas grid is the most viable end-use for new AD projects. A further product from AD is digestate, which is the residual matter left after the AD process has extracted biogas from the feedstock. Nutrients are preserved in the digestate during AD meaning that it can be rich in macronutrients such as nitrogen, phosphorous, and potassium (NPK), as well as in micronutrients. Therefore, AD adds further value to raw feedstock materials by yielding bio-fertiliser suitable for agricultural purposes.

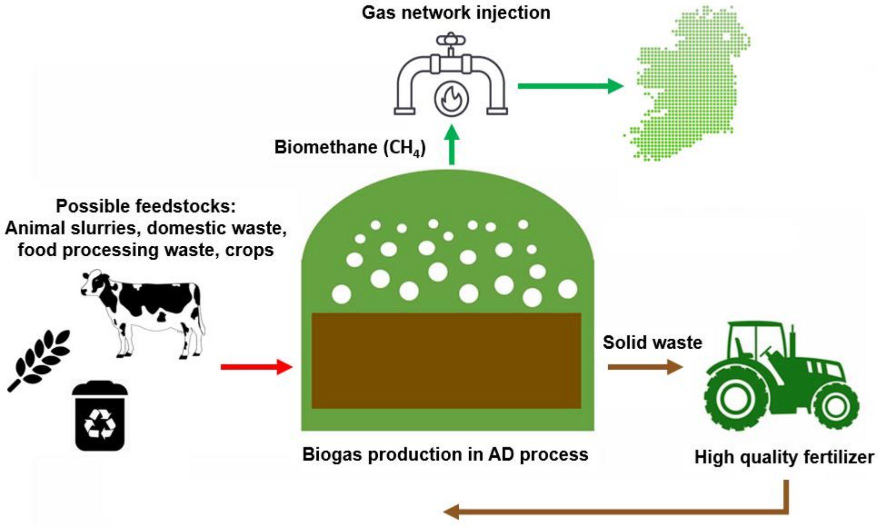

Figure 1 - Anaerobic Digestion Process

AD is receptive to a wide variety of feedstocks, such as the organic portion of municipal solid waste (brown bin waste, sewage waste), organic waste by-products from commercial food production, energy crops such as grass silage, maize, and cereals, and agricultural waste residues such as animal manure and slurries. The technology used for AD also varies between projects due to a variety of factors, such as project scale, feedstock materials, digestion characteristics, biogas end-use, and digestate treatment. More detailed descriptions of feedstock properties and AD technology is presented in sections 3.0.

Delivering a successful AD project involves optimising digester technology and design parameters against the characteristics and availability of feedstocks, plant production and demand for heat and electricity, and environmental concerns associated with feedstock sourcing and digestate disposal. Such a task commands a variety of interrelated services and disciplines, balancing the reprocessing of waste resources in a holistic and sustainable manner, whilst ensuring financial viability. A feasibility study represents the critical first step in assessing the risks and opportunities presented by AD, aiming to identify the most viable project options to take forward to more advanced development stages using high-level data and information.

2.2 Project Objectives

The feasibility study described in this report has an overall goal of stimulating AD projects in the Border Region to harness its significant waste potential, whilst delivering carbon savings to Irelands energy infrastructure through biomethane grid injection. The following represents the primary objectives for the feasibility study;

- Compile information on feedstock characteristics and sources in the Border Region
- Engage with key feedstock suppliers in the Border Region
- Identify the most techno-economically viable AD projects in the Border Region
- Develop the most viable AD projects further by assessing technical requirements
- Conduct a financial assessment of proposed AD solutions
- Conduct an environmental assessment of proposed AD solutions
- Make recommendations for further project development

3.0 FEEDSTOCK ANALYSIS

The feedstock mixture essentially forms the “fuel” for the AD process. Feedstocks come from a wide range of digestible organic materials; from agricultural slurry/manures, sewage sludge, household and commercial food waste, food processing waste, agricultural residues or grass. AD plants are capable of co-digesting multiple organic wastes in one digester that are compatible with one another, thereby ensuring a stable digestion process and maximising biogas yields. Optimising the feedstock mixture for AD plants is a decisive factor in ultimately developing a successful project. Each feedstock stream and/or feedstock mixtures combinations must be considered on a territorial basis with an assessment of where resources are based in a defined region. Feedstock competition costs and how they change over time must also be considered in order to ensure a consistent and constant flow of feedstock. The EU Renewable Energy Directive’s (RED II) mandatory sustainability criteria should also be considered when sourcing feedstocks.

The viability of AD is underpinned by the quantity, quality, cost, and availability of feedstock materials that can be practically and sustainably accessed in the surrounding area. The objective of the feedstock analysis is to compile useful information that will inform stakeholders on the high-level biogas production potential of feedstocks in the Border Region, whilst also serving as a key input to the technological analysis in section 0.

The feedstock analysis is subdivided into sections that focus specifically on each feedstock stream investigated by the study. The methodology and data behind analysing each feedstock stream is also provided. Following a high-level analysis of biological materials available in the region and suitable for AD, the following feedstock streams are put forward for analysis;

- Cattle manure (slurry and farmyard manure)
- Pig slurry
- Poultry manure (broiler and layer)
- Organic fraction of municipal solid waste (OFMSW)
- Grass silage

As well as analysing feedstock materials across a defined region, a collection of feedstocks sourced from companies involved in this study will also be assessed, these are referred to as anchor feedstocks. These are bio-degradable materials directly related to Lakeland Dairies, Carton Bros, Manor Farms and Silver Hill Duck, all of whom are food production companies in the Border Region directly supporting this study. For each feedstock stream, the following characteristics are required for the feasibility study:

- Total Solids (TS) content in % wet weight (wwt)
- Volatile solids (VS) content in % wwt.
- Energy content in MJ/kg and m^3/kg VS
- Chemical composition including nutrient content (NPK), ammonia and C:N ratio.
- Regulatory treatment requirements.
- Quantity in t/a.
- Source location in ITM coordinates.
- Seasonality and availability details.
- Cost in €/t.

Data from the CSO and EPA are the main sources of data for feedstock quantities, whilst information on feedstock properties is taken from Teagasc and other relevant literature. The feedstock analysis focusses on materials available in Cavan and Monaghan, however when investigating viable AD solutions, feedstocks may be accepted from neighbouring counties where logistically practical. Displays the study area of Cavan and Monaghan, including the largest populated areas.

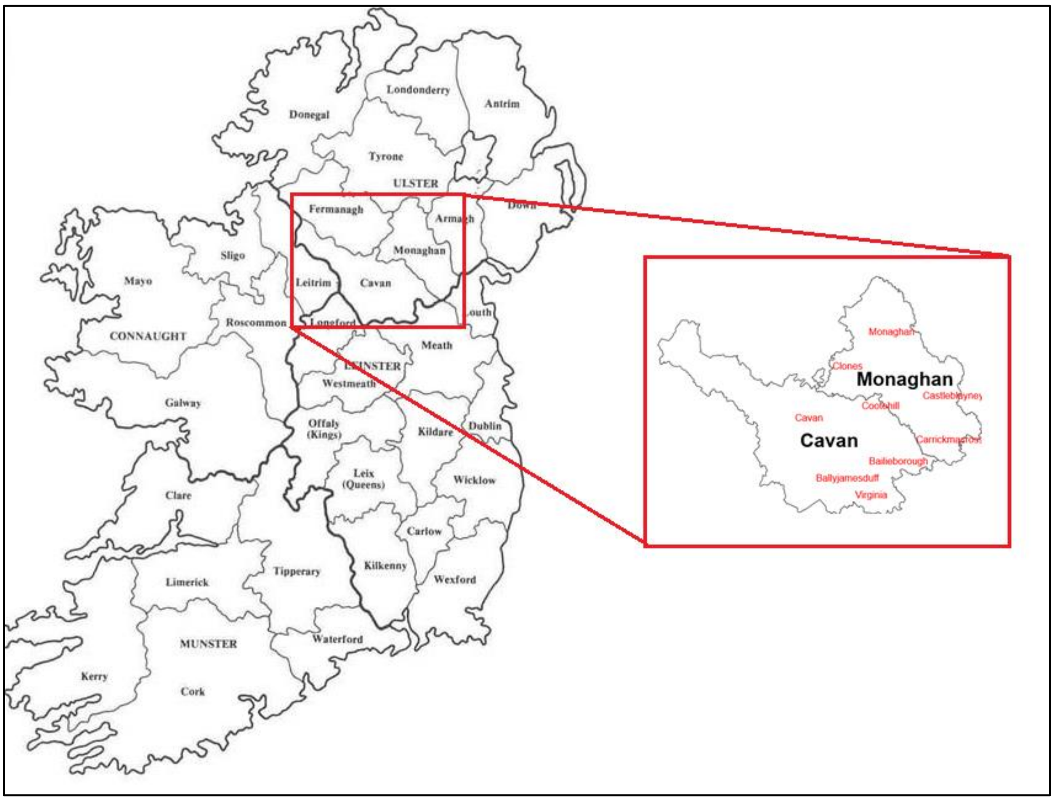

Figure 2 - Cavan and Monaghan, the focus region of the feasibility study.

3.1 Cattle Manure

The agri-food industry is one of the most important contributors to the Irish economy, accounting for over 7% of total and 8% of GDP. In this sector, beef and dairy products dominate exports and the value of output, both of which are driven by family-farm traditions that is characterised by a large national herd population spread across all agricultural parts of the country. According to the CSO Livestock Surveys for June and December 2020, the total number of cattle in Ireland varies from 6.5 – 7.4 million throughout the year, with variation owed to livestock breeding and slaughter (higher numbers reported in the June survey). The national herd collectively excretes a significant amount of material every year, with over 40 million tonnes collected, stored, and spread on fields annually to recycle vital N-P-K nutrients for grass growth; however, this material also contains volatile solids amenable to AD for biogas production. Cattle manure is therefore one of the most widely available and underutilised feedstock resources for AD in Ireland. Cattle manure is primarily in the form of liquid slurry, with a much smaller proportion of solid/semi-solid farmyard manure (FYM).

Cattle slurry is captured during winter months when the animals are housed and is generally stored in slatted tanks under and/or adjacent to the housing unit or in storage lagoons. Cattle housed off slatted tanks generate farmyard manure (FYM), such as young cattle or cows during calving. FYM is a solid/semi-solid material comprised of excrement mixed with straw bedding and is generally collected from housing units and stored in heaps or pits prior to land spreading.

This feasibility study investigates cattle slurry and FYM as potential feedstocks given their availability/accessibility across the country, and the positive benefits of decarbonisation of agriculture via AD.

3.1.1 Source

The CSO Census of Agriculture 2010 compiles data for different cattle types in Ireland, and this information is used to create a high-resolution dataset describing cattle populations in every electoral division (ED). There are 3409 EDs in Ireland, and these represent the smallest area containing detailed livestock figures at a national level. The following cattle types are considered;

- Dairy cows (> 2 years)
- Other cows (> 2 years)
- Bulls (> 2 years)
- Other cattle (< 2 years and non-dairy, suckler, or bull aged >2 years)

The 2010 study is the most recent Census of Agriculture, however the CSO are currently compiling results of the 2020 edition, with publication expected in the second half of 2022. To compensate for nationwide population changes between cattle types in the intervening years between 2010-2020, annual nationwide cattle populations are used to adjust 2010 numbers to values closer to the expected 2020 value. The following table outlines the deviation in cattle populations between 2010 and 2019, averaged between June and December due to seasonal variations in livestock herds.

Table 1 - National herd variation between 2010 and 2019.

Cattle type	2010 Population	2019 Population	Adjustment factor
Dairy cow	1,067,461	1,465,300	1.373
Other cow	1,154,607	978,300	0.847
Bull	51,855	54,900	0.944
Other cattle	4,312,194	4,433,600	1.028

The adjustment factor is used to multiply 2010 figures for cattle in each ED to get a population that is more representative of the actual 2020 population. In Cavan and Monaghan, there are a total of 159 EDs with cattle present in all but 7 EDs; these correspond to urban locations.

Table 2 - Cattle populations in Cavan and Monaghan.

Cattle type	Population
Dairy cow	82,930
Other cow	71,878
Bull	2,800
Other cattle	276,808

3.1.2 Characteristics

The energetic properties of cattle manure relevant to the design of an AD system varies depending on factors such as type (slurry or FYM), animal breed, gender, age, feed material and moisture content. When defining specific sources of feedstock material for an AD project it is important to characterise the energy content of the material to validate techno-economic models prior to physical development through tests/measurements; however, for a high-level feasibility study scoping cattle manure across a large geographical region this is not practical. In this study, energetic properties for cattle slurry and FYM are sourced from the Bioenergy and Organic Resources Research Group (BORRG) at the University of Southampton, shown in Table 3 and Table 4 respectively.

Table 3 - Energetic properties of cattle slurry.

Total solids (% wwt)	9.00%
Volatile solids (% wwt)	7.47%
Methane content (m^3/kg VS)	0.185
Calorific content (MJ/kg)	0.48
Methane vol. in biogas (%)	60%

Table 4 - Energetic properties of FYM.

Total solids (% wwt)	25.00%
Volatile solids (% wwt)	20.00%
Methane content (m^3/kg VS)	0.190
Calorific content (MJ/kg)	1.36
Methane vol. in biogas (%)	60%

Aside from the energetic properties, details on the chemical composition of feedstock are important for determining possible inhibitory effects from suboptimal ammonia levels often associated with animal manures, N-P-K nutrient components for use as a fertiliser and C:N ratio for maximising biogas yields. N-P-K values are taken from Teagasc Available Nutrient Content of Organic Manures (2021), with Fertiliser replacement value estimated by calculating the chemical fertiliser replaced, with values of 0.94 €/kg N, 1.99 €/kg P and 0.76 €/kg K assumed (Teagasc) and nutrient availability of 50% for N, 50% for P and 100% for K. Ammonium N represents the nitrogen content available for plant uptake, and is therefore calculated as 50% of the total N. The influence of these properties on biogas plant design is discussed further in the technical section of the report. The following values are assumed in the study.

Table 5 - Chemical properties of cattle slurry.

Nitrogen (N, kg/m^3)	2.00
Phosphorous (P, kg/m^3)	0.80
Potassium (K, kg/m^3)	3.5
Ammonium N (NH_4-N, kg/m^3)	1.0
C:N ratio	15:1
Fertiliser replacement value (€/m^3)	4.67

Table 6 - Chemical properties of FYM.

Nitrogen (N, kg/m^3)	1.35
Phosphorous (P, kg/m^3)	1.20
Potassium (K, kg/m^3)	6.00
Ammonium N (NH_4-N, kg/m^3)	0.68
C:N ratio	40:1
Fertiliser replacement value (€/m^3)	7.07

3.1.3 Quantity and Availability

The volume of cattle manure in each ED per annum is estimated using the specific excretion value for individual cattle types multiplied by their population in each ED. The specific excretion value is given in m^3/week for each cattle type (see Table 7). The number of weeks where slurry and FYM can be practically collected in each year depends on the minimum housing period; it is not possible to collect slurry and FYM during spring-summer months as animals are on pasture. For Cavan and Monaghan, the minimum housing period is 22 weeks. In practice the housing periods will trend upwards from this minimum requirement between farms, however the minimum housing period is deemed a suitably conservative methodology for establishing manure volumes across a broad region.

Table 7 - Cattle excretion volumes from Teagasc (Hennessy et al, 2011)

Cattle type	Excretion (m^3/week)
Dairy cow	0.33
Other cow	0.29
Bulls	0.25
Other cattle[1]	0.18

Using the individual cattle populations, minimum housing period, and excretion volumes, the total volume of slurry excreted in each ED is established. During housing, some cattle types will be stored off slatted tanks on straw bedding to form FYM, such as younger cattle or cows when calving. To disaggregate slurry and FYM quantities, proportional data from a recent Teagasc report on manure management (2020) is used. The survey reports on the proportion of slurry and FYM stored in each nitrates zone against the total cattle manure stored, for specific cattle types. As Teagasc report on cattle aged 0-1 years, 1-2 years, and 2-3 years, the 2-3 year category is added to the older cattle (dairy cow, other cow).

Table 8 - Slurry and FYM proportions by cattle type for Zone C.

Cattle type	Slurry	FYM
Dairy cow	99%	1%
Other cow	95%	5%
Bulls	96%	4%
Other cattle	87%	13%
Weighted total[2]	**91%**	**9%**

Utilising the slurry-FYM proportion allows for a final estimate of slurry and FYM in each electoral division, based on the calculation of cattle slurry excreted, and a 20% fraction of straw bedding in FYM.

Table 9 displays the total quantity of slurry for each cattle type in Cavan and Monaghan, whilst Figure 3 displays the spatial distribution of cattle slurry across the EDs. Note that 1 m^3 of feedstock is assumed equivalent to 1 t.

Table 9 - Cattle slurry quantities in Cavan and Monaghan.

Cattle type	Quantity (t/a)
Dairy cow	597,541
Other cow	441,098
Bulls	34,944
Other cattle	984,652
Total	**2,026,167**

[1] Weighted value based on excretion data and national population for specific cattle types classified as 'Other cattle'
[2] For Cavan and Monaghan only

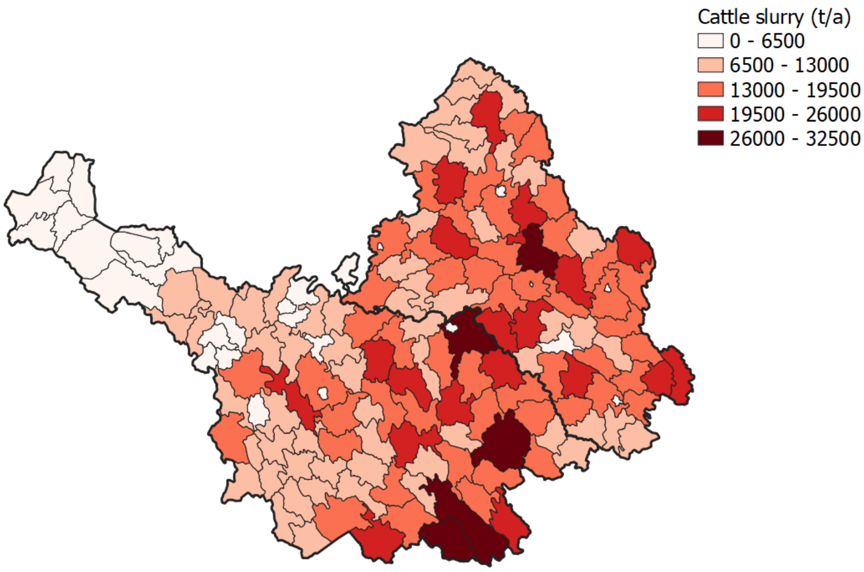

Figure 3 - Cattle slurry quantities in Cavan and Monaghan.

Using the methane content of cattle slurry in above and 100% availability of cattle slurry and biogas extraction, the cumulative methane distribution can be plotted across the region.

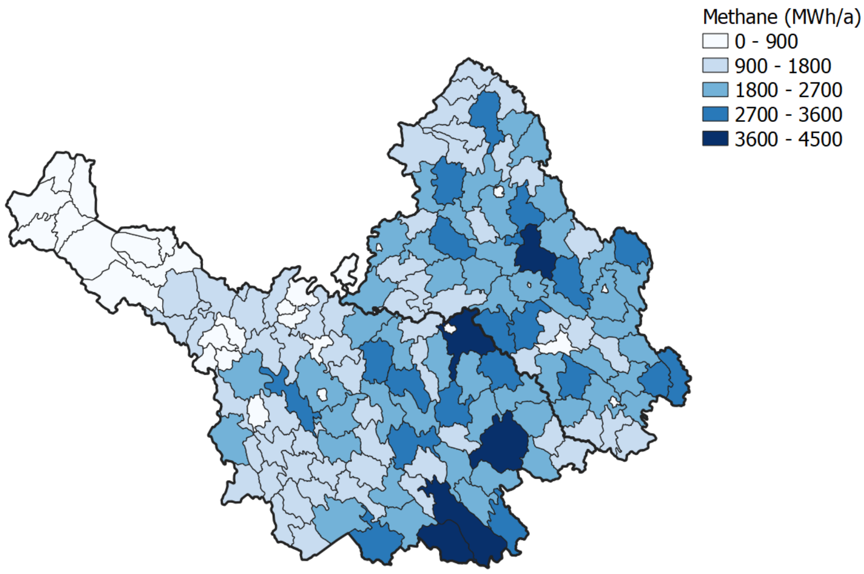

Figure 4 - Biomethane potential from Cattle Slurry in Cavan and Monaghan (MWh/a).

Table 10 displays the total quantity of FYM for each cattle type in Cavan and Monaghan, whilst Figure 5 displays the spatial distribution of FYM across the EDs and corresponding biomethane potential in Figure 6.

Table 10 - Cattle FYM quantities in Cavan and Monaghan.

Cattle type	Quantity (t/a)
Dairy cow	6,036
Other cow	23,216
Bulls	1,456
Other cattle	147,132
Total	**176,503**

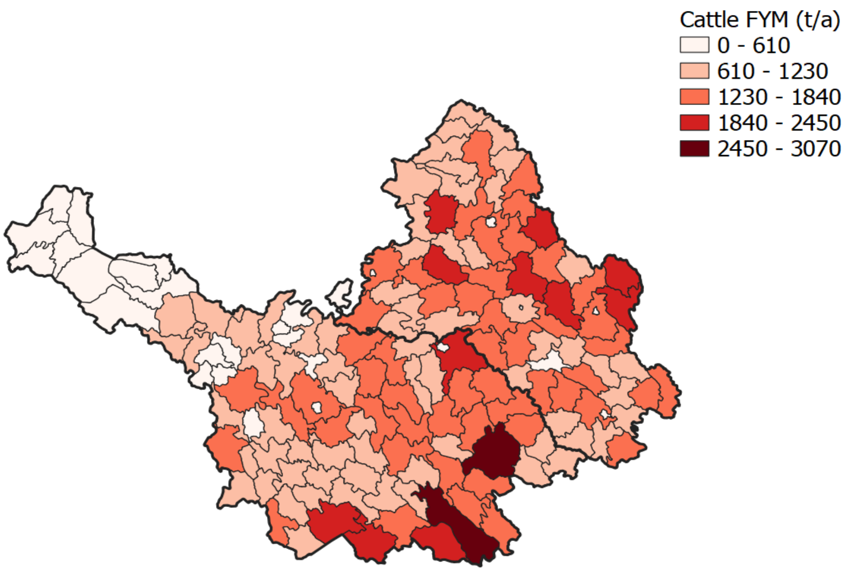

Figure 5 - Cattle FYM in Cavan and Monaghan (t/a).

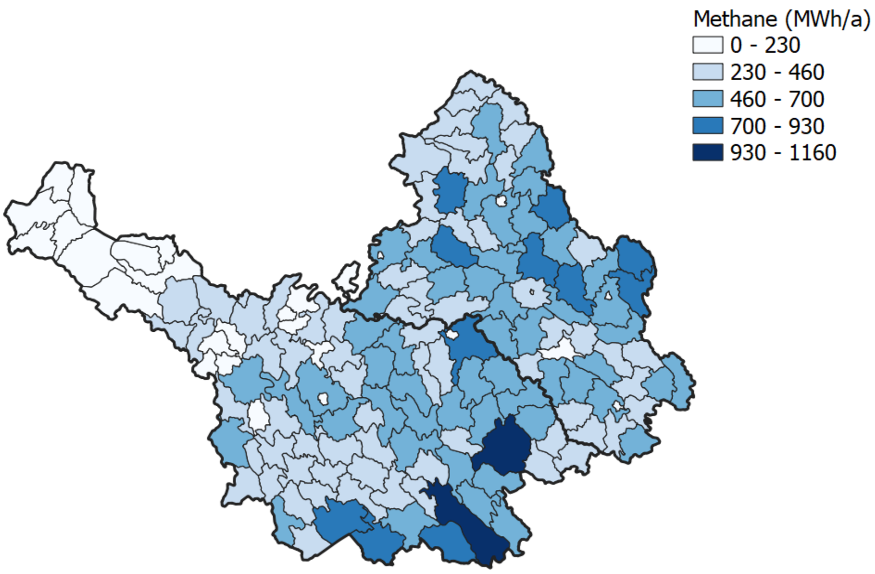

Figure 6 - Biomethane potential from cattle FYM in Cavan and Monaghan (MWh/a).

