REGATRACE (Renewable Gas Trade Centre in Europe) is a European collaboration which aims to create an efficient cross border trading system based on the trading of biomethane and issuing of Guarantees of Origin (GoO). RGFI is the lead partner for REGATRACE in Ireland that commenced in 2019, and since then has worked with key stakeholders in a public and private collaboration to develop an agreed vision and roadmap for biomethane in Ireland.

This project receives funding through the European Union's Horizon Programme for research and innovation under Grant Agreement No 857796

EXECUTIVE SUMMARY

This feasibility study on anaerobic digestion (AD) in the Ballyhoura region examines a range of AD plant pathways and findings on feasible plant configurations for Mitchelstown using agricultural feedstock and biodegradable materials.

It draws on the framework and guidance provided through the EU REGATRACE programme for conducting feasibility analyses. www.regatrace.eu. As per the REGATRACE D6.4 guidance, this feasibility study covers aspects of technical and market feasibility as well as the commercial proposition and overall risk assessment. It is also in line with the REGATRACE / RGFI Roadmap, which itself draws on extensive consultation and industry collaboration.

This project sits within Ireland's new biomethane industry where the vision is to use farm based AD biomethane to decarbonise difficult to decarbonise sectors ie the thermal demands of industry and agriculture, in line with REDII, the EU Green Deal Farm to Fork strategy and national policy in AgClimatise and Climate Action Plan. With the ongoing war in Ukraine and energy crisis this project also helps to meet the need for sustainable, indigenous secure energy supply and price stability.

The Government of Ireland has formally appointed Gas Networks Ireland as the National Issuing Body for the Green Gas Certification Scheme and is operating the Renewable Gas Registry.

This report consists of key sections:

- Technical assessment:
- EU and Ireland farm-based feedstock AD development context
- Regional Feedstock Analysis
- Basis of Design
- Ownership & Stakeholders
- Financial Assessment
- Risk assessment

Technical assessment – feedstock availability, plant design and operation

The feedstock analysis assesses the availability of a variety of feedstocks in the Ballyhoura Region based on their geographical dispersion, digestion characteristics, availability and biomethane potential. A significant proportion of the biomethane potential in the region is from cattle slurry at approximately 148 GWh. Mitchelstown represents the Electoral Division (ED) with the largest quantities of cattle slurry and FYM. More than 70% of large pig farms in the region are in or around the South-East of the region (Mitchelstown); pig slurry is considered a useful feedstock at short distances due to the large-scale localised collection points and slurry disposal requirement. Silage is in high demand in the region, however there is anecdotal evidence through survey results, that there is potential to grow more, and that maize is grown in significant quantities in the vicinity of Mitchelstown.

Extensive engagement with farming stakeholders was conducted to obtain information, investigate potential concerns and guide the project's direction. A survey circulated to local farming stakeholders and wider regional associations assessed local feedstock availability, attitudes and motivations for AD participation. Most viewed local AD development as positive, however, concerns were expressed over potential competition between plant feedstocks and animal fodder with regards to land use for grass silage production. Concerns over the availability of FYM in the region was also raised in stakeholder group meetings as survey responses yielded limited availability of the feedstock, potentially increasing reliance on grass silage. Project organisational structures were investigated using a weighted scoring system concluding that a co-operative is the most appropriate organisation structure for this project.

A spatial analysis based on 8 no. candidate plant locations was carried out and Mitchelstown was chosen for the focus of the study based on its high level of intensive pig farming in proximity, significant feedstock potential within 10 km, the adjacent planned biomethane network entry facility (BNEF), and its strong gas, utilities and road network.

Plant designs were considered, with continuously stirred tank reactor (CSTR) design being the most practical for the feedstocks available. It is the most common and widely available on the European market and has the lowest capital costs. Mesophilic AD temperatures (35 – 45 °C) are found to be more suitable to the proposed plant, 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 on-site storage for months where feedstock cannot be acquired, i.e. cannot be collected when pasture grazing, nor digestate disposed of due to prohibited spreading winter period. Various storage options for both feed stocks and digestate are presented and their relative advantages discussed.