Between Cavan and Monaghan, there is over 280 GWh of potential biomethane from cattle slurry alone, and 68 GWh from FYM. There are higher concentrations of cattle slurry and FYM in South-Eastern Cavan and Central Monaghan. There is very little slurry and FYM sourced in EDs associated with urban areas, and in North-West Cavan due to the ground being unsuitable for extensive cattle rearing in this area (bogland/mountainous/wet).

It is assumed that cattle manure will have a high availability over the months of winter storage, where slurry gathers in tanks and FYM is stockpiled in heaps and can be readily accessed for AD. During summer months, when cattle are on pasture and collection in tanks is diminished, adequate storage for cattle and FYM will be required to ensure a consistent feedstock stream throughout the year.

The raw material cost of cattle slurry and FYM is assumed as 0 €/t as both cattle slurry and FYM have no value apart from its nutrient replacement value as a biofertilizer. After biogas has been removed, digestate from the AD plant could be supplied in exchange to farmers supplying cattle slurry and FYM, as a means of compensation for farm nutrient recycling.

Such arrangements should be determined at the plant design stage where contracts are agreed between the plant operator and feedstock suppliers.

3.2 Pig Slurry

Pig meat is the fourth most valuable export of the Irish agri-food industry after dairy, beef and beverages, with exports and domestic retail sales in 2019 valued at €890 million and €438 million respectively. This important agri-food sector is supported by a large national pig population; according to the latest National Pig Census figures from DAFM, the total number of pigs in Ireland as of October 2020 stood at 1,702,921, spread amongst 1,675 active herds. The Border Region has traditionally had a very active pig farming industry; Co. Cavan has the largest pig population in the country, with 330,887 pigs representing 19.4% of the total population, whilst Co. Monaghan has 31,842 pigs (1.9%).

Unlike beef and dairy farming, pigs are mostly reared in intensive farming facilities rather than through the family-farm model. Of the 1,675 active pig herds in Ireland, 1,642,008 pigs were recorded in the largest 284 herds, meaning 17% of herds rear 96.48% of the total pig population. Intensive rearing facilities collect substantial amounts of pig manure every year, most of which is in liquid form (slurry) stored in tanks. Pig slurry has use as an organic fertiliser, with its value tied to the N-P-K nutrients that it can supply for crop growth, and thus replace chemical fertilisers. In the anaerobic digestion process, the nutrients that are fed to the plant contained in the raw feedstock are returned via the digestate, meaning AD can add further value to pig slurry through biogas extraction to complement its nutrient replacement value. Large concentrations of pig slurry are available from several sources via storage in intensive farming facilities, simplifying the feedstock management process.

The sustainability of pig farming and the reduction of environmental impact plays a central role in the development of the industry and is a major consideration as all sectors of the Irish economy will experience increasing pressure to decarbonise. The level of sustainability of the sector is becoming ever more important for the reputation of pig farming and will play an increasing role in consumer preferences and purchasing habits. Harnessing the energy available in pig slurry through AD, whilst adequately controlling ammonia emissions via digestate treatment/management, can help the sector decarbonise and embrace sustainability.

3.2.1 Source

The CSO Census for Agriculture provides data on pig populations in Ireland across EDs. However, given the nature of Irish pig farming activity, pig populations are generally clustered into intensive farming units, rather than distributed across thousands of individual farms like cattle and sheep populations. These intensive farming units represent the most practical source of feedstock, due to larger pig herds yielding a larger volume of slurry on a single site. Licenced facility operators have a responsibility to record and report annual slurry volumes to the EPA in Annual Environmental Reports (AER), and these are used to estimate available slurry at each site. The AER document provides data on slurry volume, farm name, and coordinates, and are deemed an appropriate method in sourcing pig slurry for AD. There are over 100 intensive pig farms that have been identified across Ireland via AER accounts, with 28 in Cavan and Monaghan alone. According to the 2020 National Pig Census, there are 100 active pig herds in Co. Cavan, and 31 in Co. Monaghan.

The volume of feedstock produced by pigs in each unit is read from column name ‘Quantity of organic fertiliser produced by the animals housed onsite in the reporting year’ in the EPA AER report (see Figure 7), reported in m^3 per annum.

Organic fertiliser storage capacity Lic No: [redacted]

Please complete the table using the explanation of entries below as a guide

Table OFS.1 Storage capacity for Organic Fertiliser

Type of Organic Fertiliser	Total organic fertiliser storage capacity (m3) **(Estimate)**	Opening Quantity of organic fertiliser (1st January of reporting year) **(Estimate)**	Closing Quantity of organic fertiliser (1st January of current calendar year) **(Estimate)**	Quantity of organic fertiliser produced by the animals housed on site in reporting year	Total quantity of organic fertiliser moved off site in reporting year (as recorded in the organic fertiliser register and "record 3" as submitted to DAFM*)	Where there is a difference between the amount moved off site (record 3 amount) and the amount generated (taking into account opening and closing amounts) provide details to account for this difference, e.g. applying organic fertiliser to Licencee's farmland.	Have records of movement of organic fertiliser (record 3) for the reporting year been submitted to DAFM?
Pig Slurry	35090.14	20462	6436	25331	39173.93	Negligible	Yes

*DAFM -Department of Agriculture Food and Marine

Column **a** The total organic fertiliser storage capacity is calculated by summing storage capacity onsite. If applicable, Agency agreed off-site storage should be added to the total on-site.

Column **b** This is the opening quantity of organic fertiliser recorded on 1st of January of AER reporting year

Column **c** This is the quantity of organic fertiliser at close of reporting year calculated by recording the opening quantity on 1st January of the current calendar year

Column **d** This is the quantity of organic fertiliser generated by the animals housed on site in the AER reporting year

Column **e** Total quantity of organic fertiliser moved off site and recorded in the organic fertiliser register and "record 3" as submitted to DAFM* in AER reporting year

Column **f** If there is a difference between the amount recorded in the Record 3 form submitted (**e**)and the amount recorded by adding together the opening quantity (**b**) and amount generated (**d**) and substracting the closing quantity (**c**) i.e. if **e** does not match **b + d - c**, account for the mistmatch, for example where the unit is applying organic fertiliser on their own landbank

Figure 7 - Sample EPA report outlining pig slurry quantities removed from intensive farm facilities.

3.2.2 Characteristics

The energetic properties of pig slurry relevant to the design of an AD system varies depending on factors such as animal breed, gender, age, feed material and moisture content. When defining specific sources of feedstock material for an AD project it is important to characterise the energy content of the material to validate techno-economic models prior to development; however, for a high-level feasibility study scoping pig slurry across a large geographical region this is not practical. In this study, energetic properties for pig slurry are sourced from the Bioenergy and Organic Resources Research Group (BORRG) at the University of Southampton, shown in Table 11.

Table 11 - Energetic properties of pig slurry.

Total solids (% wwt)	5.50%
Volatile solids (% wwt)	4.51%
Methane content (m^3/kg VS)	0.26
Calorific content (MJ/kg)	0.41
Methane vol. in biogas (%)	60%

Aside from the energetic properties, details on the chemical composition of pig slurry are important for determining possible inhibitory effects from suboptimal pH and ammonia levels associated with animal manure, N-P-K nutrient components for use as a fertiliser, and C:N ratio for maximising biogas yields. The following values are assumed in the study.

Table 12 - Chemical properties of pig slurry.

Nitrogen (N, kg/m^3)	2.10
Phosphorous (P, kg/m^3)	0.80
Potassium (K, kg/m^3)	1.90
Ammonium N (NH_4-N, kg/m^3)	1.05
C:N ratio	10:1
Fertiliser replacement value (€/m^3)	3.60

3.2.3 Quantity and Availability

Figure 8 displays the source location and scale of intensive pig farms by annual slurry removed (t/a); whilst displays the corresponding methane potential. The cumulative pig slurry quantity from the 28 intensive pig farms in Cavan and Monaghan is 338,698 t/a; this amounts to over 27% of the cumulative pig slurry across all licenced facilities. The largest single farm supply is 31,800 t/a, the smallest being 1,200 t/a.

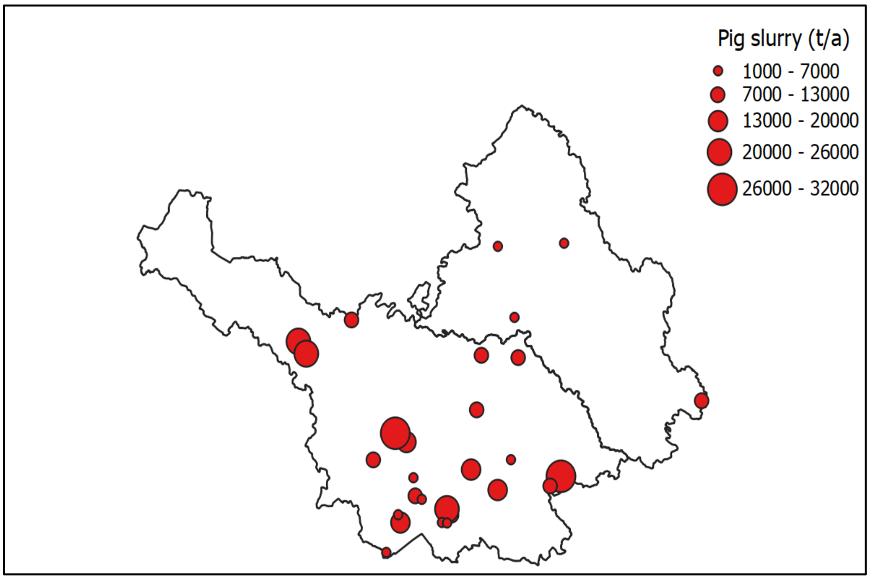

Figure 8 - Pig slurry quantity in Cavan and Monaghan (t/a).

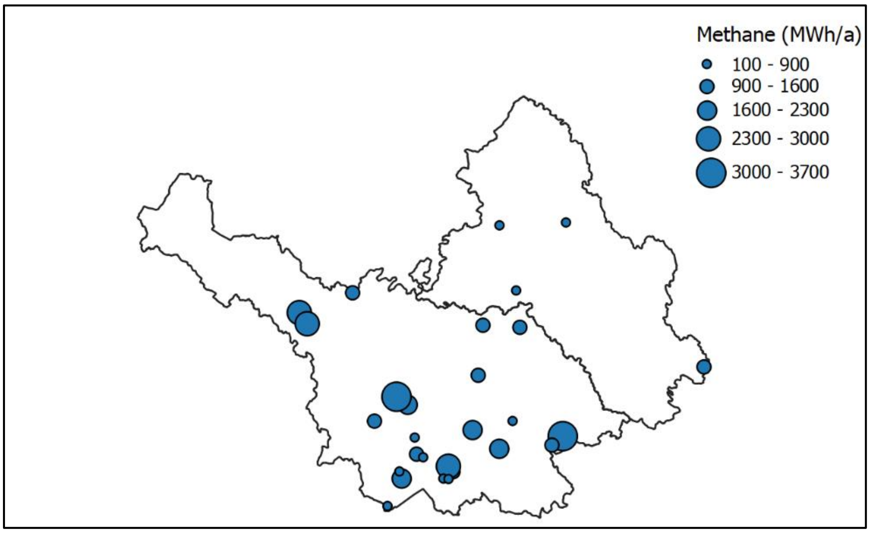

Figure 9 - Biomethane potential from pig slurry in Cavan and Monaghan (MWh/a).

Between Cavan and Monaghan, there is over 39 GWh of potential biomethane from pig slurry alone. It is evident from the thematic maps that licenced intensive pig farming facilities in this region are generally concentrated towards Southern Cavan, near the towns of Ballyjamesduff and Virginia in particular. In contrast, there is relatively little pig slurry available in Co. Monaghan.

It is assumed that there will be a high availability of pig slurry throughout the year, due to the nature of intensive pig farming where pigs are housed year-round leading to a continuous collection process.

The raw material cost of pig slurry is assumed as 0 €/t, as pig slurry has no value apart from its nutrient replacement value as a biofertiliser. After biogas has been removed, digestate from the AD plant could be supplied to farmers who rely on raw pig slurry for nutrient recycling as a means of compensation. Such arrangements should be determined at the plant design stage where contracts are devised for feedstock suppliers.

3.3 Poultry Manure

The Irish poultry sector is divided into two sub-sections: poultry meat (broilers) and egg production (layers). According to Teagasc, the Irish poultry sector produces 70 million chickens annually, 4 million turkeys and eggs from 2 million hens. The majority of poultry rearing and egg production in Ireland and the EU is carried out in large intensive units. These units collect significant quantities of poultry manure every year which is typically land spread on tillage ground for bio-security reasons or composted; however, there is potential to process poultry manure in AD, taking advantage of the high calorific and solids content for biomethane production. Counties Cavan and Monaghan have traditionally been the centre of Ireland's poultry industry with Co. Monaghan alone home to over half of Ireland's poultry population. It is estimated that both licenced and sub-licenced poultry production facilities generate more than 140,686 t/a of manure. The consideration of poultry manure is a key driver behind this feasibility study, given its attractiveness and concentration in the Border Region as a feedstock for AD.

3.3.1 Source

EPA AER are used to identify sources of poultry manure from intensive farms that are obliged to record and report such information. Similar to pig slurry, AER documents provides data on slurry volume and coordinates. There are 100 intensive poultry farms that have been identified across Ireland, with 82 of those located in Cavan and Monaghan alone.

The volume of feedstock produced each poultry unit is read from column name 'Quantity of organic fertiliser produced by the animals housed on site in the reporting year' in the EPA AER submission (see Figure 10), reported in m^3 per annum. Wash water volumes are not factored in the energy content calculation.

Organic fertiliser storage capacity Lic No:

Please complete the table using the explanation of entries below as a guide

Table OFS.1 Storage capacity for Organic Fertiliser

Type of Organic Fertiliser	Total organic fertiliser storage capacity (m3) **(Estimate)**	Opening Quantity of organic fertiliser (1st January of reporting year) **(Estimate)**	Closing Quantity of organic fertiliser (1st January of current calendar year) **(Estimate)**	Quantity of organic fertiliser produced by the animals housed on site in reporting year	Total quantity of organic fertiliser moved off site in reporting year (as recorded in the organic fertiliser register and "record 3" as submitted to DAFM*)	Where there is a difference between the amount moved off site (record 3 amount) and the amount generated (taking into account opening and closing amounts) provide details to account for this difference, e.g. applying organic fertiliser to Licencee's farmland.	Have records of movement of organic fertiliser (record 3) for the reporting year been submitted to DAFM?
Pig Slurry/Poultry Litter	0	0	0	314.3	314.3	0	Yes
Washwater (Poultry)	20.5	10	5	127.27	N/A	N/A	N/A

*DAFM -Department of Agriculture Food and Marine

Column **a** The total organic fertiliser storage capacity is calculated by summing storage capacity onsite. If applicable, Agency agreed off-site storage should be added to the total on-site.
Column **b** This is the opening quantity of organic fertiliser recorded on 1st of January of AER reporting year
Column **c** This is the quantity of organic fertiliser at close of reporting year calculated by recording the opening quantity on 1st January of the current calendar year
Column **d** This is the quantity of organic fertiliser generated by the animals housed on site in the AER reporting year
Column **e** Total quantity of organic fertiliser moved off site and recorded in the organic fertiliser register and "record 3" as submitted to DAFM* in AER reporting year
Column **f** If there is a difference between the amount recorded in the Record 3 form submitted (**e**)and the amount recorded by adding together the opening quantity (**b**) and amount generated (**d**) and substracting the closing quantity (**c**) i.e. if **e** does not match **b + d - c**, account for the mistmatch, for example where the unit is applying organic fertiliser on their own landbank

Figure 10 - Sample EPA report outlining poultry manure quantities removed from intensive farm facility.

The source location of poultry manure from smaller farms not licenced by the EPA (sub-licenced) could not be found as reporting obligations are not applicable to such holdings. However, aggregate data from Monaghan Co. Co. on poultry manure quantities for sub-licenced facilities is used to supplement that from the EPA to generate a more accurate estimate of material quantities in the region. As the source of the sub-licenced material is not available, the material is assumed as evenly distributed across each the licenced EPA facilities in Co. Monaghan which represent the regional activity of poultry farming. This simplistic assumption is important for plant modelling as transportation costs must be considered.

3.3.2 Characteristics

The energy content of poultry litter varies substantially in literature due to the nature of farming (layer or broiler) with large variations in volatile and solids content also observed. Poultry litter is an energy intensive feedstock in comparison to other animal wastes (1-8 MJ/kg according to various sources) and is concentrated to a relatively small number of sites in Ireland. BORRG at the University of Southampton provide data for the energetic properties of broiler and layer poultry.

Table 13 -Energetic properties of poultry manure (broiler).

Total solids (% wwt)	60%
Volatile solids (% wwt)	45%
Methane content (m^3/kg VS)	0.3
Calorific content (MJ/kg)	4.86
Methane vol. in biogas (%)	60%

Table 14 - Energetic properties of poultry manure (layer).

Total solids (% wwt)	30.0%
Volatile solids (% wwt)	22.5%
Methane content (m^3/kg VS)	0.33
Calorific content (MJ/kg)	2.63
Methane vol. in biogas (%)	60%

Aside from the energetic properties, details on the chemical composition of poultry manure is important for determining possible inhibitory effects from suboptimal pH and ammonia levels associated with animal manure, N-P-K nutrient components for use as a fertiliser and C:N ratio for maximising biogas yields. The influence of these properties on biogas plant design is discussed further in the technical section of the report. The following values are assumed in the study.

Table 15 - Chemical properties of poultry manure (broiler).

Nitrogen (N, kg/m^3)	14
Phosphorous (P, kg/m^3)	6
Potassium (K, kg/m^3)	18
Ammonium N (NH_4-N, kg/m^3)	7.0
C:N ratio	10:1
Fertiliser replacement value (€/m^3)	29.2

Table 16 - Chemical properties of poultry manure (layer).

pH	8.00
Nitrogen (N, kg/m^3)	6.85
Phosphorous (P, kg/m^3)	2.90

Potassium (K, kg/m^3)	6.00
Ammonium N (NH_4-N, kg/m^3)	3.43
C:N ratio	10:1
Fertiliser replacement value (€/m^3)	11.9

3.3.3 Quantity and Availability

Figure 11 displays the source location and scale of licenced poultry farms (layer and broiler combined) by the annual litter removed (t/a), whilst Figure 12 displays the corresponding methane potential. The cumulative poultry litter quantity from the 82 intensive poultry farms in Cavan and Monaghan is 65,823 t/a; 45,241 t/a from broilers, and 20,403 t/a from layers.

For sub-licenced facilities, there is an estimated 48,103 t/a from broilers, 1,083 t/a from layers, and 25,856 t/a from turkey rearing. Between the 65 licenced facilities classified as broiler, each is assigned 1,138 t/a for the analysis (broiler and turkey manure quantities split evenly over 65 locations). For layers, there is 120 t/a manure evenly distributed over the 9 licenced facilities in Co. Monaghan. In total, the analysis estimates 119,200 t/a of broiler manure, and 21,486 t/a of layer manure in the region.

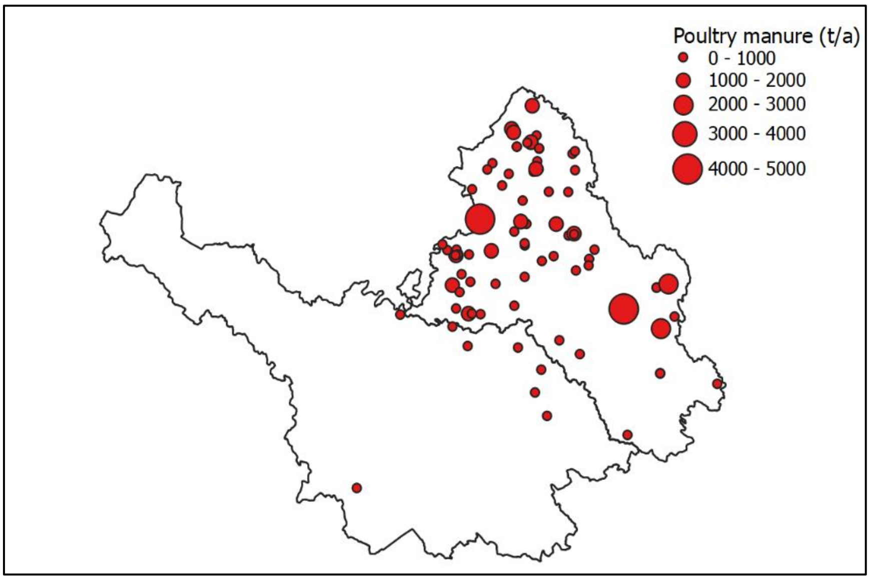

Figure 11 - Poultry manure quantity from licenced farms in Cavan and Monaghan (t/a).

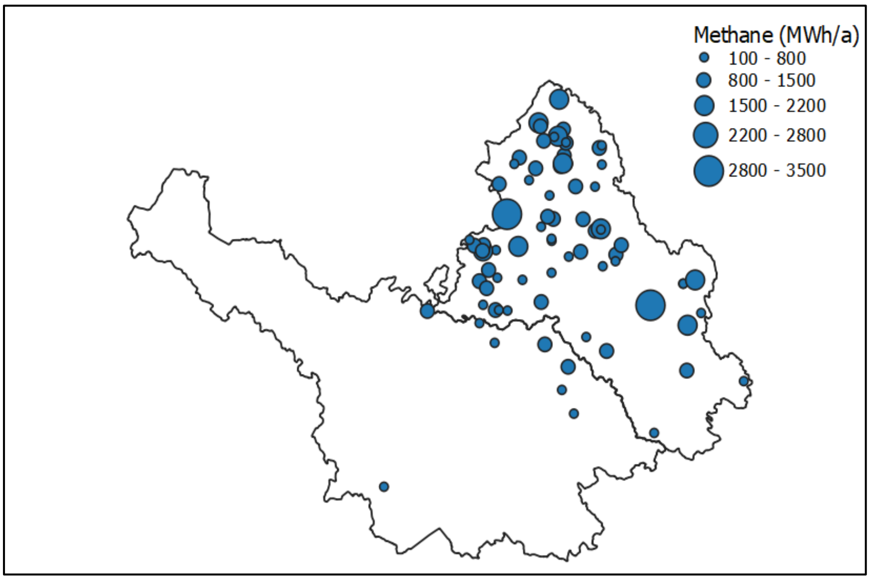

Figure 12 - Poultry manure biomethane potential from licenced facilities in Cavan and Monaghan (MWh/a).

Between Cavan and Monaghan, there is over 76 GWh of potential biomethane from poultry manure alone in licenced farms. Of the 82 licenced facilities in the region, 74 are located in Co. Monaghan. It is evident from the thematic maps that licenced intensive poultry farming facilities in this region are concentrated towards Northern Monaghan, around the towns of Clones, Emyvale and Monaghan Town in particular. Of the 8 facilities located in Co. Cavan, the majority are located near the border with Monaghan. For sub-licenced facilities, there is over 100 GWh of biomethane potential, bringing the total poultry manure available in the region to 176 GWh.

It is assumed that there will be a high availability of poultry manure throughout the year due to the nature of intensive licenced poultry farming where layers and broilers are housed year-round leading to a continuous collection process. For sub-licenced facilities, the nature of rearing may not always lend to practical feedstock collection (e.g. organic farms), however, for the sake of the feasibility study it is assumed as available for collection.