Digestate upgrading technologies are presented for treating solid and liquid fractions of digestate as to either reduce the amount of material required for disposal or create a more nutrient concentrated product which can be valorised. These are later included in the financial analysis and plant configurations as optional configurations and their impact on the plants' financial performance are assessed.

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.

Four configurations were explored and assessed in this case based on the feedstock put forward, with three sized at an output of 40 GWh and one size to produce 20 GWh (based on sizing recommendations from Project Clover and current available feedstocks in the region). Plants are designed to be wet CSTR types, operate at mesophilic temperature conditions (38-40°C), pasteurisation (Type 1 ABP rules), 25-day hydraulic retention time, 80% volatile solids destruction, 90% capacity factor (7,884 h/year operation), Carbon-Nitrogen (C:N) ratios of between 20-30:1, digestate separation into liquid and solid fractions or liquid biofertilizer and solid biofertilizer upgrade.

Potential operating constraints and project risks were identified; feedstock security, digester loading and retention, temperature, ammonia inhibition and contaminants, fertilizer upgrading risk and risks with community engagement.

The four plant configurations meet the 80% GHG savings required for RED II AD biomethane plants (limit from 2026) which considered the proposed feedstocks supplied for biomethane production, transport, processing and disposal. However, when including fertilising upgrading process, the diminished GHG savings pushed Plant C (co-digested with maize) under the 80% savings target and Plant D (co-digested silage) was pushed under when both the liquid and solid fractions were upgraded, making these configurations unviable based on the suggested feedstock makeup scenario. Detailed energy savings optimisation could push these configuration's energy savings above the minimum requirement.

The plants considered will require planning permission, EPA and ABP licensing and to manage local community concerns, early engagement is essential from the outset.

Financial assessment

This study presents the commercial feasibility of the project and potential support schemes at the time of writing in October 2022.

Capital financing of this project will likely require Government support. RGFI in presenting the key asks of industry to Government, has been advised by Government and by the Ireland Strategic Investment Fund (ISIF) that there will be both capital grant and loan support available. Discussions are at an advanced stage and details of how this will be administered are currently being finalised.

In terms of on-going support to meet the funding gap, this study refers to the Renewable Heat Obligation (RHO) Scheme that was put forward by RGFI as the most enduring, secure and fairest means of socialising the cost of producing biomethane, while supporting the industry. The RHO Scheme is now being prepared for public consultation on its design, structure and administration, having been agreed by Government to proceed. The expectation is that shippers / suppliers will provide a voluntary contribution of 0.5 – 1% of biomethane to consumers up to 2025 and a mandatory contribution of 3% from 2025 onwards, reaching a target of 10% by 2030.

A financial analysis was carried out on the four plant configurations over a 15-year plant lifetime, using the proposed Renewable Heat Obligation scheme (RHO) support as the main revenue source in conjunction with capital and operating cost estimates from biogas/biomethane/carbon dioxide/biofertilizer equipment supplier quotes.

Note: No Capital funding to the AD biomethane plant is taken into consideration in this report. RGFI, in representing the AD biomethane industry has made the case that 50% Capital Funding and the RHO are basic requirements for the economic feasibility of AD biomethane plants at the optimum scale of 20GWh. The intention is to support the rural bioeconomy, through farmers being central to developing, owning agri feedstock-based AD biomethane plants and benefiting economically, while delivering environmental benefits and decarbonising agriculture.

The assessment and analysis based on the proposed feedstocks in this case shows the viability of a 40 GWh plant co-digesting pig slurry and cattle FYM at current market pricings. Note that this study does not consider the potential for future improved upgrading and use of digestate in terms of GHG emissions reduction, carbon farming and commercial performance.