The raw material cost of poultry manure is assumed as 0 €/t. After biogas has been removed, digestate from the AD plant could be supplied to farmers who rely on raw poultry manure for nutrient recycling. For broiler manure, there are limitations on land spreading due to botulism risks on grassland, which inhibits its attractiveness as a digestate, layer manure has much less stringent restrictions (see section 3.7). Material handling issues must be addressed at the plant design stage where contracts are devised for feedstock suppliers and digestate disposal.

3.3.4 Other Poultry: Duck Slurry

Duck rearing and processing constitutes another part of poultry industry activities within the border region. It is estimated that there is 59,000 t/a of duck slurry produced in Co. Cavan and Monaghan. There are five processors in Co. Monaghan and one in Co. Cavan. Specifically, most activity pertaining to duck processing is concentrated around Emyvale in northern Monaghan. This totals to 11.2 GWh of biomethane potential from duck slurry in the region, with 7.9 GWh present in Monaghan alone.

Presented in Table 17 are duck slurry characteristics (obtained from a laboratory analysis). These indicate a low biomethane potential and, consequentially, a low energy content (a fraction of other poultry feedstocks). Additionally, the feedstock has a high ammonia content which would require ammonia stripping as part of the process to prevent Ammonia inhibition within the digester. Subsequently, the high moisture content requires increased transport cost and emissions per joule of energy collected in addition to increased CAPEX and OPEX costs (larger digesters and increased heating required for increased material throughput). Combined with the low biomethane potential and relatively low distribution throughout the region, duck slurry does not prove to be an attractive feedstock to AD development unless sources are concentrated near the AD plant itself, particularly, northern Monaghan.

Table 17 - Energetic properties of duck slurry.

Total solids (% wwt)	4.57%
Volatile solids (% wwt)	3.19%
Methane content (m^3/kg VS)	0.66
Calorific content (MJ/kg)	0.76
Methane vol. in biogas (%)	60%

Presented in Table 18 are the chemical properties and composition of duck slurry (obtained from a laboratory analysis), detailing the pH level, N-P-K nutrients available as to determine fertiliser value, in addition to the C:N ratio which provides an indication whether the feedstock requires co-digestion with other feedstocks of higher carbon content. The high ammonia content of the duck slurry, however, makes it an attractive fertiliser replacement prospect.

Table 18 - Chemical properties of duck slurry.

pH	8.46
Nitrogen (N, kg/m^3)	2.4
Phosphorous (P, kg/m^3)	0.7
Potassium (K, kg/m^3)	3.5
Ammonium N (NH_4-N, kg/m^3)	5.26
C:N ratio	10:1
Fertiliser replacement value (€/m^3)	6.31

3.4 Organic Fraction of Municipal Solid Waste

The organic fraction of municipal solid waste (OFMSW, or biowaste) represents multiple waste streams that are predominantly composed of food waste, and organic by-products from food production activities. For this study, domestic organic waste is defined as the material disposed of by individuals in household brown bins, mainly food and garden waste (grass/hedge clippings). Commercial food waste comes from hotels, restaurants, and workplace canteens. Food processing waste includes material derived from the production of meat and dairy products in slaughterhouses and dairy processing facilities respectively.

OFMSW covers a variety of predominantly food-based material types that make for very attractive feedstocks for AD given their high calorific content that lends to high biogas yields per kg, low moisture content relative to other waste substrates that results in smaller and less expensive digester designs, and lower digestate disposal costs. OFMSW is available year-round, with some seasonal variation expected due to consumer habits and tourism with respect to domestic and commercial waste, and trends in animal slaughter and milk production affecting materials from slaughterhouses and dairy processing facilities respectively. AD plants receiving OFMSW will generally receive a gate fee of 50-80 €/t, which further enhances the attractiveness of the material; however, gate fees may diminish over time due to feedstock competition as more AD plants are developed, encouraging caution when incorporating such a revenue stream into long-term plant economics.

Utilising OFMSW through biological treatment (AD and composting) represents a key component of the circular economy philosophy. National and European legislation places restrictions on the amount of OFMSW that can be landfilled, while the current EU Waste Framework Directive encourages EU Member States to improve their waste management systems, to improve the efficiency of resource use, and to ensure that waste is valued as a resource. The maximum allowable quantity of biodegradable waste that can be landfilled in Ireland is limited to 420,000 t/a from 2016, as set by the EU Directive on the Landfill of Waste (1999/31/EC). According to the EPA, there is a maximum capacity limit of 470,000 t/a that can be accepted to landfill in the three remaining landfill facilities in 2020, and 1,177,875 t/a accepted by carbon-intensive incinerators (2) and co-incinerators (3); carbon-neutral AD is therefore an attractive waste-to-energy option for valorising organic fractions of waste. OFMSW is handled by licenced waste management companies that collect and dispose of materials on behalf of domestic and commercial customers.

In food processing facilities, the material may also be collected and disposed/recycled by licenced handlers, with some material also being disposed of through land-spreading by farmers for nutrient recycling. According to EPA statistics, over half (56%) of feedstocks accepted into biological treatment centres (AD and composting) in 2018 was OFMSW, amounting to 110,000 t/a for authorised AD in the Republic of Ireland; 17% of OFMSW directed to composting and AD is transferred across the border to AD plants in Northern Ireland.

3.4.1 Source

Figure 13 provides a breakdown of OFMSW materials investigated in this study.

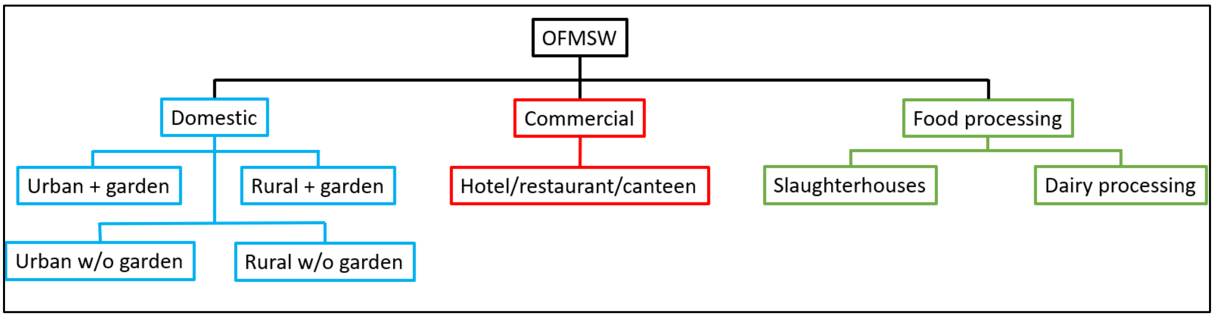

Figure 13 – OFMSW sources.

To estimate the total domestic food waste potential for AD, a similar methodology applied to cattle slurry is used. The total quantity of domestic food waste from Irish households in each ED is estimated using human population data multiplied by estimates of annual waste from individuals in different living settings.

Browne et al. (2014) describes brown bin waste as having different energy contents depending on a rural or urban setting, and whether garden waste is included. In this study, it is assumed that brown bin waste is comprised of both food and garden waste. The 2016 Census from the CSO is the most recent census for human populations for each ED in Ireland. The CSO are due to complete a census in 2021 (results due in second half of 2022), however the 2016 figures are the most recently available for resolution at an ED level. To compensate for population changes from 2016 to 2020, the data is adjusted upwards by a factor of 1.037 (population of Ireland was 4,757,976 in 2016, increasing to 4,937,786 in 2020).

The ED based evaluation of domestic food waste intends to inform of the theoretical maximum potential of domestic waste rather than the practical available material. Correspondence with local authorities and waste management administration bodies (EPA, NWCPO) is necessary to infer more realistic estimates of domestic waste for AD, with waste from commercial premises (hotels, restaurants, canteens) analysed alongside domestic portions.

For food processing waste, licenced dairy processing facilities and slaughterhouses are obliged to report waste streams to the EPA through AER submissions. Samples of typical waste reporting formats in EPA AER for slaughterhouses and dairy processing facilities are shown in Figure 14 and Figure 15 respectively, with details on the facility name, waste handler, and disposer removed. European Waste Catalogue (EWC) codes are key towards understanding the nature of waste generated at such facilities; a further discussion of same is provided in following sections.

5. ONSITE TREATMENT & OFFSITE TRANSFERS OF WASTE

Please enter all quantities on this sheet in Tonnes

Transfer Destination	European Waste Code	Hazardous	Quantity (Tonnes per Year)	Description of Waste	Waste Treatment Operation	Method Used: M/C/E	Method Used: Method Used	Location of Treatment	Haz Waste : Name and Licence/Permit No of Next Destination Facility Non Haz Waste: Name and Licence/Permit No of Recover/Disposer	Haz Waste : Address of Next Destination Facility Non Haz Waste: Address of Recover/Disposer
Within the Country	02 02 02	No	1231.3	animal-tissue waste	R13	M	Weighed	Offsite in Ireland		
Within the Country	02 02 02	No	475.64	animal-tissue waste	R13	M	Weighed	Offsite in Ireland		
Within the Country	02 02 03	No	7087.36	materials unsuitable for consumption or processing	R13	M	Weighed	Offsite in Ireland		
Within the Country	02 02 03	No	804.0	materials unsuitable for consumption or processing	R3	E	Volume Calculation	Offsite in Ireland		
Within the Country	02 02 04	No	1416.0	sludges from on-site effluent treatment	R3	E	Volume Calculation	Offsite in Ireland		
Within the Country	15 01 01	No	19.36	paper and cardboard packaging	R3	M	Weighed	Offsite in Ireland		
Within the Country	15 01 02	No	2.63	plastic packaging	R3	M	Weighed	Offsite in Ireland		

Figure 14 - Sample EPA AER outlining waste materials from a slaughterhouse facility.

5. ONSITE TREATMENT & OFFSITE TRANSFERS OF WASTE

Please enter all quantities on this sheet in Tonnes

Transfer Destination	European Waste Code	Hazardous	Quantity (Tonnes per Year)	Description of Waste	Waste Treatment Operation	Method Used: M/C/E	Method Used: Method Used	Location of Treatment	Haz Waste : Name and Licence/Permit No of Next Destination Facility Non Haz Waste: Name and Licence/Permit No of Recover/Disposer	Haz Waste : Address of Next Destination Facility Non Haz Waste: Address of Recover/Disposer
Within the Country	02 05 02	No	2460.4	sludges from on-site effluent treatment	R10	M	Weighed	Offsite in Ireland		
Within the Country	13 07 01	Yes	0.5	fuel oil and diesel	R9	M	Weighed	Offsite in Ireland		
To Other Countries	15 01 01	No	3.901	paper and cardboard packaging	R3	M	Weighed	Abroad		
To Other Countries	15 01 02	No	1.82	plastic packaging	R3	M	Weighed	Abroad		
Within the Country	16 02 16	No	1.025	components removed from discarded equipment other than those mentioned in 16 02 15	R4	M	Weighed	Offsite in Ireland		
Within the Country	20 01 21	Yes	0.071	fluorescent tubes and other mercury-containing waste	R4	M	Weighed	Offsite in Ireland		

Figure 15 **- Sample EPA AER outlining waste materials from a dairy processing facility.**

3.4.2 Characteristics

Domestic & Commercial Waste

The energy content of food waste varies substantially due to the nature of waste (domestic, commercial, food processing), with large variations in volatile solids content also observed. For rural domestic brown bin waste with a combination of food and garden waste, the energy content is 2.7 MJ/kg, in an urban setting this is 2.0 MJ/kg (Browne et al., 2014). For this study, brown bin waste is assumed as containing both food and garden waste. Data from

Browne et al. (2014) is used for the energetic properties of OFMSW. In this study, commercial waste takes the values of domestic waste.

Table 19 - Energetic properties of domestic brown bin waste (food & garden).

Total solids (% wwt)	33.4% (rural), 25.7% (urban)
Volatile solids (% wwt)	27.5% (rural), 18.9% (urban)
Methane content (m³/kg VS)	0.264 (rural), 0.216 (urban)
Calorific content (MJ/kg)	2.6 (rural), 2.0 (urban)
Methane vol. in biogas (%)	60% (rural and urban)

The following values are assumed in the study for the chemical composition of domestic brown bin waste;

Table 20 - Chemical properties of domestic brown bin waste (food & garden).

pH	7.90 (rural and urban)
Nitrogen (N, kg/m^3)	8.08 (rural), 10.13 (urban)
Phosphorous (P, kg/m^3)	0.67 (rural and urban)
Potassium (K, kg/m^3)	1.40 (rural and urban)
Ammonium N (NH_4-N, kg/m^3)	4.3 (rural and urban)
C:N ratio	16:1 (rural and urban)
Fertiliser replacement value (€/m^3)	17 (assume similar to layers)

Food Processing Facilities

The main source of waste in slaughterhouse is derived from the faeces, urine, blood, lint, fat carcasses, non-digested food in the intestines of the slaughtered animals, the production leftovers and the cleaning of the facilities (Bustillo-Lecompte et al., 2015). EPA AER from Irish facilities record several waste streams, with organic material applicable under animal-tissue waste (EWC: 02 02 02), materials unsuitable for consumption or processing (EWC: 02 02 03), sludges from on-site effluent treatment (EWC: 02 02 04) and wastes not otherwise specified (EWC: 02 02 99). Upon inspection of the treatment type and treatment agent in the EPA AER, animal-tissue waste (EWC: 02 02 02) is generally removed off-site by a proteins company engaged in material rendering to meat and bone meal; it is therefore assumed that this material is unavailable for AD given its existing value for rendering companies, and difficulty in processing material such as bone for AD. Waste recorded under EWC: 02 02 03 and EWC: 02 02 04 is considered in this study.

For materials suitable for AD, Browne et al. (2013) describes slaughterhouse waste in Irish facilities as being typically composed of paunch grass, green sludge, and dewatered activated sludge (DAS) from WWTP. In some cases, paunch grass and sludge from WWTP are reported separately in EPA AER, using EWC codes EWC: 02 02 03 and EWC: 02 02 04 respectively. It is therefore possible to estimate the energy content of paunch grass using a value of 1.34 MJ/kg for facilities that explicitly define waste quantities for EWC: 02 02 03 (Browne et al., 2013). For instances where there is no reference to paunch grass (EWC: 02 02 03), it is likely that the material has been included under another EWC code; for simplicity it is assumed that no paunch grass is available from the facility. For WWTP sludge, there is no reference in the AER for the proportions of green sludge and DAS that make up the composition; Browne et al. (2013) states that green sludge and DAS represents 32% of the WWTP sludge volume, while DAS represents the remaining 68%. Green sludge has an energy content of 2.6 MJ/kg, and DAS has an energy content of 0.6 MJ/kg; these figures are weighted against their respective proportions to return an averaged calorific value of 1.27 MJ/kg for WWTP sludge. The energetic properties of slaughterhouse waste are presented in Table 21, with data from Browne et al. (2013), O'Shea et al. (2016), and BORRG.

Table 21 - Energetic properties of slaughterhouse waste.

Total solids (% wwt)	13.70% (paunch and WWTP sludge)
Volatile solids (% wwt)	10.96% (paunch and WWTP sludge)
Methane content (m^3/kg VS)	0.34 (paunch), 0.32 (WWTP sludge)
Calorific content (MJ/kg)	1.34 (paunch), 1.27 (WWTP sludge)
Methane vol. in biogas (%)	60% (paunch and WWTP sludge)

Details on the chemical composition of slaughterhouse waste is taken from Browne et al. (2013) and BORRG;

Table 22 - Chemical properties of slaughterhouse waste.

Nitrogen (N, kg/m^3)	2.8 (paunch), 5.38 (WWTP sludge)
Phosphorous (P, kg/m^3)	0.273 (paunch and WWTP sludge)
Potassium (K, kg/m^3)	0.78 (paunch and WWTP sludge)
Ammonium N (NH_4-N, kg/m^3)	1.4 (paunch), 2.7 (WWTP sludge)
C:N ratio	16.6:1 (paunch) 10.4:1 (WWTP sludge)
Fertiliser replacement value (€/m^3)	4.29

Most dairy processing facilities in Ireland rely upon aerobic wastewater treatment plants (WWTP) to manage waste by-products from a variety of dairy products and utilise standard secondary treatment technique such as bio-towers and activated sludge aeration (Ryan and Walsh, 2012). According to Teagasc, dairy processing sludge from these facilities is applied to agricultural land as an organic fertiliser for crop production while the wastewater is treated in a water treatment plant.

Browne et al. (2013) measured the energy content of sludge waste from a cheese processing facility. Biologically treated effluent represents 83.3% of the total sludge content, while the remaining 16.7% comprised of dissolved air flotation (DAF). For simplicity, these proportions are assumed representative of dairy processing facilities in Ireland. The energy contents of these materials are 1.26 MJ/kg and 1.93 MJ/kg respectively. These figures are weighted against their respective proportions to return an averaged calorific value of 1.37 MJ/kg for dairy processing sludge. The aggregated energy content is assumed representative of waste streams reported under EWC: 02 05 02 (sludges from on-site effluent treatment). Data from Browne et al. (2013) and BORRG is used for energetic properties.

Table 23 - Energetic properties of dairy processing waste.

Total solids (% wwt)	9.13%
Volatile solids (% wwt)	7.46%
Methane content (m^3/kg VS)	0.38
Calorific content (MJ/kg)	1.37
Methane vol. in biogas (%)	60%

Details on the chemical composition of dairy processing waste is taken from Browne et al. (2013) and Teagasc.

Table 24 - Chemical properties of dairy processing waste.

Nitrogen (N, kg/m^3)	4.90
Phosphorous (P, kg/m^3)	3.35
Potassium (K, kg/m^3)	0.66
Ammonium N (NH_4-N, kg/m^3)	2.45
C:N ratio	14.8:1
Fertiliser replacement value (€/m^3)	7

3.4.3 Quantity and Availability

Domestic & Commercial Waste

The quantity of brown bin waste from each electoral division is estimated using the population (kg per head [kg/hd]) of each multiplied by an estimated annual waste volume for food and garden waste based on the living setting type. Cré, the Composting and Anaerobic Digestion Association of Ireland, provides estimates on the different food and garden waste volumes on an annual basis from individuals in urban, city, and rural settings.

Table 25 - Food and garden waste quantities from individuals.

Waste type	Quantity (kg/hd a)
City food waste	42
Rural food waste	81
Urban food waste	88
City garden waste	33
Rural garden waste	60
Urban garden waste	74

The living setting for each electoral division is determined using the following criteria;

- City living settings are determined based on the structure of the raw CSO data for Dublin, Cork, Galway, Limerick and Waterford. For Cavan and Monaghan, city data is not applicable.
- If the name of the electoral division contains the word “Urban”, an urban living setting is assumed.
- For all other electoral divisions, the separation between urban and rural settings is based on the population; if the population is less than 1,500, a rural setting is assumed, otherwise urban setting is assumed.

Figure 16 and Figure 17 display the theoretical domestic brown bin waste potential in Cavan and Monaghan by quantity and corresponding biomethane potential respectively

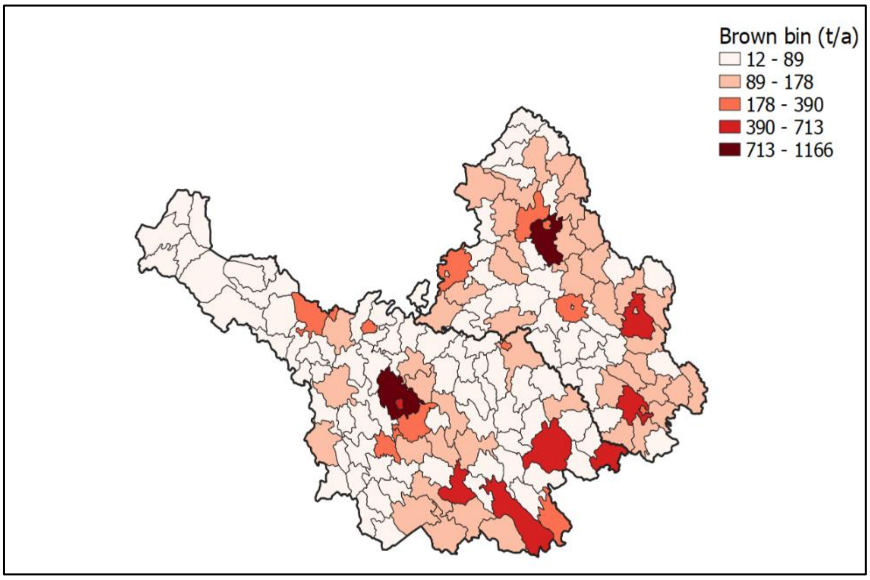

Figure 16 - Theoretical brown bin waste quantity in Cavan and Monaghan (t/a).

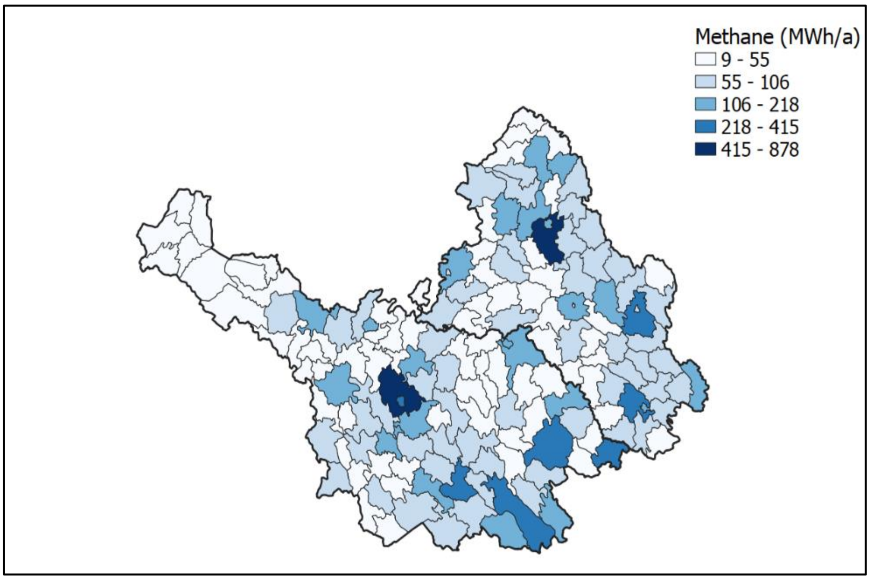

Figure 17 - Theoretical biomethane potential from domestic brown bin waste in Cavan and Monaghan (MWh/a).

The quantity of domestic brown bin waste is concentrated towards the main population centres in the region, as per the model structure. Use of CSO population data provides a high-level estimate of the theoretical potential for food waste as a feedstock for AD; however, this approach represents an idealised scenario where all residential food waste in Ireland is assumed to be available for AD via kerb-side brown bin collection by licenced waste management companies, and appropriate behaviour from all households. Comparing this data to figures released by the EPA, such an assumption misrepresents the current situation with household food waste; organic brown bin waste represents 9% of the total household waste (325 kg/hd/a in 2018), with over 60% of organic waste placed in the incorrect bin (black for residual waste, and green for recycling). Only 43% of Irish households have access to a brown bin. Capturing food waste from households as a feedstock for AD at a large scale will require changes in current food waste collection systems and behaviour/attitudes from individuals towards appropriately segregating waste at the point of disposal.

Correspondence with waste management personnel in Cavan County Council, Monaghan County Council, EPA, and NWCPO is used to ascertain more detailed information on the quantity and availability of OFMSW from domestic and commercial organic waste collection. According to those contacted, the level of brown bin usage in both counties is low compared to national trends. This information is supported by EPA Household Waste Statistics. In 2018, the total brown bin waste collected in Co. Cavan was 108 t and 364 t in Co. Monaghan. Following correspondence with the NWCPO, a dataset for household kerbside waste and non-household waste collected in 2019 by licenced waste management operators has been provided for this study. The dataset includes information on waste collection licence area (county), waste tonnage and the destination facility. EWC: 20 01 08 (biodegradable kitchen and canteen waste) describes all material reported; all material is therefore suitable for AD and is representative of domestic and commercial waste collected in the area. Across Ireland, in 2019, a total of 93,956 t and 159,389 t of kerbside domestic waste and non-household commercial waste respectively was collected. In 2019, Co. Cavan, kerbside household waste amounted to 30.5 t whilst in Co. Monaghan 844 t was collected; totalling 874.5 t between both counties which was distributed amongst 7 licenced waste management companies.

For non-household waste (commercial), Co. Cavan generated a total of 579 t of collected waste in 2019 whilst Co. Monaghan generated 1,550 t; totalling 2,129 t between both counties. This was distributed amongst 9 licenced waste management companies. The NWCPO figures indicate a higher volume of food waste collected from household brown bins than that reported by the EPA, with significantly more waste available from commercial collections. Just over 3,000 t/a was collected between both counties in 2019, amounting to a biomethane potential of 2,170 MWh/a, using modelled estimates. The volumes of waste collected in Cavan and Monaghan are relatively minor compared to the rest of the country. Food waste volumes in this region accounts for under 0.25 MW capacity (gas), meaning that it will form a relatively minor part of the overall feedstock mix for a commercial-scale plant (>3 MW). Additionally, the material must also be sourced from 12 different licenced waste handlers, with competition for waste from existing AD facilities in Northern Ireland and other treatment options (rendering, composting etc.) is likely to be present. Given the relatively minor impact that this quantity of food waste will have on AD operations, and sourcing issues, domestic and commercial sources of OFMSW is excluded from further analysis in this feasibility study.

Food Processing Facilities

Licenced slaughterhouses are obliged to report waste streams to the EPA through AER submissions. Due to the diverse nature of techniques applied and materials processed in slaughterhouses, the nature of waste material and reporting methods can vary substantially between facilities. EWC codes are therefore consulted to provide clarity as to what quantities of materials are potentially suitable for AD with non-biological waste categories (cardboard, plastics, metals etc.) ignored. The EWC codes listed in the database include:

- EWC: 02 02 02 – animal tissue waste
- EWC: 02 02 03 – materials unsuitable for consumption or processing
- EWC: 02 02 04 – sludges from on-site effluent treatment
- EWC: 02 02 99 – waste not otherwise specified

Waste described under EWC: 02 02 03 and EWC: 02 02 04 is considered suitable for AD in this study.

Licenced dairy processing facilities are also obliged to report waste streams to the EPA through AER submissions. Similar to the slaughterhouse data, EWC codes are consulted for dairy processing facilities.

- EWC: 02 05 01 – materials unsuitable for consumption or processing
- EWC: 02 05 02 – sludges from on-site effluent treatment
- EWC: 02 05 99 – wastes not otherwise specified

Waste described under EWC: 02 05 02 is considered suitable for AD in this study. Figure 18 displays the location and waste quantity yielded by slaughterhouse facilities and dairy processing facilities in Cavan and Monaghan with Figure 19 displaying the corresponding biomethane potential.

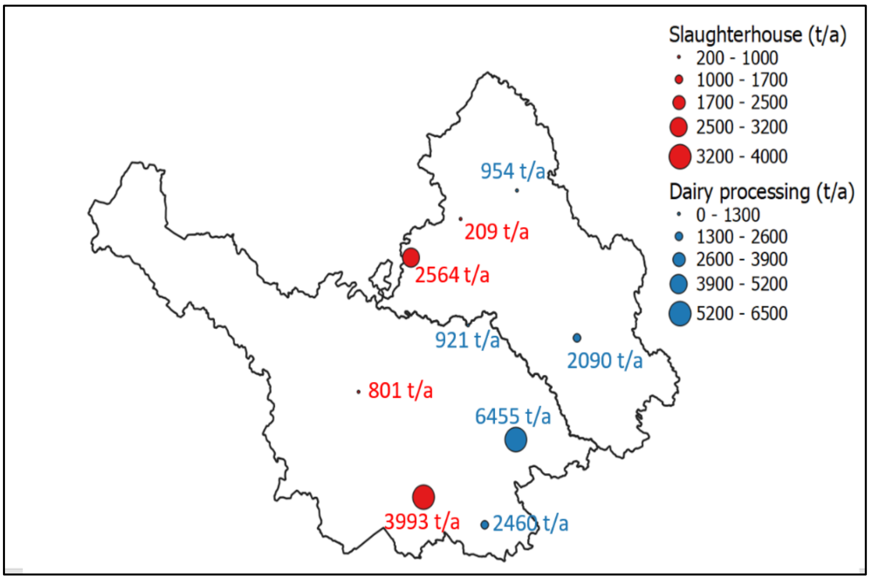

Figure 18 - Slaughterhouse and Dairy processing waste in Cavan and Monaghan (t/a).

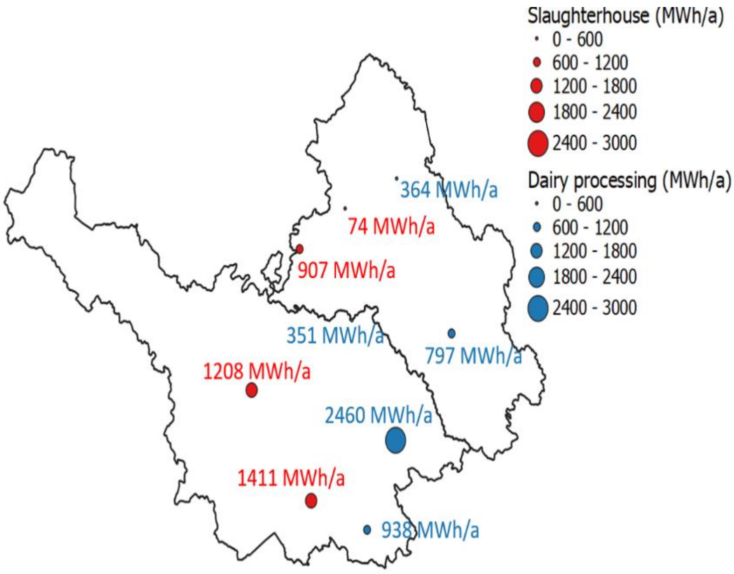

Figure 19 - Biomethane potential from slaughterhouse and dairy processing waste in Cavan and Monaghan (MWh/a).

In Co. Cavan, there are 2 no. slaughterhouse facilities and 3 no. dairy processing facilities reporting waste via EPA AERs deemed suitable for AD. In Co. Monaghan, there are 2 no. slaughterhouse-facilities and 2 dairy processing facilities reporting waste in EPA AER deemed suitable for AD. There are 7 no. slaughterhouse facilities collectively located in nearby counties Longford, Meath, and Westmeath; these facilities may be considered in plant design phases of the project but are excluded from the feedstock analysis which focuses exclusively on waste in Cavan and Monaghan. There is a cumulative 7,567 t/a of slaughterhouse waste between both counties, amounting to 3.6 GWh of biomethane potential. For dairy processing facilities, there is a total of 12,880 t/a waste resulting in 4.9 GWh of biomethane potential.

3.5 Grass Silage

Across mainland Europe, energy crops have served as a vital feedstock for the growth of the European biogas industry over the past 20 years. Although there is a wide variety of crops applicable to AD, maize silage has become the predominant energy crop in European AD plants due to its cost-effectiveness, high energy content, and low moisture content relative to other agricultural feedstocks that lends favourably to AD project economics. Maize is currently not an optimal energy crop for AD in Ireland due to climatic constraints; only 16,600 ha of farmland was dedicated to maize production in 2019 (< 0.4%). Instead, grass silage is seen as a more optimal option for the Irish biogas Industry.

Irish agriculture has traditionally been characterised by extensive grass-based farming systems due to a wet and mild climate and relies heavily on ruminant livestock farming. Grassland represents the most significant resource for biomass in Ireland, accounting for over 90% of agricultural land; 4.2 million ha of grassland from 4.5 million ha of total farmland. Of this grassland area, 57%, 26%, 13%, and 4% is devoted to pasture, silage, rough grazing and hay, respectively. Rough grazing includes grazed unreclaimable bogland, and grazed mountain and lowland partially covered in scrub, bushes, or rock (McEniry et al., 2013). According to Teagasc, over 85% of Irish farms grow grass silage every year. Grass silage is normally used as a feed for cattle and sheep, however, it also has potential for use in AD given the capacity for growth in Ireland, high energy and low moisture contents.

Crops dedicated to the production of biogas are subject to ongoing discussions about environmental efficiency and ethics with regards to competition for food production. The cultivation and harvesting of energy crops require resources, generates CO_2 emissions, and may lead to direct and indirect land use change. Hence, future biogas systems should limit the use of crops to those which do not directly compete with food production and generate specific added environmental values, such as fostering biodiversity and soil fertility. Grass silage is considered as a potential feedstock for AD in the Border Region given its favourable properties for biogas production, and significance as the main foodstuff behind the Irish agricultural industry.

However, it should be noted that unlike the other feedstocks mentioned in this study, the RED II does not allocate CO_2 emission bonuses to silage. Consequentially, AD plants cannot use silage as the main feedstock and qualify as a renewable gas, the plant GHG savings cannot attain the 80% target set by RED II for plants operating after 2026. Further details on RED II GHG savings are in section 3.6 and further details on grass silage emissions are presented in section 3.6.5.

3.5.1 Source

There is no direct source of information on grass silage availability for AD. Instead, the total quantity of grass silage grown in each electoral division is estimated using information from the 2010 Census of Agriculture for grass land dedicated to silage production, combined with Teagasc data on grass growth throughout the country. The area under pasture and rough grazing was not included in the analysis.

Teagasc data on grass silage consumption for ruminants (cattle and sheep) is then used to estimate total feed requirements via animal populations in each electoral division. Finally, the excess silage in each electoral division available for possible AD is calculated by subtracting the animal requirement from estimates of grass silage growth.

It is difficult to estimate nationwide availability of grass silage based on a number of factors, not least due to significant variation in annual yields and the increasing national herd that has led to fodder shortages in recent years. The grass silage dataset is not intended to provide accurate information on the availability of grass silage for AD, rather details on locations where it may be sourced based on agricultural census data. At the plant design phase, more rigorous research into specific and reliable sources of grass silage will be required if this feedstock stream is to be utilised.

3.5.2 Characteristics

The composition of grass silage depends on a variety of factors, including grass species, fertiliser application, soil type, seasonal weather conditions, and ensiling practices. Perennial ryegrass, Italian ryegrass, and white clover account for nearly all of the agricultural grass/clover seed sold in Ireland (Teagasc). Of these, perennial ryegrass is by far the most significant, accounting for 95% of grass seed sold in Ireland. According to various literature sources, solids content varies between ~20-30%, volatile solids is ~85-90%TS, biomethane content ranges from ~0.3-0.4 m^3/kg VS, resulting in a calorific content of ~2.5-3.5 MJ/kg. As with all feedstocks, a biomass analysis is recommended for specific feedstock types prior to development of a biogas plant once specific sources have been identified. In this study, data from BORRG and Teagasc is used to define energetic properties of grass silage.

Table 26 - Energetic properties of grass silage.

Total solids (% wwt)	28.3%
Volatile solids (% wwt)	25.2%
Methane content (m^3/kg VS)	0.33
Calorific content (MJ/kg)	3.01
Methane vol. in biogas (%)	60%

The following values are assumed in the study for the chemical composition of grass silage, from BORRG, Teagasc and Murphy et al. (2011);

Table 27 - Chemical properties of grass silage.

pH	4.0
Nitrogen (N, kg/m^3)	3.78
Phosphorous (P, kg/m^3)	0.72
Potassium (K, kg/m^3)	6.08
Ammonium N (NH_4-N, kg/m^3)	1.89
C:N ratio	26:1
Fertiliser replacement value (€/m^3)	7.8

3.5.3 Quantity and Availability

The 2010 Census of Agriculture provides data on the amount of land (ha) in each electoral division dedicated to grass silage, hay and pasture. Only land dedicated to grass silage is considered for the study.

Grass silage is typically harvested in Ireland in one or two cuts per annum. According to O'Donovan et al. (2011), approx. 79% of silage land falls into the one cut category, with the remaining 21% falling under the two-cut category. Less than 1% of land undergoes three cuts per annum and is therefore assumed negligible. McEniry et al. (2013) provides maximum grass yield data for grassland under typical nitrates application; 9.8 tDM/ha and 10.51 tDM/ha for one and two cuts respectively. In the above, tDM/ha represents tonnes of dry matter yield per hectare; to determine the total grass yield, these figures are divided by 28.3%, which is the assumed dry matter content of grass silage. Grass yields will not be at the maximum levels quoted above due to different agricultural practices and soil groups across the country. McEniry et al. (2013) provides estimates on grass yield as a function of the maximum possible yield in a particular soil group; 85% for soil group 1, 80% for soil group 2, and 70% for soil group 3. According to Teagasc, 47.85% of Irish grassland falls under soil group 1, 44.75% falls under soil group 2, and 7.4% falls under soil group 3. Soil group 1 can grow the largest range of crops with few limitations, while soil group 3 has a limited use range. No data could be ascertained on the spatial distribution of these soil group categories throughout Ireland; it is therefore assumed that all electoral divisions are representative of the national average. The authors recognise that averaging growth rates and soil group types across a region is a potential weakness for the spatial analysis, however in the absence of more accurate information it is necessary to evaluate possible sources of grass silage if utilised for AD.

Animal feed requirements are calculated using average annual grass requirements for different cattle and sheep types, then subtracted from the total grass silage grown. O'Mara (2006) summarises silage intake requirements in kgDM/hd/a across different regions (south and east, west and midlands, and north-west), for different cattle types, focusing on housing periods for dairy and suckler cattle during calving seasons. The silage requirement data used in this study is calculated using figures from O'Mara (2006) for the north-west region, then divided by a factor of 0.7 and 0.65 to reflect dry matter digestibility for dairy and suckler cattle respectively (0.7 kg/kgDM, 0.65 kg/kgDM). McEniry et al. (2013) provides data in kgDM/hd/a for bulls, younger cattle, and a variety of sheep types using nationwide averages, assuming a utilisation rate of 0.73 kg/kgDM. The total grass consumption requirements for the different ruminant types are summarised in Table 28.

Table 28 - Ruminant grass silage consumption.

Animal type	Consumption (kgDM/hd/a)
Dairy cow	1,939
Suckler cow	1,764
Bulls	1,738
Younger cattle	720
Ewe	89
Ram	80
Younger sheep	80

The method behind estimating the cattle populations in each electoral division is described in section 3.1.3 for cattle slurry as a feedstock source and a similar method is applied for estimating sheep populations. Sheep manure has not been included for as a potential feedstock material in this study. Sheep are not generally housed for prolonged periods in Ireland, making it impractical to collect meaningful quantities of the substrate.

Finally, excess grass silage for each electoral division is calculated by subtracting feed requirements from yield estimates. To ensure a conservative estimate, 15% grass silage waste is assumed (Agriland, 2019). Figure 20 displays the corresponding of excess grass silage across the EDs (t/a) whilst Figure 21 displays the corresponding methane potential (MWh/a) assuming 100% availability and digestion efficiency.

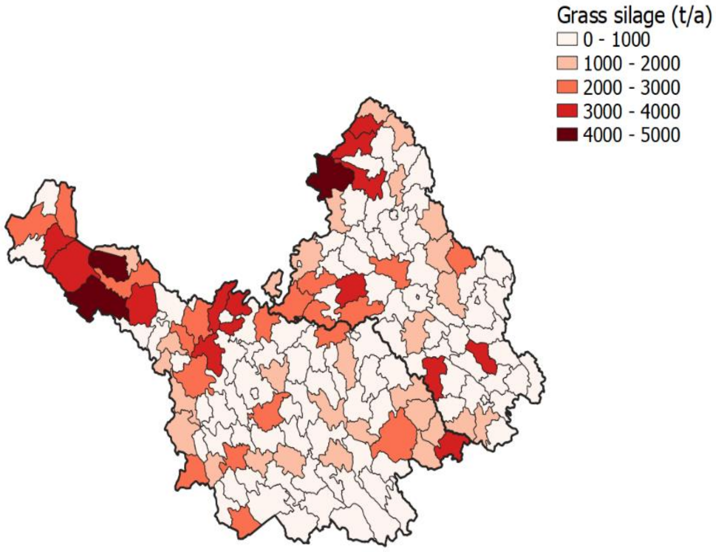

Figure 20 - Excess grass silage quantity in Cavan and Monaghan (t/a).

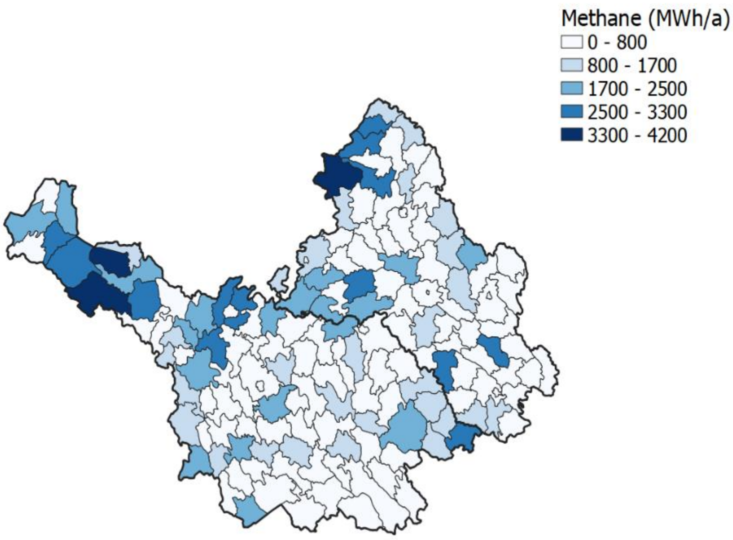

Figure 21 - Biomethane potential from excess grass silage in Cavan and Monaghan (MWh/a).

Between Cavan and Monaghan, there is a cumulative excess grass quantity of 237,224 t/a which yields 198 GWh of biomethane. This accounts for over 11% of the total grass silage growth in the region. In some EDs, the excess grass silage reaches a negative value due to animal feed requirements exceeding the estimated silage production. Negative values are set to zero to communicate the distribution of potential grass silage sources in the thematic maps of Figure 21, however, negative values are factored in the total feedstock and biomethane values reported above as it is assumed that excess grass from neighbouring EDs supplement those with any shortages. Excess grass silage is concentrated towards different regions of Cavan and Monaghan with shortages noted in mid to southern Cavan and mid-Monaghan.

There is some difficulty in estimating grass silage availability on a broad scale using grass growth estimates from literature and animal populations, as details such as up to date animal populations and land dedicated to silage growth, farm-specific grass yields and farming practices, and possible sourcing of feed elsewhere becomes lost. For example, the thematic maps indicate significant levels of grass silage in the North-Western corner of Co. Cavan, however this region is characterised by peatland and mountainous ground, meaning grass growth estimates in this region are likely overestimated. However, the above model is indicative of potential sources of excess grass silage for AD, which feeds into the basis of design. If grass silage is to be utilised in an AD project, available quantities from specific sources will have to be verified; this should be done at later stages of project development.

The cost of grass silage is assumed as 30 €/t; this is in line with prices assumed by the Renewable Gas Forum Ireland (RGFI) for grass silage analysis in AD, and the median of estimates from other sources (~20-40 €/t). Such a high cost for feedstock presents a barrier for achieving economic viability with a grass-based AD project, with instability in the market also creating long-term uncertainty. Furthermore, some financial incentives for AD are not as attractive for energy crops compared to manures and other waste classified materials; the Renewable Transport Fuel Obligation (RTFO) in the UK awards half the credits for biomethane derived from the digestion of energy crops versus waste residues, see section 3.6.5 for further details.

When considering grass silage as a potential feedstock for AD, the 'Food versus Fuel' debate and other farm concerns must be considered, such as seasonal drought potential and nitrates regulations inhibiting yield potential, as well as a growing national herd and standards on ruminant diets that affect grass requirements for consumption. Bord Bia operate a series of quality assurance schemes which cover both primary production and processing for a variety of agricultural sectors, including beef and dairy. New 'Grass Fed' standards could further restrict the amount of grass available for AD; grass must comprise at least 90% of the diet of beef cattle, and 95% for dairy cattle. To keep in line with the bioeconomy principles, avoid carbon-intensive grass growth and ensure circularity, grass silage must always be prioritised for animal feed before fuel.

Incentives in the grass systems are required to encourage farmers to use surplus grass silage for AD, in particular for the beef sector which is significantly more vulnerable than the dairy sector in terms of farm income and margin. There is potential to substantially increase the amount of grass silage that could be available as an AD feedstock through better grass production and management practices such as Grass 10 from Teagasc and the 3 step Soil Improvement Programme from Devenish.

3.6 Sustainability of Feedstock Streams

The recast Renewable Energy Directive 2018 (RED II, 2018/2001/EU) is a binding legal framework that sets out mandatory sustainability criteria for renewable energy projects operating in the EU including biogas plants. If the carbon savings from a biogas project is to contribute towards a member states decarbonisation target and in turn receive government support, the plant must adhere to minimum GHG savings targets relative to fossil fuel equivalents. Rules of the RED II are therefore adopted by the technoeconomic model as the default sustainability criteria for future biogas plants in Ireland with plant configurations that fail to meet RED II targets excluded from further development.

The RED II outlines mandatory sustainability targets over traditional energy sources in units of gCO_2/MJ and a model for evaluating the life cycle emissions from biogas projects. The life cycle analysis (LCA) is broken into two parts; emissions associated with individual feedstock streams and emissions associated with plants operations. In this section, emissions associated with individual feedstock streams, to the point where they are accepted by the biogas plant, are presented; emissions calculations associated with feedstock processing and biogas plant operations are discussed later in the report.

3.6.1 GHG model of Feedstocks

Annex VI of the RED II provides rules for calculating GHG impact of biomass substrates and mixtures and how they compare to fossil fuel comparators in terms of gCO_2 per MJ of useful energy produced. Section A provides typical and default values for GHG impact of generic substrates and mixtures. Section B describes the methodology for calculating GHG impact for substrate mixtures; given the unique nature of feedstocks available to the Border Region and the strong likelihood of co-substrates making up the feedstock mixture, bespoke calculations are deemed more appropriate than assuming default/typical values for generic mixtures that are largely based on continental biogas projects. More specifically, Annex VI Section B Subsection C is used with GHG emissions calculated from the following equation:

$$GHG = \sum_{1}^{n} S_n \times \left(e_{c,n} + e_{t,n} + e_{l,n} - e_{save}\right) + e_p + e_{t,prod} - e_{css} - e_{ccr}$$

- GHG =total emissions from the production of the biogas or biomethane before final energy conversion in gCO_2/MJ
- S_n =Share of feedstock n, as a fraction of the contribution to the total energy content of the feedstock mixture (%)
- $e_{c,n}$ =emissions from the extraction or cultivation of feedstock n
- $e_{t,,n}$ =emissions from transport of feedstock n to the digester
- $e_{l,n}$ =annualised emissions from carbon stock changes caused by land-use change, for feedstock n
- e_{save} =emission savings from improved agricultural management of feedstock
- e_p =emissions from processing
- $e_{t,prod}$ =emissions from transport and distribution of biogas and/or biomethane;
- e_u =emissions from the fuel in use, that is greenhouse gases emitted during combustion
- e_{ccs} =emission savings from CO_2 capture and geological storage
- e_{ccr} =emission savings from CO_2 capture and replacement.