Incorporating silage or maize in the co-digestion is feasible, however, the returns are improved where the liquid fraction of the biofertilizer is upgraded to extract more value from the digestate as well as provide operational benefits to the plant (reduced transport and storage of digestate). The largest IRR (9.8%) calculated involved the co-digestion of pig slurry and FYM with liquid fraction upgrading. A similar return (9.2%) can be achieved by replacing a portion of the FYM with grass silage (plant D) also including liquid fraction upgrading.

In the absence of Capital Funding, the 20 GWh is not feasible due to economies, CAPEX and OPEX of 40 GWh plants are only 30% more while revenue increase 77%. The analysis shows 12 c/kWh of the proposed RHO rates (8 to 12 c/kWh) is necessary to ensure the viability of these plants.

Table of Contents

1.0 Glossary & Terminology

Table 1 - List of acronyms and abbreviations used in the report.

ABP	Animal By-Products
AD	Anaerobic Digestion
AER	Annual Environmental Report
BD CLG	Ballyhoura Development CLG
BNEF	Biomethane Network Entry Facility
BOD	Biological Oxygen Demand
CAF	Climate Action Fund
CAPEX	Capital Expenditure
Cat	Category
CBOD	Carbonaceous Biological Oxygen Demand
CDP	County Development Plan
CGI	Central Grid Injection
CHP	Combined Heat & Power
CLG	Company Limited by Guarantee
CNG	Compressed Natural Gas
Co-op	Co-operative
CSO	Central Statistics Office
CSTR	Continuously Stirred Tank Reactor
DAC	Designated Activity Company
DAF	Dissolved Air Fraction
DAFM	Department of Agriculture, Forestry & Marine
DAS	Dewatered Activated Sludge
DECC	Department of Environment, Climate and Communications
DM	Dry Matter
EBA	European Biogas Association
ED	Electoral Division
EIAR	Environmental Impact Assessment Report
EPA	Environmental Protection Agency
EWC	European Waste Codes
FW	Fingleton White
FYM	Farmyard Manure
GDPR	General Data Protection Regulations
GHG	Greenhouse Gases
GNI	Gas Networks Ireland
HGV	Heavy Goods Vehicle
IRR	Internal Rate of Return
ISIF	Ireland Strategic Investment Fund
ITM	Irish Transverse Mercator Coordinates

LCO_2	Liquefied Carbon Dioxide
Ltd	Private Company Limited by Shares
MV	Medium Voltage
NTMA	National Treasury Management Agency
OFMSW	Organic Fraction of Municipal Solid Waste
OPEX	Operational Expenditure
RED II	EU Renewable Energy Directive II
REFIT	Renewable Energy Feed In-Tariff
RESS	Renewable Electricity Support Scheme
RGFI	Renewable Gas Forum Ireland
RO	Reverse Osmosis
RFO	Renewable Fuel Obligation scheme
RHO	Renewable Heat Obligation Scheme
SEAI	Sustainable Energy Authority of Ireland
SSRH	Support Scheme for Renewable Heat
VFA	Volatile Fatty Acids
WWTP	Wastewater Treatment plant

Table 2 - Units & terminology used throughout the report.

Acronym	Name	Measure	Explanation
a	Per annum	Time	Per year.
C:N	Carbon Nitrogen Ratio	-	Ratio of Carbon to Nitrogen in a given substance.
CH_4	Methane	-	Chemical symbol for methane/biomethane.
CO_2	Carbon Dioxide	-	Chemical symbol for carbon dioxide.
NH_3	Ammonia	-	Chemical symbol for ammonia.
NH_4	Ammonium	-	Chemical symbol for ammonium.
ha	Hectare	-	Equivalent to 10,000 m^2
μm	Micrometer / micron	Distance	Equivalent to one millionth of a meter.
kWh	Kilo Watt hour	Energy	Energy required to sustain 1 kW power rate for 1 hour. Equivalent to 3.6 MJ.
MWh	Mega Watt hour	Energy	Equivalent to 1,000 kWh.
GWh	Giga Watt hour	Energy	Equivalent to 1,000,000 kWh.
TWh	Terra Watt hour	Energy	Equivalent to 1,000,000,000 kWh.
MJ	Mega Joule	Energy	Equivalent to 1,000,000 J or 0.2777778 kWh. Joule (J) is the fundamental unit of energy.
MW	Mega Watt	Power	Equivalent to 1,000,000 W. The Watt (W) is the fundamental unit of power (rate of energy consumed/produced), equivalent to 1 J per second.
gCO_2	Grams CO_2	Mass	Grams of Carbon Dioxide
$MtCO_{2eq}$	Mega tonnes of CO_2 equivalent	GHG	Equivalent of 1,000,000 tonnes of CO_2 in GHG potency.