The share of energy content (S_n) is calculated using the following:

$$S_n = \frac{P_n \times I_n}{\sum_{1}^{n} P_n \times I_n}$$

Where P_n is the energy content of feedstock n in MJ/kg of wet feedstock and I_n represents the proportion of each individual feedstock in the total mixture by weight (%). The energy content of each feedstock is adjusted based on the volatile solids destruction (VSD) which effectively represents the efficiency of the digestion process to extract the total available energy from the feedstocks (typically 80-90%).

Calculations of the remaining parameters in the GHG equation varies between each feedstock stream. Emissions from the extraction or cultivation of feedstock and land use change, $e_{c,n}$ and $e_{l,n}$, is assumed negligible for agriculture manures and other waste materials such as brown bin waste, dairy processing waste and slaughterhouse waste. No CO_2 capture/storage is assumed, meaning e_{ccs} and e_{ccr} are excluded from the calculation.

3.6.2 Transport Emissions

Emissions due to transport is common to the sustainability contribution across all feedstock streams. These emissions represent those from fuel combusted by trucks/tractors in delivering feedstock to the biogas plant. It is assumed that HGV trucks will be used to transport feedstocks to site, which have a specific diesel consumption of 2.66 MJ/t km (i.e.

energy required to move 1 tonne over 1 km). This figure is derived from fuel consumption data presented by SEAI for transport in Ireland (SEAI 2020), with the total diesel energy requirement in MJ evaluated using the payload in t and the transport distance in km. The empty journey to collect feedstocks is also considered, using an unladen fuel consumption value of 8.44 MJ/km. The CO_2 intensity for diesel is taken as 73.3 gCO_2/MJ (SEAI, 2019). For every kg of raw feedstock transported (accounting for full and unladen HGV journey), the carbon emissions are 0.3801 gCO_2/kg. The gCO_2/MJ can then be evaluated using the calorific value of each feedstock, in MJ/kg, multiplied by the gCO_2/kg value, multiplied by the km travelled. Feedstocks with a high energy density, such as grass silage, OFMSW, and poultry manure, will generate lower CO_2 emissions due to a higher energy yield per kg transported; this is demonstrated in figure 22

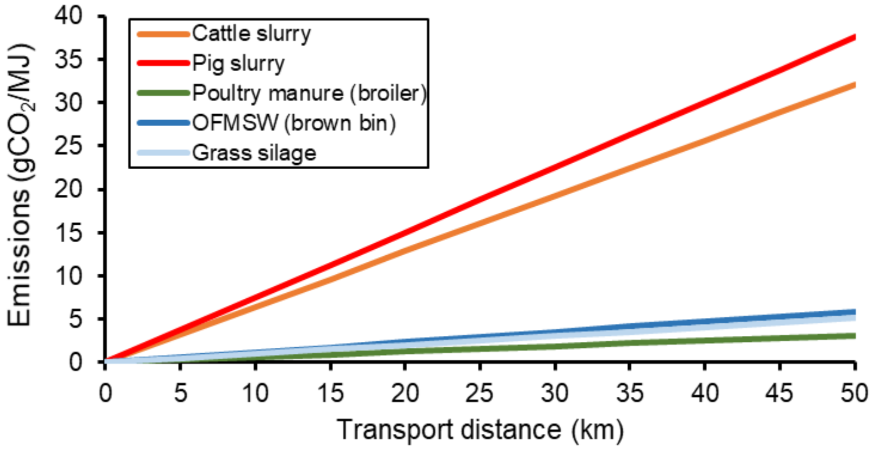

Figure 22 - Specific GHG emissions for feedstock transportation.

3.6.3 Agricultural Manure Emissions

For agriculture manures/slurries, specifically cattle manures, pig slurry and poultry manure, GHG emissions are derived from those due to feedstock transport plus credits from emissions saved due to improved manure management.

When manure is stored on farms prior to land-spreading, it releases gases in the atmosphere as a result of bacterial activity. Methane is the main gas released by manure decomposition but also nitrogen compounds such as N_2O, NH_3 and nitrogen oxides (NO_x) are released. When the manure is treated by AD, the methane produced is collected as biogas, to be used in CHP or upgraded to biomethane. If the manure was not utilised for biogas production, sub-optimal on-farm manure storage practices (slatted tanks, lagoons, pits, etc.), would cause higher GHG emissions compared to methane removal via AD and subsequent digestate management.

RED II acknowledges the benefit of AD for treating animal manures by assigning a credit for manure use in biogas plants of -45 gCO_2/MJ. This credit will act to minimise the contribution of animal manures to the biogas plant GHG emissions, resulting in a negative emissions value for transportation over short distances. This makes manure an attractive co-substrate with other more energetic feedstocks that have a penalising emissions value such as grass silage. The total GHG emissions impact of agricultural manures is displayed in Figure 23.

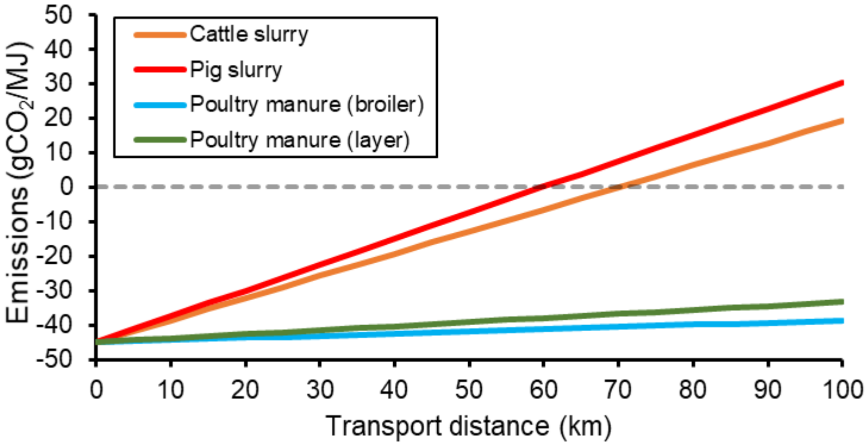

Figure 23 - GHG emissions associated with agricultural manure feedstocks.

3.6.4 OFMSW Emissions

Article 29, Paragraph 1 of the RED II stipulates an exemption for municipal solid waste from RED II sustainability criteria. According to Giuntiolio et al. (2015), this rule is applicable to sewage sludge from wastewater treatment plants with other forms of biowaste (described in Section 2.4) subject to sustainability accounting. There is no credit attached to OFMSW materials in RED II unlike agricultural manures, meaning that emissions are derived solely from feedstock transport. Emissions from the various streams are shown in Figure 24.

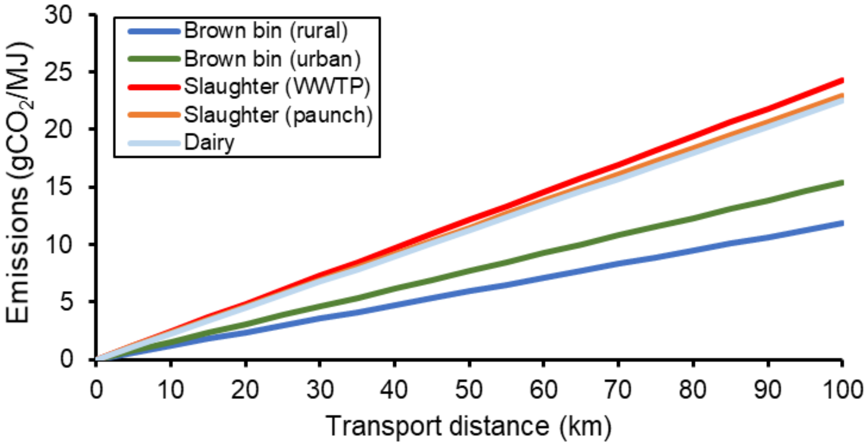

Figure 24 - GHG emissions associated with OFMSW feedstocks.

3.6.5 Grass Silage Emissions

The calculation of GHG emissions for grass silage is the most involved of all feedstock streams as sources of emissions must be tracked across the whole production chain. GHG emissions must be considered for transport (see Section 3.6.2), harvesting and cultivation operations, production and application emissions associated with fertilisers. The calculation of GHG emissions for silage growth is sensitive to a variety of factors that may change significantly between each source of feedstock (likely that different farms will supply grass to the plant), however the model presented in this study is deemed sufficiently accurate to provide a high level estimate for the feasibility study.

For harvesting and cultivation, data from Korres et al. (2010) is used to model emissions from grass seed production, ploughing, sowing, harrowing, rolling, fertiliser spreading that occur only in a re-seeding year, and emissions from silage harvesting, ensiling, and fertiliser spreading that occur every year. It is assumed that land dedicated to silage growth is re-seeded every 8 years, meaning emissions from actions associated with re-seeding are divided by a factor of 8 to obtain annualised emissions that can then be related to grass yields. The energy consumption for agronomic operations is shown in Table 29;

Table 29 - Energy consumption and frequency for agronomic operations.

Operation	Energy consumption (MJ/ha)	Frequency (years)
Ploughing	1,141.7	8
Sowing	148.8	8
Harrowing	238.1	8
Rolling	249.9	1
Fertiliser spreading	154.8	1
Silage harvesting	1,309.0	1
Ensiling	416.0	1

The quantity of fertiliser required for grass silage growth depends on a variety of factors such as the target grass yield, soil quality, P and K soil index, the ratio of inorganic to organic fertiliser, and liming. There are other factors that are difficult to define such as soil drainage, seasonal weather changes, grazing, and farming practices. A comprehensive description of the calculation methodology for fertiliser requirements is beyond the scope of this feasibility study; instead, production emissions for inorganic portions of N-P-K are presented and used to estimate fertiliser production emissions given a typical agricultural scenario. The required fertiliser components are disaggregated in kg/ha requirements for N, P, and K respectively. A target yield of 10 tDM/ha is assumed for grass silage for the calculation of GHG emissions (McEniry et al., 2013). Guidelines from Teagasc for N-P-K application in kg/tDM, nitrate limitations (according to NAP), and soil build up values are then used to calculate the required nutrient quantities for this grass yield scenario. The model assumes soil group 2 (average soil quality), and a P & K soil index of 2 (poor to average quality). For inorganic fertilisers, CO_2 emissions from production can be estimated using nutrient requirements in gCO_2/kg grass. Table 30 displays the production emissions for inorganic fertilisers (including lime emissions).

Table 30 - Fertiliser production emissions (Wells, 2001)

Fertiliser type	Production emissions (kg CO_2/kg Fertiliser)
Nitrogen (N)	3.25
Phosphorous (P)	0.90
Potassium (K)	0.60
Lime	0.43

The nutrient requirement for grass silage growth can be satisfied using inorganic fertilisers only, or through the supplementation of organic fertilisers. For simplicity, it is assumed that grass silage supplies to biogas plants utilise inorganic fertilisers only; this is a conservative estimate as organic fertilisers in the form of animal manures and/or digestate will likely be utilised in farm nutrient recycling plans. For example, applying inorganic fertilisers only results in emissions increase of ~15% compared to using inorganic + organic fertilisers via AD digestate from a 50:50 cattle slurry to grass silage feedstock mixture, with transport over a 5 km distance. More complete GHG accounting for on-farm manure and/or digestate nutrient recycling should be conducted for individual feedstock supply chains once identified at a later stage of plant development.

Lime dissolution emissions are accounted for assuming a yearly application of 1.25 t/ha of $CaCO_3$, and loss of 0.44 $kgCO_2$/kg lime.

Further sources of emissions from the grass silage production chain include direct and indirect N_2O emissions. Chapter 11 of 2006 IPCC Guidelines for National Greenhouse Gas Inventories provides rules and guidelines for estimating these emissions. The Tier 1 method is used; however, a full breakdown of this model is beyond the scope of the feasibility study. Direct N_2O emissions are derived from organic and inorganic N fertiliser spreading, N from grazing animals, N in crop residues, N mineralisation in soil, land use change and draining/management of soils. Indirect N_2O emissions are derived from volatilisation and leaching of N fertilisers.

The reference farming model for grass silage is outlined in Table 31. Figure 25 displays GHG emissions associated with grass silage under the reference farming conditions used in the model, as a function of transportation distance.

Table 31 - Reference farm conditions for grass silage.

Variable	Value
Target grass silage yield	9 tDM/ha
Fertiliser type	Inorganic only
Soil group	1
P soil index	2
K soil index	2

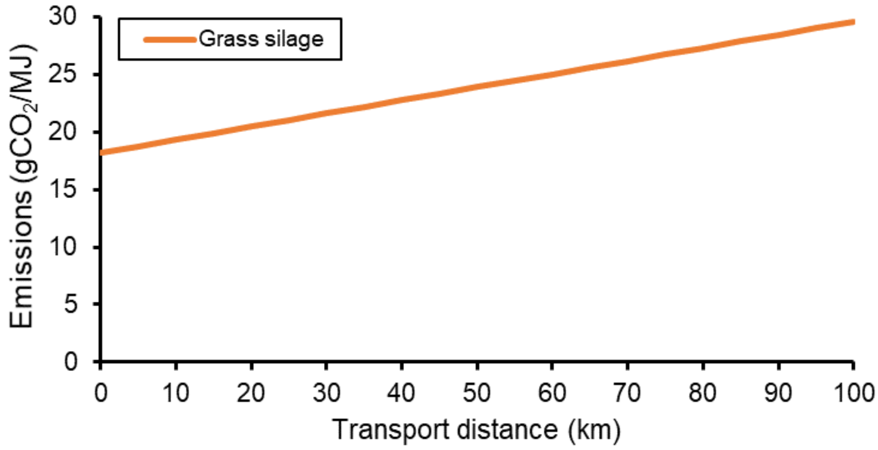

Figure 25 - GHG emissions associated with grass silage (assuming reference farm conditions).

3.7 ABP Regulations

The ineffective treatment of waste animal materials such as animal manures, sludges, food waste, food production waste or slaughterhouse waste may lead to the spread of diseases such as BSE and foot and mouth disease which can be devastating to agriculture and agri-food industries. As these materials act as feedstocks for AD plants, animal by-product (ABP) regulations are enforced by the Department of Agriculture, Food and Marine (DAFM) to ensure correct handling prior to removal from the plant as digestate. The regulations can be found in DAFM "Approval and operations of biogas plants transforming animal by-products and derived products in Ireland" and fall under the remit of the European Union (Animal By-Products) Regulations 2014 (S.I. No 187 of 2014) and in accordance with Regulation (EC) No. 1069 of 2009 and Regulation (EU) No. 142 of 2011.

In the ABP-Regulation, animal by-products are divided into 3 categories:

- Category 1 contains materials with the highest risk for public health, animals or the environment (hygienic risk, risk of BSE, etc.).
- Category 2 includes all animal by-product which can be allocated neither to Category 1 nor to Category 3 (e.g. manure or digestive tract content or animals not fit for human consumption).
- Category 3 comprises animal by-products which would be fit for human consumption, but are, for commercial reasons, not intended for human consumption.

DAFM classifies AD plants into nine different types, differing in relation to the transformation parameters, feedstocks allowed (type and quantity), feedstock source and digestate disposal. Type 1 AD plants are most common as these permit the greatest flexibility of feedstocks and digestate may be spread on land in Ireland and EU. Type 1 ABP plants process Category 2, Category 3 and Non-ABP feedstocks and must comply with the following requirements:

- Maximum particle size before entering the pasteurisation tank: 12 mm
- Minimum temperature of all material in the reactor: 70^0 C
- Minimum time in the reactor at 70^0 C (all material): 60 continuous minutes
- Digestate land spread allowed in EU and Ireland

The ABP regulations are not relevant to AD plants that only use the following non-ABP feedstocks in their process: waste-water treatment plant sludge (e.g. sewage and dairy sludge), cereal grains, edible material of plant or vegetable origin, bread, dough, chocolate and grease trap waste. Table 32 outlines the ABP category of materials considered in this study.

Table 32 - ABP category for feedstocks.

Feedstock	ABP	Notes
Cattle slurry	2	Manure
Cattle FYM	2	Manure
Pig slurry	2	Manure
Poultry manure (broiler)	2	Digestate for tillage land only
Poultry manure (layer)	2	Manure
Brown bin waste	3	Catering waste
Slaughterhouse waste	3	Derived from products for human consumption
Dairy processing waste	3	Derived from products for human consumption
Grass silage	Non-ABP	No restrictions on energy crops

For all feedstocks except for poultry manure, pasteurisation of the material at the conditions specified for Type 1 plants renders the digestate as safe to remove to agricultural land as a biofertilizer, mitigating biosecurity concerns.

For poultry manure, Type 1 pasteurisation conditions are not sufficient to destroy the toxin that leads to botulism, a deadly disease for cattle. Botulism occurs when carcasses of dead birds go unidentified and are collected in the manure. To avoid botulism outbreaks, the DAFM have issued “Code of Good Practise for End Users of Poultry Litter” which stipulates that broiler poultry litter and turkey rearing litter may only be used as a fertiliser on tillage land where the material is ploughed in and buried with no animals nearby. This inhibits the attractiveness of broiler poultry manure as a co-substrate with other feedstocks in the region as the pasteurisation conditions for digestate will not completely remove the risk of botulism, making it unsuitable to spread on grassland which is much more available in the region for digestate removal.

3.8 Summary

Details on number of feedstock sources in Cavan and Monaghan are presented in Sections 3.0, with corresponding GHG emissions discussed in Section 3.6. with respect to total quantity and biomethane potential in Cavan and Monaghan, cost, emissions over 10 km, and other advantages and disadvantages. Between the various feedstock streams studied, there is a cumulative biomethane potential of ~700 GWh/a in Cavan and Monaghan, the majority due to cattle slurry, grass silage and poultry waste contributing 280 GWh, 198 GWh and 176 GWh respectively. A breakdown of the various feedstock streams and their respective qualities is presented in Table 33.

Table 33 - Summary of feedstock streams.

Feedstock	Total quantity (t/a)	Biomethane potential (GWh/a)	Cost (€/t)	Emissions (gCO_2/MJ over 10 km)	Advantages	Disadvantages
Cattle Manure	2,026,167 (slurry) 176,503 (FYM)	280	0	-38.58	High availability. Zero material cost. Higher nutrient value digestate can be exchanged with farmers for slurry. Qualifies for RED II manure credit. High water content beneficial for co-digestion with dry feedstocks.	Low energy content increases AD CAPEX and OPEX. Distributed over a large number of farms. Sub-optimal C/N ratio requires attention for AD design.
Pig Slurry	328,000	39	0	-37.48	High availability. Concentrated to a relatively small number of sources. Beneficial to pig farmers who for reducing land spreading costs. Qualifies for RED II manure credit. High water content beneficial for co-digestion with dry feedstocks.	Low energy content increases AD CAPEX and OPEX. Digestate cannot be returned to pig farmers, appropriate disposal mechanism is required. Sub-optimal C/N ratio requires attention for AD design.
Poultry Manure	65,823 (licenced) 75,042 (sub-licenced)	76 (licenced) 100 (sub-licenced)	0	-44.37 (broiler) -43.83 (layer)	High energy content minimises AD CAPEX and OPEX. High availability. Concentrated to a relatively small number of sources. Qualifies for RED II manure credit.	High ammonia content inhibits AD. Digestate cannot be returned to poultry farmers, appropriate disposal mechanism is required. Sub-optimal C/N ratio requires attention for AD design.
Duck Slurry	59,000 (slurry)	11	0	-22.58	Concentrated to a relatively small number of sources in northern Monaghan. Qualifies for RED II manure credit. High water content beneficial for co-digestion with dry feedstocks.	Low energy content increases AD CAPEX and OPEX. Sub-optimal C/N ratio requires attention for AD design. High ammonia content inhibits AD process.
OFMSW	3,000 (brown bin) 7,567 (slaughter) 12,880 (dairy)	2.2 (brown bin) 4.5 (slaughter) 4.9 (dairy)	0		High energy content minimises AD CAPEX and OPEX. Attracts a gate fee. Systems already in place for feedstock collection via waste management companies.	Low availability due to large rural population. Possible competition with other AD in the region. Sub-optimal C/N ratio requires attention for AD design.
Grass Silage	237,224 (excess after feed requirement)	198	20-40	21.49	High energy content minimises AD CAPEX and OPEX. Digestate from AD can be recycled as fertiliser for grass as part of a circular nutrient recycling plan. Provides farmers with a new income stream option.	High emissions. High cost. Competition with animal feed requirements could lead to unstable supplies and fluctuating costs. Energy crops are not attractive for supports (see RTFO)

4.0 BASIS OF DESIGN

The design of an AD project can be a complex, highly interactive and iterative process which considers a wide range of fixed and variable factors to produce a fit-for-purpose design at the best-cost solution. This section helps in identifying the most viable AD project options at a high level that form a select number of solutions for the conceptual design stage. When considered alongside the feedstock analysis presented in Section 3.0, this section will serve as an indicator of the potential for AD across numerous sites in the Border Region.

The analysis proceeds by first defining suitable site locations as the basis for analysis. Five candidate feedstocks are then selected for each site based on the biomethane potential within a specified radius. The composition of feedstocks deemed most suitable for each site are then analysed using a simplified techno-economic model that incorporates high level estimates of plant costs and performance, considering biomethane injection to the grid and digestate removal as a biofertiliser. Finally, plant configurations with the most realistic development potential are taken forward for more detailed investigation at the conceptual design stage, accounting for the profile of feedstocks in the region.

4.1 Site Location

4.1.1 Considerations

In selecting an appropriate site for an AD project, there are a number of factors that must be considered, including the following;

- Location with respect to feedstock sources and digestate disposal
- Location with respect to the gas grid for biomethane injection
- Adequate road access for transport to/around site
- Proximity to utilities for plant operation; electricity, water, and gas
- Planning constraints in relation to zoned areas for non-industrial development according to County Development Plans, Special Areas of Conservation (SAC), Special Protected Areas (SPA), Natural Heritage Areas (NHA), and Proposed Natural Heritage Areas (pNHA) according to the National Parks & Wildlife Service (NPWS)
- Consideration of zoned areas for industrial development according to County Development Plans, such as existing brown field sites
- Consideration of strategic aims of the County Development Plan for the development of renewable energy projects and infrastructure

Clearly, the selection of an appropriate site requires several interdependent factors in developing an adequate solution.

4.1.2 Feedstock Catchment & Security

The analysis starts by defining practical feedstock sources at a number of candidate locations in the Border Region. Securing potential feedstock presents the greatest risk to the success of any AD project.

A total of 13 locations have been selected for the analysis, seven in Co. Cavan and six in Co. Monaghan. The locations have been selected based on their proximity to the gas grid for biomethane injection, population centres that indicates suitable roads for feedstock transport and geographical disparity that allows the analysis to cover a broad area across both counties. Figure 26 displays the gas transmission system into Cavan and Monaghan. Figure 27 displays the 13 locations selected for the study. Proximity to potential gas injection point is also beneficial, minimising emissions associated with a virtual pipeline.

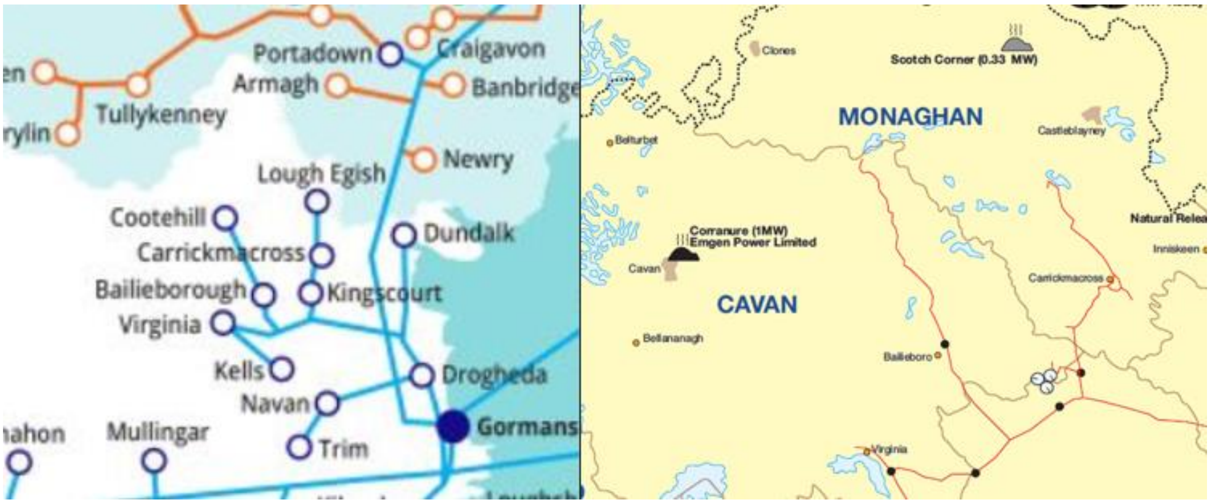

Figure 26 - Gas transmission system in Cavan and Monaghan (from Gas Networks Ireland[3] and La Tene maps[4]).

4.1.3 Candidate Locations

Figure 27 - Provisional AD plant locations in the Border Region.

Coordinates for the candidate site locations are provided in Table 34. The location of the candidate sites are approximate for the basis of design study, with more exact site locations to be defined in greater detail later in the study for the optimum designs.

[3] https://www.gasnetworks.ie/corporate/company/our-network/pipeline-map/
[4] http://latenemaps.com/

Table 34 - Coordinates of candidate AD plant location.

Location name	Latitude (°N)	Longitude (°E)	ITM X (Easting)	ITM Y (Northing)
Bailieborough	53.91711	-6.97193	667537	796906
Ballybay	54.13162	-6.90532	671543	820842
Ballyconnell	54.11652	-7.57943	627497	818689
Carrickmacross	53.97571	-6.72006	683964	803696
Cavan Town	53.99093	-7.36146	641874	804820
Clones	54.17995	-7.23292	650075	825938
Cootehill	54.07417	-7.08124	660129	814285
Emyvale	54.34462	-6.96073	667573	844491
Kilnaleck	53.86210	-7.32158	644732	790597
Lough Egish	54.06228	-6.80836	678010	813228
Monaghan Town	54.24950	-6.97111	667053	833895
Shercock	53.99461	-6.89590	672397	805605
Virginia	53.83591	-7.08128	660471	787771

4.1.4 Feedstock Suitability

Given the locations of 13 candidate sites, this section analyses the quantity of feedstock available to a potential plant within a certain catchment area. The catchment area is a radius of 10, 20 or 30 km around the plant, allowing for a sustainable collection distance. To optimise sustainability and minimise cost, the plant should be located as close to the feedstock source as possible. Table 35 to Table 40 show the cumulative feedstock and biomethane potential within a defined catchment zone for each candidate site.

Table 35 - Feedstock quantities within 10 km from site (t/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass Silage
Bailieborough	1,828,614	187,007	259,715	10,376	12,309	31,927	11,927	7,284	21,418
Ballybay	1,479,672	133,326	89,340	35,864	20,403	116,519	10,420	5,282	130,525
Ballyconnell	766,065	69,145	128,044	6,820	2,972	24,401	-	5,856	244,334
Carrickmacross	1,499,784	157,079	116,075	7,706	13,559	36,649	11,927	-	22,155
Cavan Town	1,430,073	133,629	326,723	8,911	2,972	35,324	9,837	9,849	228,127
Clones	1,220,347	104,682	139,816	36,663	15,783	106,069	1,875	8,573	163,328
Cootehill	1,665,972	146,271	241,711	21,998	20,403	101,699	12,881	10,058	179,722
Emyvale	617,745	54,055	10,904	40,502	18,293	102,558	954	5,282	63,943
Kilnaleck	1,521,727	162,582	305,615	4,036	1,260	8,347	9,837	7,284	168,139
Lough Egish	1,573,957	151,500	135,018	16,510	24,337	78,868	10,420	209	79,183
Monaghan Town	994,568	87,127	27,328	29,590	20,403	110,484	3,965	5,282	111,389
Shercock	1,814,073	177,420	175,395	16,617	19,558	66,892	11,927	6,767	48,637
Virginia	1,680,218	184,035	283,979	4,036	-	8,126	9,837	7,284	6,122

Table 36 - Biomethane potential for feedstock quantities within 10 km from site (GWh/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass silage
Bailieborough	26.67	6.59	5.40	0.00	0.00	0.99	2.46	0.00	17.43
Ballybay	33.42	7.64	0.14	0.81	3.83	29.40	0.80	0.00	17.30
Ballyconnell	13.33	3.08	6.87	0.00	0.00	0.00	0.00	0.00	23.73
Carrickmacross	30.98	8.06	0.00	0.00	0.00	8.95	0.00	0.00	1.02
Cavan Town	25.64	5.76	6.53	0.85	0.00	0.00	0.00	1.21	12.40
Clones	14.01	3.48	0.56	1.03	5.93	34.26	0.00	0.98	15.85
Cootehill	31.27	7.01	2.07	0.44	1.01	15.89	0.35	0.00	24.83
Emyvale	20.53	5.33	0.00	3.11	0.00	55.42	0.36	0.93	12.93
Kilnaleck	25.52	6.14	12.78	0.00	0.00	0.71	0.00	1.41	14.48
Lough Egish	31.90	7.56	0.00	0.31	5.23	11.55	0.80	0.00	16.18
Monaghan Town	33.51	7.99	1.14	1.00	2.61	58.22	0.36	0.07	7.53
Shercock	34.97	8.31	0.00	0.00	0.00	8.34	3.26	0.00	21.60
Virginia	29.29	7.47	6.67	0.00	0.00	0.00	0.94	1.41	0.00

Table 37 - Feedstock quantities within 20 km from site (t/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass silage
Bailieborough	845,188	82,711	125,059	-	-	6,831	11,927	3,993	42,690
Ballybay	854,447	74,098	27,328	12,634	20,403	64,534	3,965	209	70,548
Ballyconnell	309,596	26,898	58,597	-	-	612	-	3,291	100,952
Carrickmacross	780,999	81,887	57,817	2,238	13,368	17,556	8,545	-	3,499
Cavan Town	700,471	62,616	204,831	4,036	1,260	6,264	-	7,284	136,047
Clones	509,602	43,758	31,627	17,369	10,969	51,154	921	2,774	86,632
Cootehill	879,914	74,292	58,646	10,376	15,783	58,137	9,466	2,774	103,454
Emyvale	345,335	30,591	9,686	21,612	7,997	70,072	954	2,717	36,233
Kilnaleck	729,336	73,315	217,437	-	-	523	2,460	7,284	52,027
Lough Egish	812,839	72,966	22,271	7,706	9,625	36,649	9,466	-	62,161
Monaghan Town	616,152	53,660	10,904	27,952	14,523	99,257	954	5,282	66,603
Shercock	903,385	82,264	90,445	1,465	6,924	19,125	9,466	-	73,820
Virginia	796,325	85,589	188,609	-	-	732	8,915	3,993	11,947

Table 38 - Biomethane potential for feedstock quantities within 20 km from site (GWh/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass silage
Bailieborough	116.80	31.25	14.66	0.00	0.00	9.22	4.55	1.41	35.63
Ballybay	118.08	27.99	3.20	2.67	15.70	87.12	1.51	0.07	58.89
Ballyconnell	42.78	10.16	6.87	0.00	0.00	0.83	0.00	1.21	84.27
Carrickmacross	107.93	30.94	6.78	0.47	10.03	23.70	3.26	0.00	2.92
Cavan Town	96.80	23.66	24.02	0.85	1.01	8.46	0.00	2.62	113.56
Clones	70.42	16.53	3.71	3.67	8.54	69.06	0.35	0.98	72.31
Cootehill	121.60	28.07	6.88	2.19	12.15	78.48	3.61	0.98	86.36
Emyvale	47.72	11.56	1.14	4.56	6.19	94.60	0.36	1.01	30.24
Kilnaleck	100.79	27.70	25.50	0.00	0.00	0.71	0.94	2.62	43.43
Lough Egish	112.33	27.57	2.61	1.63	7.38	49.48	3.61	0.00	51.89
Monaghan Town	85.15	20.27	1.28	5.90	11.14	134.00	0.36	1.91	55.60
Shercock	124.84	31.08	10.61	0.31	5.23	25.82	3.61	0.00	61.62
Virginia	110.05	32.33	22.12	0.00	0.00	0.99	3.40	1.41	9.97

Table 39 - Feedstock quantities within 30 km from site (t/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass silage
Bailieborough	1,828,614	187,007	259,715	10,376	12,309	31,927	11,927	7,284	21,418
Ballybay	1,479,672	133,326	89,340	35,864	20,403	116,519	10,420	5,282	130,525
Ballyconnell	766,065	69,145	128,044	6,820	2,972	24,401	-	5,856	244,334
Carrickmacross	1,499,784	157,079	116,075	7,706	13,559	36,649	11,927	-	22,155
Cavan Town	1,430,073	133,629	326,723	8,911	2,972	35,324	9,837	9,849	228,127
Clones	1,220,347	104,682	139,816	36,663	15,783	106,069	1,875	8,573	163,328
Cootehill	1,665,972	146,271	241,711	21,998	20,403	101,699	12,881	10,058	179,722
Emyvale	617,745	54,055	10,904	40,502	18,293	102,558	954	5,282	63,943
Kilnaleck	1,521,727	162,582	305,615	4,036	1,260	8,347	9,837	7,284	168,139
Lough Egish	1,573,957	151,500	135,018	16,510	24,337	78,868	10,420	209	79,183
Monaghan Town	994,568	87,127	27,328	29,590	20,403	110,484	3,965	5,282	111,389
Shercock	1,814,073	177,420	175,395	16,617	19,558	66,892	11,927	6,767	48,637
Virginia	1,680,218	184,035	283,979	4,036	-	8,126	9,837	7,284	6,122

Table 40 - Biomethane potential for feedstock quantities within 30 km from site (GWh/a).

Sites	Cattle slurry	Cattle FYM	Pig slurry	Duck slurry	Layer	Broiler	Dairy	Slaughter	Grass silage
Bailieborough	252.71	70.65	30.45	2.19	9.34	43.10	4.55	2.62	17.88
Ballybay	204.48	50.37	10.48	7.57	15.70	157.30	3.97	1.91	108.95
Ballyconnell	105.87	26.12	15.01	1.44	2.35	32.94	0.00	2.11	203.95
Carrickmacross	207.26	59.34	13.61	1.63	10.26	49.48	4.55	0.00	0.00
Cavan Town	197.63	50.48	38.31	1.88	2.35	47.69	3.75	3.53	190.42
Clones	168.65	39.55	16.39	7.74	12.15	143.19	0.71	3.12	136.33
Cootehill	230.23	55.26	28.34	4.64	15.70	137.29	4.91	3.60	15.02
Emyvale	85.37	20.42	1.28	8.55	14.07	138.45	0.36	1.91	53.37
Kilnaleck	210.30	61.42	35.84	0.85	1.01	11.27	3.75	2.62	140.35
Lough Egish	217.51	57.23	15.83	3.49	18.57	106.47	3.97	0.07	66.10
Monaghan Town	137.44	32.91	3.20	6.25	15.70	149.15	1.51	1.91	92.28
Shercock	250.70	67.03	20.57	3.51	14.99	90.30	4.55	2.39	40.60
Virginia	232.20	69.52	33.30	0.85	0.00	10.97	3.75	2.62	0.00

4.1.5 Summary

From section 4.1.4 , it is evident from the analysis that regardless of the catchment radius; cattle slurry, despite poor feedstock qualities (only slightly better than pig slurry and high moisture content.), is widely available in significant quantities and likely to be found in proximity to an AD plant developed in the region, providing substantial biomethane potential Consequentially, this means that FYM is also available although at far smaller quantities. Broiler and layer manure is concentrated in the northern Monaghan area, evident from the biomethane potential for Monaghan town, Ballybay, Emyvale, Lough Egish and Cootehill being the most significant. Likewise, duck slurry is concentrated in the northern Monaghan region albeit in much smaller quantities compared to other poultry feedstocks. Grass silage is available to most locations except for Virginia and Carrickmacross, with significant concentrations near Cavan Town and Ballyconnell. Although there is much pig slurry in the way of tonnage, it is a poor feedstock (low biomethane potential) and should avoided.

4.2 Plant Design

4.2.1 Plant Scale

The scale of an AD plant is generally classified by either the volume/mass of feedstocks processed (m^3/a, t/a), or maximum energy generating capacity (gas/heat/electricity). In the case of co-digestion of several substrates, which is generally required to maximise biogas extraction, defining scale based on energy generating capacity is preferred. This is due to the simplicity of such a figure in comparison to feedstock throughput, where widely varying energy contents and compositions can yield different biogas outputs. Capacity is defined as the maximum amount of energy which can be produced by a plant at any one point in time. The capacity factor of a biogas plant is typically 85%, which is multiplied by the generating capacity and number of hours per year (8760) to define the annual energy generation in MWh/a. For the purposes of the feasibility study, MW biomethane will be used as a defining figure for plant scale. Throughput of feedstocks and MWh/a will be referenced where appropriate, including mixture composition.

According to the European Biogas Association (EBA), there was a total of 18,943 biogas plants and 725 biomethane plants in operation across Europe at the end of 2019. Cumulatively, these plants generated 193 TWh of biomethane, equivalent to 19.4 billion Sm^3 of biomethane (or 32.3 billion Sm^3 of raw biogas assuming 60% CH_4 content). The Green Generation facility in Nurney, Co. Kildare, is the first, and so far only, biomethane AD facility operating in the Republic of Ireland. On average, biomethane plants across Europe are considerably larger than plants classified as biogas; this is due to the economies-of-scale associated with grid injection and upgrading units. The average European biogas plant generates 8.8 GWh/a, which is just under 1 MW gas capacity; the vast majority of biogas plants are smaller farm-based units (100 – 500 kWe). For European biomethane projects, the average plant generates 35.9 GWh/a, equivalent to 4.1 MW gas capacity. This figure is in line with plant scales assumed by GNI, where experience from European models is incorporated, and it is assumed that AD plants in the 20-40 GWh range will feed into the Mitchelstown CGI; this is equivalent to ~2.5-5.0 MW capacity assuming 85% capacity factor. Studies by the RGFI and KPMG also assume a plant scale of 20-40 GWh. Such plant scales are considered as small-to-medium for biomethane; to account for a range of plant scales from small-to-larger units, the basis of design in this study will consider plants in the range of 3 – 7 MW (25 – 50 GWh/a @ 85% capacity factor).

4.2.2 Solids Content

In a dry AD system, the feedstock material has a solids content of >20%, whilst wet systems are defined by a lower solids content (typically 5-15%). Dry AD systems are beneficial for feedstocks with a high solids content, as there is a lower operational cost due to lower material throughput (handling and heating), and no additional water is required. Wet AD systems are more popular in Europe for handling feedstock mixtures with a high moisture content. In a wet AD system, the feedstock can be mixed for maximum biogas extraction using continuously stirred tank reactors (CSTR) and pumped through the plant using conventional pumping systems; however, the gas output per unit feedstock is lower and high water content necessitates a higher energy consumption for heating and mixing. The addition of water is generally motivated by a need to make the substrate amenable to pumping and mixing, and to alleviate ammonia concentrations. Dry systems will generally have a higher capital expenditure than wet systems. Given the high availability and low solids content of feedstocks identified in the Border Region (Section 3.0), and popularity/market maturity of wet systems in Ireland and the UK, continuously stirred wet AD is considered in the study.

4.2.3 Temperature Regimes

Mesophyllic AD systems operate at 35-45°C, with thermophyllic digestion occurring at 50-60°C. Thermophyllic conditions permit a greater throughput of material and greater pathogen kill than mesophyllic, however capital and operational costs are generally higher. The digestion process under mesophilic conditions typically has greater stability than under thermophilic conditions as a more diverse set of bacteria grows at mesophilic temperatures, with these bacteria generally more robust and adaptable to disturbances in the form of changing feedstock composition, variable loading rates, and fluctuating environmental conditions.

4.2.4 Digester Design

The digester is the heart of the AD system and is where anaerobic bacteria transform the organic feedstock mixture into biogas. For wet AD systems, continuously stirred tank reactors (CSTR) are the most commonly employed configuration. In these systems, a consignment of feedstock is loaded to the top of a vertical cylindrical tank, known as the digester, and allowed to ‘fall’ slowly to the bottom as it is stirred and digested. When it reaches the bottom the digestion process is largely complete and the digestate is removed. These systems are simple in design and operation.

Digesters are constructed as a sealed tank, typically made of coated steel or concrete. The substrate is continuously stirred and maintained at a specific temperature (35-40°C for mesophyllic operation) using mixing/agitation equipment and heaters, respectively. The heat is usually supplied from a CHP unit in the case of an electricity generating plant, using biogas produced by the digester. For non-electricity plants, such as biomethane, the produced gas can be used to heat the plant in a boiler. The flow of material into and out of the digester is constantly regulated so that it is retained for a specified number of days for digestion; the optimum time for the process will vary depending on the feedstock properties. The time a batch of material is designed to spend in the digester is known as the hydraulic residence time (HRT) and is typically 20-40 days for mesophilic AD operating on agricultural substrates. The size of the digester therefore depends on the volume of material to be processed and HRT.

CSTR digester technology can be classified as vertical or classical in design. For the vertical arrangement, the mixing equipment is suspended from the roof of the digester, with heating supplied by heat exchangers outside of the digester. The roof is not flexible for vertical digesters and a separate biogas holder is required. A distinctive feature of this design is a digester height that is greater than its diameter. For the classical arrangement, the mixing equipment is inclined through the side-wall, with heating supplied by hot water pipes located in-wall and under-floor. A flexible roof acts as the biogas holder. A distinctive feature of this design is a digester height that is smaller than its diameter.

The vertical arrangement yields better heat and mass transfer performance than the classical design and is therefore more efficient with lower heat and electricity requirements. A smaller footprint means that these designs are beneficial in locations where space is an issue, such as in built up areas and existing processing facilities with site limitations. However, these designs are more expensive for construction, require a separate gas holder, and more complex to operate. Vertical designs are best suited to large AD projects.

The classical arrangement is sometimes referred to as a ‘farm style’ digester as it is the most commonly used design for smaller on-farm projects, due to its compatibility with agricultural feedstocks, and ease of operation. This design is less efficient than the vertical arrangement, and occupies more ground space, however the classical design is easier to maintain than the vertical design where full-time technical staff are required to service a more complex system.

4.3 Feedstock & Digestate Management

4.3.1 Feedstock Management

For the study it assumed that most feedstocks are brought to the plant in a “just-in-time” manner, that is, the participating famer can hold onto the feedstock for a period of time prior to treatment at the AD plant. Farms must have manure management systems in place as per the Nitrates directive (such as slatted sheds etc.). This is typically the case for poultry farms also, which are cleaned after each batch (6-8 weeks).

For feedstocks such as FYM, this is not the case. Collection of the feedstock is restricted to the winter months when the livestock are housed indoors and can only be fetched once the pasture grazing has resumed. Likewise, silage is only produced and collected during the summer months before being put into storage in silage pits or bales. Thus, plants seeking to use considerable amounts of these feedstocks must give adequate consideration for feedstock storage for several months of feedstock. Thus, planning and CAPEX should allow for the construction of silage pits or slurry tanks with sufficient storage volume (depending on the feedstock’s properties and quantities required). For FYM and grass silage, a simple roofed or covered silage pit can be sufficient.

4.3.2 Digestate Management

Along with biogas, the AD process also outputs a nutrient rich digestate. Of the feedstock that enters the digester, approximately 90% of the mass will be outputted as digestate. Thus, consideration must be given as to its management and disposal. A number of end-use treatment mechanisms for digestate, including storage and separation are explored, as shown in Figure 28. However, this can be constrained if ABP feedstocks are used as explained in section 3.7.

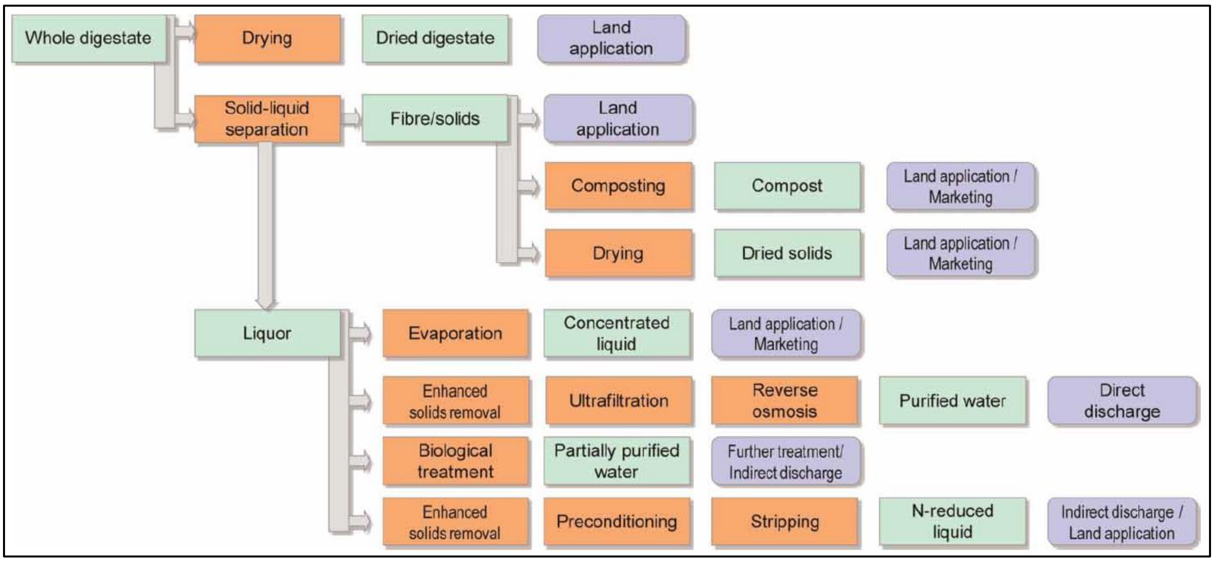

Figure 28 - Digestate processing (source: Fuchs and Drosg, 2013)

Under the Nitrates Directive act it is prohibited to spread slurry or fertiliser during designated winter months. This period depends on location and type of fertiliser to be spread. The period of prohibited fertiliser application is presented in Table 41 with the zones shown in Figure 29. This inhibits the disposal and land spreading of digestate during these periods and accommodation for 3-4 months storage should be included in any AD development.

Table 41 - Prohibited application period of fertilisers.