HRT	Hydraulic Retention Time	Time	Time feedstock is to reside in the AD digester.
OLR	Organic Loading Rate	VS/m^3	Amount of VS per unit volume of feedstock in the digester.
TS	Total Solids	-	Portion of material constituting exclusively of solids.
VS	Volatile Solids	-	Portion of solids that can be broken down into biogas in AD process.
VSD	Volatile Solids Destruction	-	Efficiency of AD process in breaking down VS into biogas.

2.0 INTRODUCTION

Anaerobic digestion (AD) presents a viable method for decarbonising traditionally hard-to-decarbonise agriculture and heat industries in addition to providing an indigenous and secure energy source. AD is both a mature technology and a mature industry having developed throughout Europe over the last 20 years. The European Biogas Association (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) despite Ireland having the highest biomethane potential per capita in the EU given the strong agricultural and agri-food industries.

The slow deployment of AD in Ireland has been primarily due to lack of government support to stimulate an indigenous biogas industry and clear legislation and policies. However, through the work of RGFI and industry collaboration, presenting the decarbonisation imperative and the business case for biomethane, the Irish government have in the Climate Action Plan recognised the important role that biomethane as a zero emissions gas can play in helping meet critical decarbonisation targets as set out in EU Directives and national legislation under the sectoral carbon ceilings targets by 2030. The Climate Action Plan 2021 by the Irish government sets out a series of objectives that must be achieved over the coming decade. Under the agricultural section, strategies, and objectives to reduce agricultural associated GHG emissions. The last target sets out that contribution of agricultural feedstocks to the production of 1.6 TWh per annum of indigenous sustainably produced biomethane for injection into the gas grid by 2030, which is estimated to have an additional abatement impact of 0.1 to 0.2 MtCO_2eq for agriculture and 0.4 MtCO2eq for the energy sector. As of August 2022, the government and agricultural sector have agreed to a 25% reduction (5.75 MtCO_2eq) in the sector's GHG emissions by 2030. AD was highlighted as a key method and technology of achieving this.

The Ballyhoura region situated around the Ballyhoura mountains of East Limerick, West Tipperary and North Cork is home to an intensive agriculture and agri-food industry. Ballyhoura Development CLG appointed Fingleton White to carry out a feasibility study on a community led AD project using agri-waste to complement the existing farm practices and land management. The desired outcome being to improve sustainability and decarbonise farm and food production, providing a diverse alternative, additional income stream and benefiting the farmer, farming groups, and the rural economy.

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. Digestate is the residual matter left after the AD process has extracted biogas from the feedstock. Fertiliser nutrients that are contained within the manures and feedstocks, Nitrogen (N) -Phosphorous (P)-Potassium (K), are preserved and concentrated in the digestate during the AD process in addition to breaking down volatile fatty acids present, producing a less odours than slurries and manures. Therefore, AD adds further value to raw feedstock materials by yielding bio-fertiliser suitable for agricultural purposes.