Fertiliser Type	Start Date	End (Zone A)_	End (Zone B)	End (Zone C)
Chemical	15th September	12th January	15th January	31st January
Organic	15th October	12th January	15th January	31st January
FYM	1st November	12th January	15th January	31st January

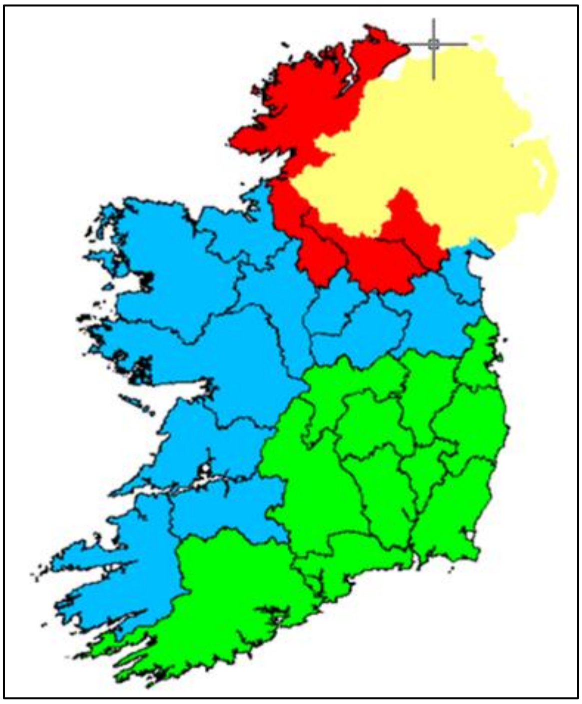

Figure 29 - Prohibited zoned areas[5] (A green, B blue, C red)

[5] Glanbia Connect: https://www.glanbiaconnect.com/farm-advice/detail/article/tim-to-think-slurry

Pasteurisation
Pasteurisation is used to destroy pathogens in organic feedstocks prior to removal from the AD plant as an organic fertiliser. Pasteurisation is a mandatory requirement if the feedstock mixture includes materials classified as animal by-products (ABP) or animal manures from other farms. ABP regulations stipulate pasteurisation requirements based on the feedstock mixture, source, and end-use/disposal of digestate. Under the ABP Regulations, DAFM considers applications for approval for different types of AD plants depending on the feedstocks used and the end-use of digestate. The ABP legislation classifies 'animal by-products' under 3 categories; Category 1 – very high risk, Category 2 – high risk, and Category 3 – low risk. Specific materials that cannot be processed in AD plants are Category 1 animal by-products such as BSE, carcases and suspects, specified risk material and catering waste from international transport. ABP rules specific to the feedstocks investigated in this study are discussed further in section 3.7.

Pasteurisation may be applied before or after digestion; in this study, pasteurisation is assumed as part of the digestate treatment step and occurs after digestion. Pasteurisation is facilitated using maceration that shreds material (prior to entering the digester) to an appropriate size, and heat exchangers that raise the temperature to a mandatory level. Heat recovery should be employed to minimise the parasitic heat requirements for the unit.

Digestate separation
Digestate contains all the nutrients that are available in the raw feedstock mixture. Digestate from AD is therefore most commonly used as an organic fertiliser and compost / soil conditioner, providing agricultural land with readily available N-P-K nutrients and rich organic matter, thus creating a circular economy with AD at its core. The physico-chemical characteristics of digestate varies, strongly depending on the nature and composition of the substrates as well as on the operational parameters of the AD process.

Digestate is normally applied as an organic fertiliser to crops without the need for any further processing; this makes use of the whole digestate form. However, in some instances it may be useful to upgrade the digestate to more specific products of value.

Digestate typically comes in three forms;

- **Whole**: similar in its appearance to a livestock slurry, with typically less than 5-10% dry matter.
- **Liquor**: this is whole digestate which has had most, or all, of the solid material removed.
- **Fibre**: this is similar to compost, and is the solid material separated out of the whole digestate.

Storage
Storage is required if digestate is to be used as an organic fertiliser in agriculture as it cannot be applied all year round. When land spread, organic fertiliser is either absorbed by soil and plants or lost to air and water. In Ireland, land spreading is limited to certain times of the year to mitigate these negative effects, with variations and time constraints in different regions of the country (nitrate zones). Land spreading of organic fertiliser is restricted from 1 November to 31 January in zone 3, which includes Cavan and Monaghan. Suitable storage is required to cover periods when digestate cannot be removed and depends on the digestate treatment that potentially varies the properties and quantity of digestate to be handled against the untreated whole version.

For RED II, fugitive emissions from storage must be accounted for in LCA calculations. If the AD plant utilises open storage, the digestate will continue to release methane that was not collected during the digestion process, according to the digestion efficiency. This has the effect of increasing the emissions associated with the whole process. Closed storage is sealed, with no emissions assumed and therefore beneficial to GHG accounting of the plant. Closed storage is generally achieved using over ground tanks, or covered ground lagoons.

Figure 30 - Closed digestate storage - (left) covered lagoon, (right) sealed tank (source: Geoline[6] , Permastore[7])

4.4 Biogas End-Use

4.4.1 Heat Only

When biogas is combusted to produce heat alone, some of this heat can be used to maintain the operating temperature of the digesters and pasteurisation unit. The remaining heat can then be used for domestic heating or industrial processes. This is a relatively efficient process (80-90% of useful energy converted), however, there must be an adequate heat load and financial supports to make the plant viable. In Ireland, the Support Scheme for Renewable Heat (SSRH), provides a tariff for heating systems based on AD. A tariff of 2.95 c/kWh is available for heat up to 1000 MWh/a, and 0.5 c/kWh up to 2400 MWh/a over a 15 year period; these rates do not sufficiently incentivise heat alone biogas end-use, with such systems uncompetitive against conventional heating systems.

4.4.2 Electricity Only & CHP

Electricity-only production involves burning gas for the sole purpose of generating and exporting electricity. This process is relatively inefficient (30-35% of useful energy converted), as the system fails to take advantage of a parallel energy stream available through heat recovery. CHP units can enable a simultaneous heat and electricity load to extract waste heat from the combustion process. This simultaneous heat and power generation yields efficiencies of 80-90%, provided a useful heat load is near the plant. In Ireland, biogas plants developing electricity developed over the past 10 years have availed of the Renewable Energy Feed-In Tariff (REFIT). The REFIT schemes provide certainty to renewable electricity generators by guaranteeing a minimum price for each unit of electricity exported to the grid over a 15 year period. AD plants (CHP and non-CHP) were awarded REFIT contracts under REFIT 3, with large/small non-CHP and CHP units receiving 10-12 c/kWh and 13-16 c/kWh respectively. REFIT 3 gave specific attention to bioenergy, and was the most recent and final REFIT scheme, closing in December 2015. The REFIT has been replaced by an auction-based scheme, the Renewable Electricity Support Scheme (RESS),

[6] https://www.geoline.ie/anaerobic-digestion/digestate-storage-lagoon/
[7] https://www.permastore.com/applications/farmbiogas/biogen-digestate-tank/

which invites renewable electricity projects to bid for and receive a guaranteed price for the electricity they generate. Biogas CHP cannot compete with wind and solar PV in the RESS. This is highlighted by the RESS 1 auction results from August 2020, where no biogas projects were awarded contracts, and guaranteed prices were considerably lower than the REFIT price levels that are required to make such a venture economically viable. Electricity generation from biogas is therefore not viewed as a viable option for future development of biogas given the competition with cheaper renewable technologies.

4.4.3 Biomethane

The alternative to electricity generation and heating is the production of biomethane for injection into the national grid. As a renewable gas that is virtually identical to fossil natural gas, biomethane is a highly flexible energy vector that has the potential to decarbonise hard-to-abate heat and transport sectors. Biomethane is derived from Biogas by scrubbing the CO_2 using specialised upgrading technologies, leaving high purity CH_4 that is compatible with the grid gas. Injection to the network can be achieved via pipeline connection at the AD plant or using a "virtual pipeline" comprising of HGVs transporting gas trailers to a centralised injection site (BNEF – Biomethane Network Entry Facility). The efficiency of biomethane upgrading (~0.25 kWh/m^3) is estimated to be 92% (determined from the final energy delivered vs energy in the raw biogas).

Biomethane is viewed as a key enabler of the decarbonisation of Irish heat and transport sectors. Heat and transport sectors account for 39% and 42% (81% cumulative) of Ireland's total energy requirement, and 19% and 24% of total GHG emissions respectively (for year 2018, SEAI). Both sectors are considerably behind the electricity generation sector in terms of renewable contribution; the share of renewable electricity is 33.2% (RES-E), with renewable heat at 6.5% (RES-H), and 7.2% for transport (RES-T). These shares fall well short of Irelands renewable energy targets, however there is significant work underway by various bodies to mobilise biomethane as an attractive biogas end-use for prospective developers to meet these challenges.

Gas Networks Ireland (GNI) has a strategic objective to convey 20% renewable gas on the national transmission and distribution networks by 2030, the majority of which is biomethane. GNI is proactive in driving an indigenous biomethane industry, through international collaboration with experienced European biomethane stakeholders, development of the Mitchelstown Centralised Gas Injection (CGI) facility and offering various levels of support to commercial developers and researchers in the area. Collaborative organisations such as Renewable Energy Ireland, Renewable Gas Forum of Ireland (RGFI), and the Irish Bioenergy Association (IrBEA), are actively investigating the nationwide potential of biomethane and seeking direction and policy support that will help stimulate the industry. Ongoing research into biomethane from organisations such as Teagasc, MaREI, and Devenish will also help to inform decision making.

Direct grid injection is accomplished by connecting the outlet of the upgrading unit at the AD plant to the gas grid. The upgrading unit is connected to a biomethane network entry facility (BNEF), which comprises several crucial pieces of equipment to ensure that the biomethane is compliant with all necessary standards and regulations, prior to physical entry to the gas network. The various pieces of equipment may include the following;

- **Gas pressure reduction** to satisfy the correct network pressure
- **Gas analysis** to check for energy content, contaminants, and gas quality compliance
- **Metering** to measure and record gas flows to the network
- **Propanation** to raise the calorific value of the gas to minimum network standards
- **Odorant injection** to provide the gas with a smell for safety detection purposes

There are different ownership models for the injection equipment. In a maximum ownership model, the AD plant operator owns and operates the BNEF, with the gas network operator owning the remotely operated valve (ROV). The ROV is the final piece of equipment involved in the injection scope and permits gas entry to the grid. In a minimum ownership model, the gas network operator owns and operates all equipment downstream the upgrading unit (minus propanation). If there are any quality issues once the gas leaves the BNEF, the gas is rejected and will not enter the grid. The rejected gas will either go to 'flare' (burnt off) or it is recycled and reprocessed back through the BNEF.

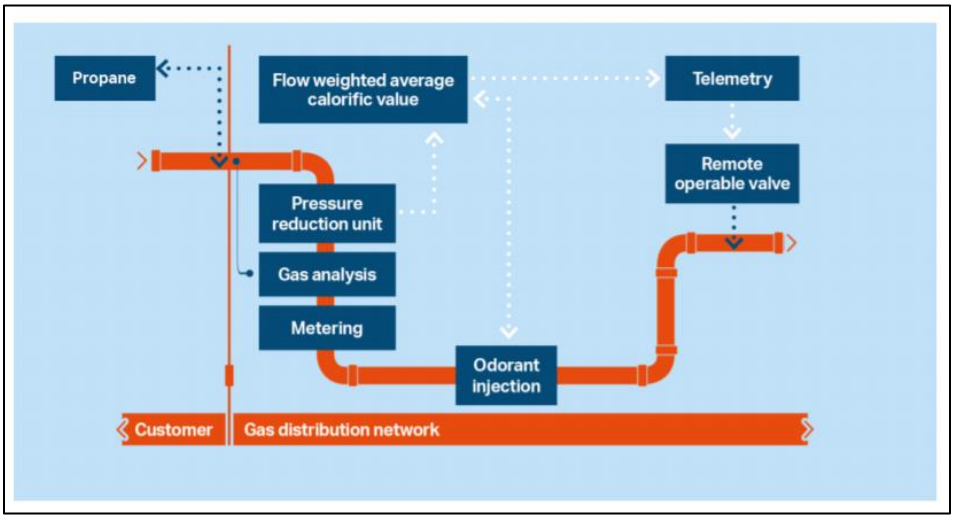

Figure 31 - Operating principle of a BNEF for a minimum ownership model (source: Cadent[8])

For direct injection to be economically viable, the AD plant should yield large gas quantities and be located near a gas grid connection that can accept biomethane, as developing a pipeline route is expensive. If the AD plant is located far from the gas grid, direct injection is likely not possible or not economically viable. An alternative to direct grid injection is by means of gas transportation by road to a centralised grid injection facility (CGI), also known as virtual pipeline. In the virtual pipeline model, the AD plant operator compresses gas to 250 bar to specialised trailer units. These trailers contain several gas bottles, which in total can transport ~10,000 Sm^3 from the AD plant to a dedicated injection site using HGV. This method is useful for plants with a smaller gas output located away from the gas grid that makes direct pipeline injection unviable. However, there is also a requirement for the CGI to be located relatively nearby; in the Mitchelstown CGI project, the design was based on AD located within a 50 km radius. The Mitchelstown CGI (currently under development) and the Nurney biomethane plant are to date the only such facilities in ROI and is located ~250-350 km from possible AD sites in Cavan/Monaghan.

At the present time, there are no support schemes in the republic for AD projects or biomethane production. The Renewable Heat Obligation (RHO) scheme, which is currently under review at the time of writing this report, seeks to oblige a percentage of fuel suppliers stock to be supplied by renewable fuels. In return, a support is to be instated of 8-12 c/kWh for sourcing these fuels. It is assumed that a support of 12 c/kWh will be allocated going forward in this study (similar to UK RTFO). Given the potential of biomethane to decarbonise heat and transport sectors and current support scheme landscape, upgrading of biogas to biomethane is the technology pathway of choice for this study.

[8] https://cadentgas.com/nggdwsdev/media/Downloads/Bio-guide-to-connect-FINAL-280220.pdf

4.5 Preliminary Plant Design

4.5.1 Design Assumptions

For basis of design, the following operating conditions/costs and assumptions are applicable;

- Target 'wet' AD (14% TS)
- 60% CH_4, 40% CO_2 composition in biogas
- Mesophilic temperature conditions (38-40°C)
- Pasteurisation to 70°C for 1 hour (Type 1 ABP rules)
- 30 days hydraulic retention time
- 80% digestion efficiency of feedstocks to biogas (volatile solids destruction)
- 85% capacity factor for planned/unplanned maintenance (7446 hr/a operation)
- C:N ratio of 20-30:1 is considered optimal for digestion
- Digestate separation to solid and liquid fractions
- Ammonia stripping (75% efficient) + water addition to reach target solids content*
- Upgrade to biomethane and gas injection via virtual pipeline model or gas injection to site near gas grid
- Transport costs, heating costs, and electricity costs for operation all considered
- Digestate removed from site by end-user as a biofertiliser
- Gas revenue of 10 – 12 c/kWh.

Note that these assumptions are required to identify favourable configurations, design refinement will commence throughout project development. The above assumptions allow a variety of feedstocks (like those presented in this report) to be co-digested, allowing for the optimisation of many parameters (such as C:N ratio, solids content). Wet AD plant operation is summarised in Figure 32.

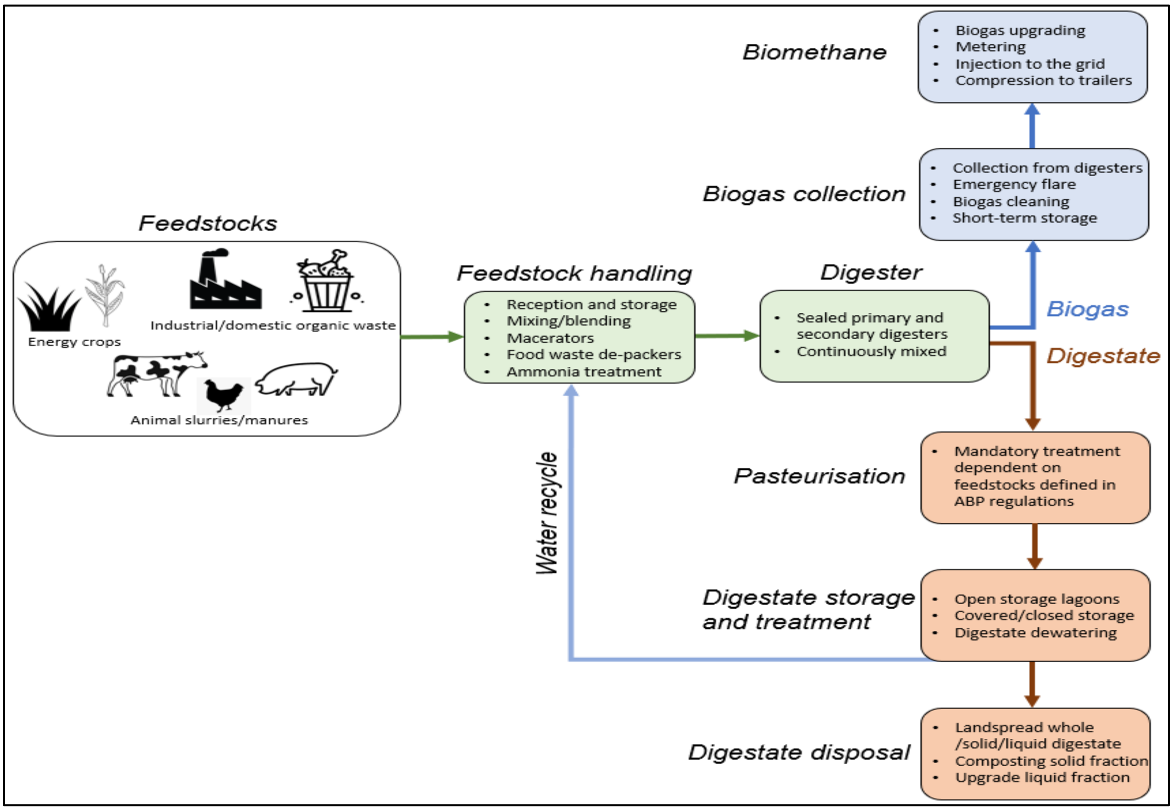

Figure 32 – Typical processing of wet AD system.

4.5.2 Plant Description

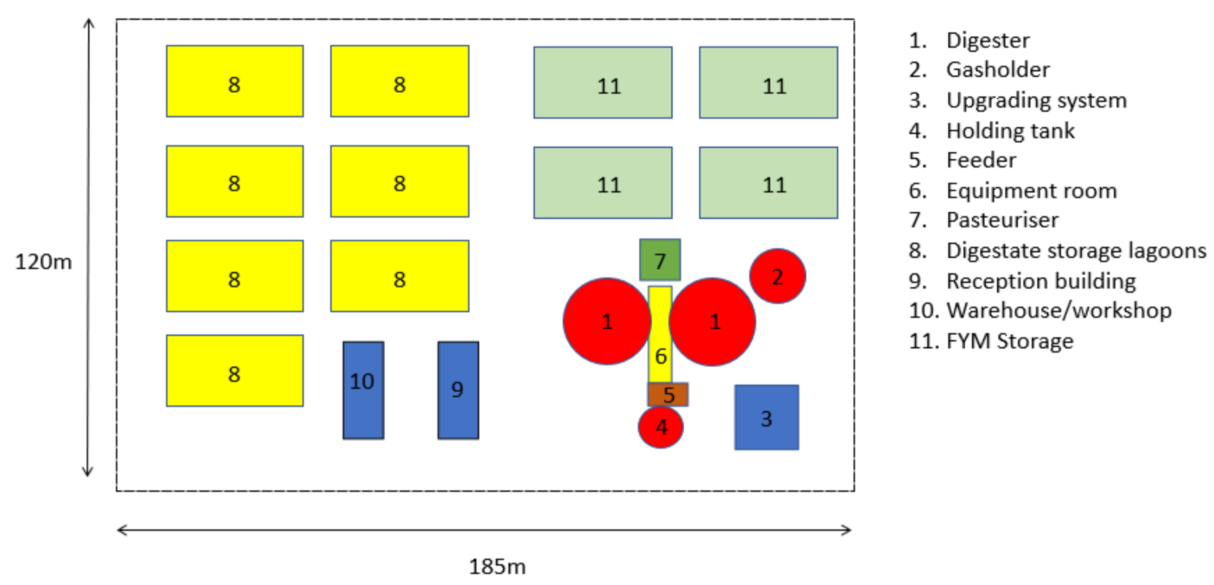

Figure 33 – Example of AD plant layout

An AD facility includes many pieces of equipment that can be configured in several different ways to enable the overall process and maximise biogas extraction for the specific feedstock input. Each AD plant is bespoke to the specific conditions that define a project, from both technical and economic point of view. Even considering the focused basis of design for this study defined in section 4.5.1 there still exist many variations of plant configuration and equipment, which vary according to the following factors;

- Feedstock reception
- Feedstock properties (total and volatile solids, calorific value, pH, C/N ratio, etc.)
- Raw feedstock storage (silo for dry materials, tank for liquids, etc.)
- Feedstock pre-treatment (maceration, de-packing, water addition, etc.)
- Feedstock handling, mixing, and feeding
- Digester design and operation (single/multiple, temperature, residence time, pH)
- Plant heating, electricity, and water provision
- Biogas collection and intermediate storage
- Biomethane upgrading technology
- Biomethane removal from site (direct injection, virtual pipeline)
- Pasteurisation (ABP requirements)
- Digestate storage and removal (covered/sealed storage, whole/separated)
- Digestate dewatering
- Handling/treatment of whole/wet/dry digestate

4.5.3 Plant Configurations

Co-digestion of multiple feedstocks presents the most optimal way of achieving and maintaining optimal digestion parameters such as C:N ratios, ammonia levels, solids content, etc. This ensures optimal conditions within the digester, promoting growth of methanogenic bacteria, thus optimise biogas yields.

Presented in Table 42 is a variety of potential AD plant feedstock configurations which would be suitable in the Border Region (the specific location of these plants would differ as to optimise their requirements). It should also be noted that the corresponding feedstock ABP regulations may result in additional challenges where digestate management and disposal are concerned.

Table 42 – Example of Plant Configurations

Configuration	Plant Configuration	Plant Output	Feedstock Required
A	50% CS, 25% FYM, 25% GS	5 MW	169,048 t/a
B	50% CS, 50% FYM	5 MW	169,048 t/a
C	70% Broiler, 30% FYM	7 MW	57,904 t/a

4.6 Project Risks & Operating Constraints

Maintaining the stability of the AD process during operation is of paramount importance. In many cases, a strongly inhibited microorganism population or a total crash of the whole plant can have severe financial consequences for the project operator/owner, with restarts often requiring several months of preparation at significant cost. Correct process monitoring procedures are encouraged, as these will often alert plant operators to potential issues in time for suitable mitigation efforts to be executed. In this section, the various issues related to AD plant operation are discussed (IEA Bioenergy, 2013).

4.6.1 Feedstock Security

The most detrimental risk to an AD plant is a failure in its feedstock supply. Large quantities (typically, more than 100-200 tonnes for a 5-10 MW plant) of feedstocks are pre-treated, mixed daily prior to entering the digester as to optimise biogas yield. It is assumed that most feedstocks arrive to the plant just on time (on the day) with no storage provided (with exception to key feedstocks). Biomethane production can be impacted should an otherwise staple feedstock become scarce or unavailable. To mitigate this impact would require similar substitute feedstocks (similar properties C, N, CH_4) which may involve more distant collection ranges or have a price (silage), impacting on sustainability and increasing operating costs. Consequentially, should substitute feedstocks have a lower biomethane potential (eg. replacing poultry manure with cattle slurry), quantities and throughput need to increase to meet desired the production, resulting in higher energy, heat and transport requirements.

4.6.2 Digester Loading & Retention

Inconsistent feeding
Inconsistent biogas production rates may be the result of unstable feeding, which is when large daily variations in the organic loading rate (OLR) occur due to changes in the quantity and quality of feedstock that is being processed. The inconsistency in feeding does not have a significant influence on process stability if correctly monitored and is largely dependent on the feedstock mixture fed to the plant. The OLR can be varied through the feedstock concentration, and hydraulic residence time (HRT). In AD plants utilising agricultural manures, an OLR of 3.0 kg VS / m^3 day is normal.

Organic overload
Organic overload occurs when the amount of organic matter fed to the biogas plant exceeds the total degradation capacity of the microbes to produce biogas. In this situation, the organic material will undergo partial degradation to volatile fatty acids (VFA) at the hydrolysis stage and will accumulate in the digester. The difficulty in reaching further degradation stages then results in low methane yields, and overall poor digester performance. The increased acidification in the digester will result in decreased pH, to a point where biogas

production is zero and the process dies. In practice, typical causes of organic overload (and consequently acidification) are changes in feedstock mixture and composition, incorrectly measured inputs or increased mixing which suddenly leads to inclusion of unreacted material (e.g. floating layers) into the digestion process (Schriewer, 2011). Changes to the feedstock mixture should be introduced gradually.

Hydraulic overload
Hydraulic overload occurs when the hydraulic retention time (HRT) – the residence time required for efficient digestion of organic material in the digester – is exceeded and not enough time allowed for multiplication of the anaerobic microbes, their concentration will decline and they will gradually be washed out of the digester as digestate. When microbes are flushed from the digester, faster-growing acidifying microbes like VFAs will overpower methanogens, in a similar manner to organic overload, eventually ceasing biogas production. It is therefore important that all liquid inputs, as well as solid inputs, to a digester are measured and recorded.

4.6.3 Temperature

The microbial temperature of the digester depends on its specific operating regime (psychrophilic, mesophilic, thermophilic). In an AD plant, mixed cultures are involved, meaning the composition of the different microbes will adapt to the temperature of fermentation. It is recommended to control digester temperature as tight as possible for fermentation, limiting daily temperature variations to <2°C for mesophilic processes. Correct monitoring of digester temperature and adequate control of the heating system is necessary to avoid instability.

4.6.4 Ammonia Inhibition

Ammonium nitrogen (NH_4-N) is produced by the degradation of proteins at the hydrolysis stage of AD for feedstocks containing nitrogen. In a digester, the NH_4-N (Total Ammonia Nitrogen, TAN) is present as ammonium ions (NH_4^+) and as free ammonia (NH_3). The free ammonia portion of the TAN is considered as the primary inhibitory substance as it passes through the cell membrane of the microbes (Chen et al., 2008). Temperature and pH in the digester are proportional to the free ammonia presence, meaning careful control is required.

In practice, high TAN feedstocks can pose problems on process stability in AD plants. Rapid changes from low nitrogen feedstocks to high nitrogen feedstocks can be especially problematic (such as poultry), with gradual adaptation required. The literature defines different TAN thresholds at which ammonia inhibition starts, generally in the range of 3.0-5.0 g NH_4-N / litre for mesophilic conditions (Yirong et al., 2017). In this study, TAN levels of 3.0 g NH_4-N / litre are set as the upper limit for AD stability. Treatment mechanisms for ammonia include ammonia scrubbing, which removes the ammonia content of the feedstock via ammonia ammines, separating the ammonia from the feedstock/digestate. This ammonia can be used as an organic fertiliser, another potential revenue source for the plant.

4.7 Environmental Sustainability

4.7.1 Protected Areas

Restricted areas for development according to the NPWS are displayed in Figure 34. The National Parks & Wildlife Service (NPWS) is responsible for the designation of conservation sites in Ireland, which is required under European and national legislation aims to conserve habitats and species. The NPWS works with farmers, other landowners and users, and national and local authorities, to achieve an appropriate balance between land use for farming and other human activity, with the need to conserve natural ecosystems.

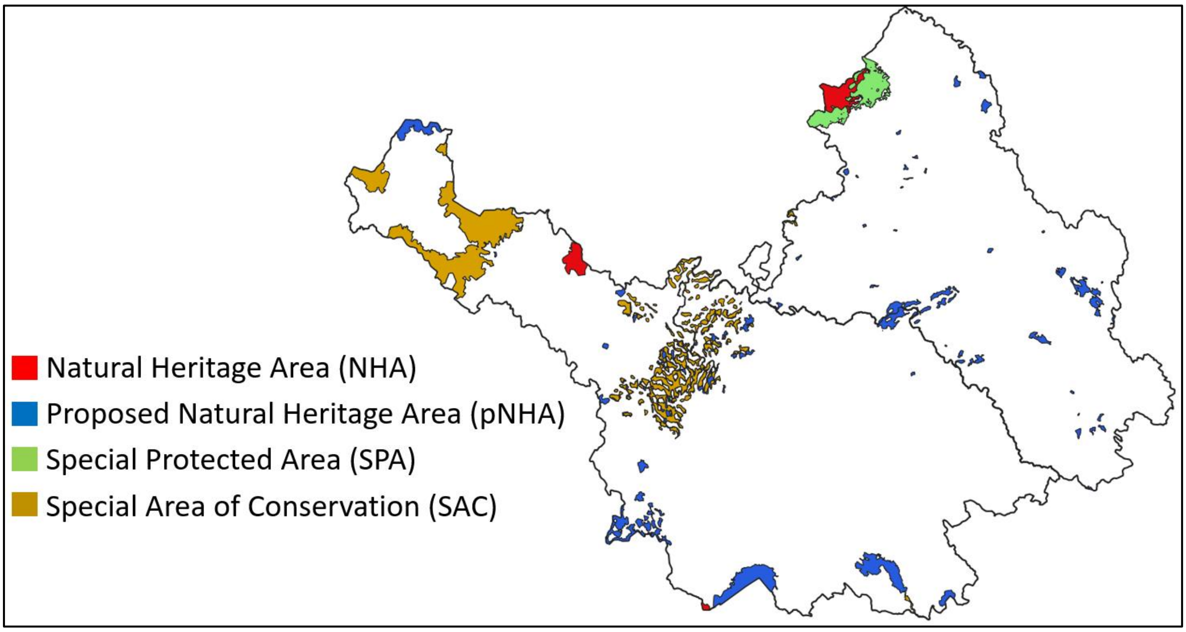

Figure 34 – Protected sites (labelled as one of NHA, pNHA, SPA, SAC) for Cavan and Monaghan according to NPWS.

In Co. Monaghan, there is one SAC, one SPA site, one NHA site, and 38 pNHA sites. In Co. Cavan, there is 6 SAC sites, 3 SPA sites and 1 NHA site. Most of these sites are hills, lakes, rivers, bogs, or historical buildings. For a large-scale industrial project like an AD plant, these sites would not be suitable irrespective of their protected status, as the necessary infrastructure such as good road access, and utility connectivity, would not be present. In the selection of an appropriate site for AD projects, these areas are avoided.

4.7.2 County Development Plans

County developments plans (CDP) for both Cavan and Monaghan[9] were consulted for strategic approaches to renewable energy developments in the region. The most recent CDP for Monaghan County covers 2019 – 2025 while Cavan are in the process of drafting and reviewing a CDP for 2022 – 2028.

Monaghan County

In assessing strategic aims of the CDP, there are several areas outlined by Monaghan County Council that are pertinent to the development of an AD plant.

- Paragraph 15.20 outlines strategy for renewable energy;

"In assessing planning applications for these types of development, particular regard will be shown to the following:

  - *Monaghan County Development Plan 2019-2025*
  - *Impact on the visual amenities of the area.*
  - *Impact on the residential amenities of the area.*

[9] https://monaghan.ie/planning/new-county-development-plan/

- *Scale and layout of the project, any cumulative effects due to other projects and the extent to which the impacts are visible across the local landscape.*
- *Visual impact of the proposal with respect to protected views, scenic routes and designated scenic landscapes.*
- *Impact on nature conservation, ecology, soil, hydrology, groundwater, archaeology, built heritage and public rights of way.*
- *Impact of development on the road network in the area.*
- *Level of noise disturbance and where applicable shadow flicker.*
- *Level of compliance with national and regional guidance documents."*

- The renewable energy policy as described in Monaghan's County Council's Renewable Energy Development Exemptions Policy (EP1) is relevant to the development of AD plants in the region;
  "To encourage and facilitate renewable energy proposals at suitable locations where it is demonstrated the development will not have a detrimental impact on the visual and residential amenities of the surrounding area and other matters of acknowledged importance where it is located and assessed in line with the criteria set out in Section 15.20 of the Monaghan County Development Plan 2019-2025."

- Paragraph 8.13 outlines the county's Energy policy;
  "The Planning Authority will adopt a favourable approach to renewable energy developments. Projects involving indigenous sources of energy such as solar, landfill gas, biomass, energy crops, forestry waste, biogas from sewage sludge and farm slurry will be assessed with the prime policy of the Planning Authority to permit developments that are environmentally sustainable and in accordance with the proper planning of the area."

- Paragraph 8.16 outlines strategy for bioenergy (including biogas);
  "This [biogas] has positive environmental impacts by diverting slurry from land spreading with resultant improvements in air quality. Monaghan County Council acknowledges the potential of bioenergy to realise several objectives contained in this Development Plan in the areas of Energy Supply and Energy Security, Climate Change, Environmental Quality and Pollution and Economic Development & Rural Development. In this context Monaghan County Council will promote and support its development and proposals for Bio-energy related development shall be considered on a case by case basis in accordance with planning and environmental considerations."

Cavan County

A CDP for Cavan county has been drafted and is under review for 2022-2028[10], however, it does not include a renewable energy strategy. The draft indicates that a renewable energy strategy is to be drafted six months after the issue of the CDP. The Chief Executive's summary makes references and provisions to support renewables namely wind and biogas that will be included in the eventual renewable energy strategy.

[10] https://www.cavancoco.ie/development-plan-review.htm?StructureID_str=585

- *BD01 Facilitate the development of projects that convert biomass to energy, subject to proper planning considerations including the impact of nitrogen deposition on sensitive Natura 2000 sites.*
- *BD02 which promotes and prioritises the use of waste streams from agriculture and forestry for renewable energy projects including anaerobic digestion.*
- *BD05 Support the National Policy Statement on the Bioeconomy (2018) and the exploration of opportunities in the circular resource-efficient economy.*
- *BD07 Supports the future-proofing of infrastructure planning to allow for the potential upgrading of existing industrial sites to bio-refining plants while also supporting the use of bio-renewable energy for the sustainable production of bio-based products.*

4.7.3 EPA Licensing

Anaerobic digestion plants must operate under a waste or emissions licence depending on the amount of feedstock to be processed. Plants processing less than 10,000 tonnes of waste can apply for a waste licence which is issued by the local authority. Amounts greater than 10,000 tonnes require an application for an emissions licence made to the EPA.

5.0 FINANCIAL ASSESSMENT

5.1 Budget

Due to the highly variable and bespoke nature of AD projects, it is difficult to accurately define a single metric for evaluating overall plant costs (e.g. CAPEX for t/a processed, m^3 digester, MW capacity etc.). Instead, it is more accurate to piece together various major pieces of equipment or costs. This methodology is open to inaccuracies; however, it serves to identify the most viable project options, which will be then refined using more accurate CAPEX estimates through supplier/vendor quotation.

The difficulty is further complicated when different plant configurations are considered despite being a similar size and output range (MW) as costs can change significantly across various options. In this section there are three AD plant configurations considered.

5.1.1 Equipment

CAPEX for various pieces of equipment is estimated using models derived from information from vendors for generic plant designs, or estimates:

- Digester section (per m^3, including macerator/feed unit, slurry reception tank, digesters, post digesters, pumps, flare, gas boiler)
- Upgrading unit (per Nm^3/h biogas processed)
- Pasteurisation
- Silage storage
- Digestate storage
- Site civil works
- Biomethane connection (direct grid injection or virtual pipeline)

5.1.2 Quotations and Estimates

A variety of quotes were provided by biogas equipment suppliers on the CAPEX of a CSTR AD plant in the 5-10 MW range for a variety of feedstock combinations. The configurations detailed in section 4.5.3 are presented with their associated capital costs in Table 43.

The costs are broken down into digester equipment, biomethane upgrading equipment, civil works and other. Digester equipment constitutes all equipment and assets required and that are associated with the AD process. Examples includes digester, loader, maceration equipment, stirrers, gas holder, filtrate pump, ammonia stripper and HGVs. Biomethane upgrading consists of assets and equipment that participate in the extraction of biomethane from biogas and includes compressor, biomethane tanker, upgrader, gas holder and BNEF equipment. Civil works and construction refer to the associated costs due to construction, equipment, training, labour, land and utilities connection. Other costs encompass items such as project management, consultancy and contingency which are estimated.

Table 43 - CAPEX breakdown of AD plant.

CAPEX Item	Config A	Cost B	Cost C
Digester Equipment	€8,185,000	€7,615,000	€9,170,000
Biomethane Upgrading Equipment	€4,000,000	€3,735,000	€4,015,000
Civil Works & Construction	€2,600,000	€2,600,000	€2,600,000
Other (Design, Project Management, Engineering Procurement Construction)	€3,000,000	€2,790,000	€3,155,000
Total	**€17,785,000**	**€16,740,000**	**€18,940,000**

5.2 Operating Costs

This section provides a general breakdown of operating costs of an AD plant. Primarily this focuses on day-to-day operations and costs such as heating and electrical requirements, water requirements, transport requirements, feedstock costs (such as silage), personnel and operator wages as well as general maintenance.

5.2.1 Energy Requirements

Heat and electricity are required for the AD process. For electricity, an MV connection is assumed to the nearest substation with adequate capacity. Site location criteria makes consideration for the electricity substation. An electricity price of 12 c/kWh is assumed based on the required connection size (SEAI commercial energy prices). For plant heating, fuel oil is imported and combusted in an oil boiler. The oil boiler supplies heat to the digesters, pasteurisers, and ammonia stripper. A heat exchanger with an effectiveness of 60% is also assumed in the process for heat recovery. Oil has an assumed price of 8 c/kWh (SEAI commercial energy prices). Alternatively, if a plant were located near to a gas connection, natural gas could be used to fulfil the heating requirements of the plant with the benefit of being cheaper than heating oil at 4.5 c/kWh (SEAI commercial energy prices). However, for the purposes of this study oil is utilised for heating requirements.

Although for the purposes of this report oil was used to model the heating costs and associated sustainability, it should be noted that heat pumps could be investigated as an alternative heat source. The low temperature demand of the digesters (38 – 40^0 C) in conjunction with the relatively mild climate is favourable towards such applications.

5.2.2 Other Operational Costs

Although it is assumed that feedstock will have no cost except those associated with transportation, costs can occur particularly in instances where silage is used. These costs are substantial due to the quantities required for biogas production and will dimmish the profitability of biomethane produced.

5.2.3 Quotations and Estimates

Various quotes from biogas equipment suppliers have been obtained and included into the technoeconomic model to calculate operation costs. Presented in Table 44 are the calculated operating costs for the proposed plants.

Table 44 - OPEX breakdown of AD plant.

OPEX Item	Cost A	Cost B	Cost C
Feedstock	€1,300,000	€0	€0
Electrical	€810,000	€725,000	€880,000
Heating	€750,000	€675,000	€695,000
Transport	€800,000	€580,000	€865,000
Other (Salaries, Maintenance, water)	€650,000	€660,000	€925,000
Total	**€4,310,000**	**€2,640,000**	**€3,365,000**

5.3 Revenue Streams

5.3.1 Incentives and Support Schemes

The main incentive and support for a biomethane producing facility falls under the Renewable Heat Obligation scheme (RHO) which is currently under review. This is similar to the Renewable Fuel Obligation scheme (RFO) whereby a certain proportion of all fuel supplied to the market must be renewables or from renewable sources. The scheme then offers support to those suppliers on a c/kWh basis. The RHO seeks to allocate 8-12 c/kWh for renewable fuel.

5.3.2 Wholesale Biogas/Biomethane

In addition to the support provided by the Renewable Heat Obligation Scheme (RHO), the wholesale price of gas is given consideration and its impact on potential revenue. As shown in Figure 35, the price of gas has fluctuated over the decade, with prices recently reaching as high as 9.2 c/kWh[11]. However, these are exceptional and intermittent with futures indicating a return to the 3 c/kWh range. Prices are more likely to average in the range of 1 to 3 c/kWh (the average price over the decade being 2.94 c/kWh) and are thus incorporated into the model.

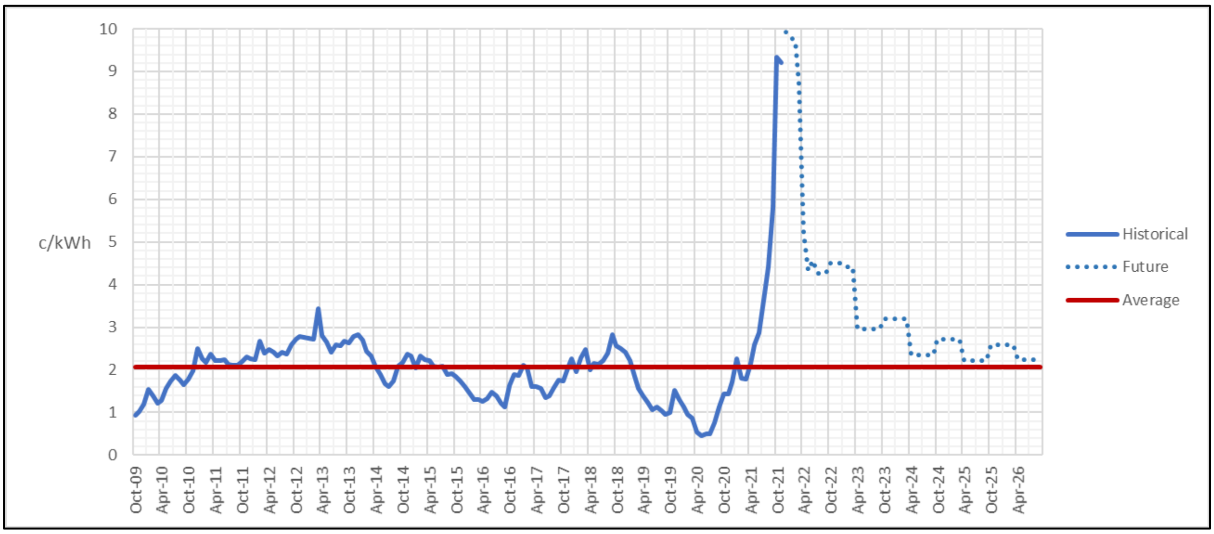

Figure 35 - Historic day ahead gas prices over the past decade.

Given the plant configurations presented, the expected biomethane yields from such plants are presented in Table 45.

[11] MAREX Spectrometer November 2021

Table 45 - Plant biomethane output.

Plant Configuration	Feedstock Input (t/a)	Biomethane Output (m^3/a)
A	169,048	4,988,265
B	169,048	3,465,488
C	57,904	5,458,201

Assuming a gas price of 10 c/kWh is allocated, the above configurations would yield the following revenue and IRR over a 15 year plant lifetime as shown in Table 46.

Table 46 - Financial model based on calculated costs and revenue at 10 c/kWh support.

Plant Configuration	Annual Revenue	IRR
A	€775,000	-6%
B	€870,000	-3%
C	€2,150,000	7%

Table 47 - Financial model based on calculated costs and revenue at 11 c/kWh support.

Plant Configuration	Annual Revenue	IRR
A	€1,280,000	0%
B	€1,220,000	1%
C	€2,705,000	11%

Table 48 - Financial model based on calculated costs and revenue at 12 c/kWh support.

Plant Configuration	Annual Revenue	IRR
A	€1,785,000	5%
B	€1,570,000	4%
C	€3,258,000	15%

Results presented demonstrate a clear advantage to plants which focus on processing feedstocks that have high biomethane content (i.e. CH_4/kg feedstock) as less material is required and processed, leading to lower OPEX costs and less transport, heating and energy are required while biogas yields are larger and overall more sustainable (less emissions associated with OPEX). However, a support of 10 c/kWh does not sufficiently support plants using feedstocks with lower biomethane as seen in Table 46 with only configuration C being viable. The plant configurations presented only become marginally viable at support of 12 c/kWh.

5.3.3 Biofertilizer

In section 3.0, fertiliser replacement value was assigned to each feedstock. As stated previously, the AD process produces large amounts of digestate that requires disposal in lines with ABP regulations. The digestate itself retains the nutrients that ordinary manure would have although now treated and of higher quality. Benefits include reducing the need for chemical fertiliser, reducing soil erosion and nutrient runoff. It is still subject to the prohibited fertiliser period as described in Table 41 in section 4.3.2.

Ammonia stripping of the feedstock not only allows prevention of ammonia inhibition in the digester and facilitating the recycling of water but also the extracted ammonium sulphate can be used as a direct substitute to conventional synthesised ammonia fertiliser, thus, reduce demand for a fossil fuel derived product as a fertiliser. This is particularly worthwhile with feedstocks that are typically high in ammonia such as poultry manure where the ammonia should be removed regardless as to prevent inhibition of the AD process in the digester.

There is currently no standards in Ireland for fertiliser or manure by products. In the UK and Northern Ireland, the AD sector is further supported by the Biofertiliser Certification Scheme (BSI PAS 110:2010) which treats certified digestate as a product and not a waste. This certification obliges AD operators to follow standards and regulations to ensure the digestate is a high quality, reliable and safe product. The introduction of such standards in an EU or Irish context would greatly incentivise AD development within Ireland and would allow for the exportation of high quality digestate, easing access to suitable lands for disposal and use. Such regulations are advocated for by Renewable Gas Forum Ireland (RGFI) and other AD groups.

6.0 Conclusion

There is major potential for the development of Anaerobic Digestion in the Border Region given the intense, regional agricultural activity and the geographic concentration of high biomethane potential feedstocks. The cumulative biomethane potential in the region amounts to 764 GWh/a (cattle slurry 280 GWh, FYM 68 GWh, pig slurry 39 GWh, poultry 176 GWh, grass silage 198 GWh and OFSMW 3 GWh). Although unrealistic in practise to capture all potential feedstocks, the quantities present would allow for the development of large plants in the 5-10 MW range (producing 37.2 – 75 GWh of biomethane). The RED II initiative seeks to provide a GHG bonus of -45 gCO_2/MJ for manure emissions captured by AD. This does not apply to grass silage or energy crop feedstocks which impact on plant sustainability.

Candidate plant sites were considered along with the available feedstocks within 10, 20 and 30 km distance from them. AD would be particularly suited in the northern Monaghan area where there is a large concentration of the poultry industry where large amounts of poultry manure are situated, an ideal feedstock candidate given its high methane content.

Consideration to plant design highlights the parameters of interest and optimisation with regards to the available feedstock (solids content, temperature regime, etc). CSTR AD plants were found to be preferable due to the lower capital expenditure required, better biogas extraction and market availability.

Management of feedstock and digestate will require that on-site storage would have to be incorporated into an AD plant design as stable feedstocks such as FYM cannot be collected year-round. The period prohibiting the spreading of slurry and fertiliser during the winter months also require that sufficient digestate storage for 4 months is included.

The development of AD for biomethane production with the intent for gird injection was found to be the most viable option over CHP and electricity generation given that existing schemes favour other renewables for their production. Biomethane production is to be supported by the Renewable Heat Obligation scheme, allocating 8 – 12 c/kWh, which is currently under review. Biomethane injection can be facilitated by the extension of the gas network for injection to occur on the AD site or via virtual pipeline where HGVs carry gas to a BNEF injection point.

Project risks and constraints identified include feedstock security, organic/hydraulic overloading, temperature fluctuations, ammonia inhibition and contaminants. Environmental sustainability highlights NPW special and sensitive areas to be avoided.

A financial assessment determines that for the development of an AD plant in the 5 -7 MW range would require a CAPEX of €16-19m with OPEX of €2.6m – 4.3m. Revenue streams are identified, namely support for biomethane production allocated under the RHO and revenue from fertiliser sales, derived from both extracted ammonia and digestate. Three plant configurations are presented based on the most viable feedstocks available and a financial model was developed assuming a 10c/kWh support over a 15 year plant lifetime. It is demonstrated that this was only sufficient for plants using high methane content feedstock (poultry), with poor performance from low methane content feedstocks (Cattle manure). This is attributed to the fact that lower biomethane content feedstocks require more CAPEX and OPEX whilst producing less biogas. Higher support at 12 c/kWh is required to make these marginally feasible. As the majority of feedstock (by tonnage) in the region is cattle based, this higher support should be considered if decarbonisation of the agricultural sector is to be promoted and encouraged.

The biomethane potential due to the large quantities of agricultural wastes in the border region makes AD development an attractive and technically feasible endeavour. Ultimately, the economic viability of such a project is dependent on government support via the implementation of a favourable and adequate support level through the Renewable Heat Obligation scheme. Further support through biofertilizer standards can encourage AD development, allowing for the production and exportation of digestate/fertiliser.