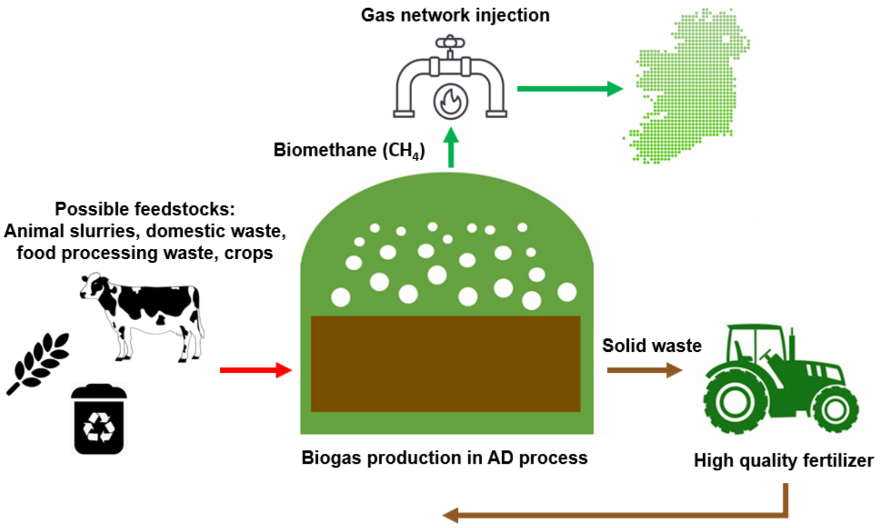

Figure 1: Anaerobic Digestion Process

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 multispecies sward, red clover rye grass mix, 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 section 3.

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. This task demands a variety of interrelated services and disciplines, balancing the reprocessing of biodegradable materials 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

This feasibility study is to provide a business case for the development of a showcase, community led AD project in the Ballyhoura region to harness its significant agri-biodegradable materials potential to decarbonise the local agricultural sector and promote a circular, rural bioeconomy. The project investigates the feasibility of a 20 GWh plant depending on the availability and suitability of animal manure/slurries, silages, catch crops, organic municipal waste, and other feedstocks. The following list represents the primary objectives for the feasibility study;

- Assemble information on feedstocks in the Ballyhoura region, namely quantities, characteristics, dispersion, and sustainability
- Engage with key stakeholders in the region
- Identify various technologies and processes to add further value to the project
- Identify and develop a techno-economically viable AD project in the region
- 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 fuel of the AD process is feedstocks or substrates, comprising of digestible organic materials such as animal manures, crops, sewage sludge, food processing waste, home, and commercial food waste. The co-digestion of several compatible feedstocks allows for producing optimal conditions in the digester and thus maximise biogas yields. Optimising feedstock mixtures is crucial and should be considered on feedstock characteristics, physical/chemical properties, geographical distribution, and availability in addition to potential costs. A consistent and constant flow of feedstock is crucial to avoid disruption to any biogas operation. The EU Renewable Energy Directive's (RED II) mandatory sustainability criteria should also be considered when sourcing feedstocks.

The objective of the feedstock analysis is to compile useful information to inform stakeholders on the high-level biogas production of feedstocks in the Ballyhoura region; specifically quantity, quality, cost and availability of local feedstocks. The 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. The main feedstocks considered are:

- Cattle manure (FYM & Slurry)
- Pig Slurry
- Energy Crops (Maize, Grass Silage)
- Organic Waste
- Minor Feedstocks (Poultry, WWTP effluent, Equine)

For each feedstock stream, the following characteristics are considered for the study:

- Total Solids (TS) content in % wet weight (wwt)
- Volatile Solids (VS) content in % wwt
- Energy content MJ/kg and m^3/kg VS
- Chemical composition including nutrient content (NPK), ammonia & 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. Although the study is focused on the Ballyhoura region, feedstocks from nearby counties where logistically practical. Figure 2 displays the area of study and communities associated with Ballyhoura Development CLG within the Ballyhoura region consisting of east Limerick, West Tipperary, and North Cork. In addition to this, extensive engagement with key regional and agricultural stakeholders, along with a survey conducted among IFA and other local farming associations, either confirmed or provided additional data on the local farming practises, available feedstocks and attitudes towards AD. Their advice and contributions helped steer the direction of the project as well as highlight particular risks and areas of investigation.

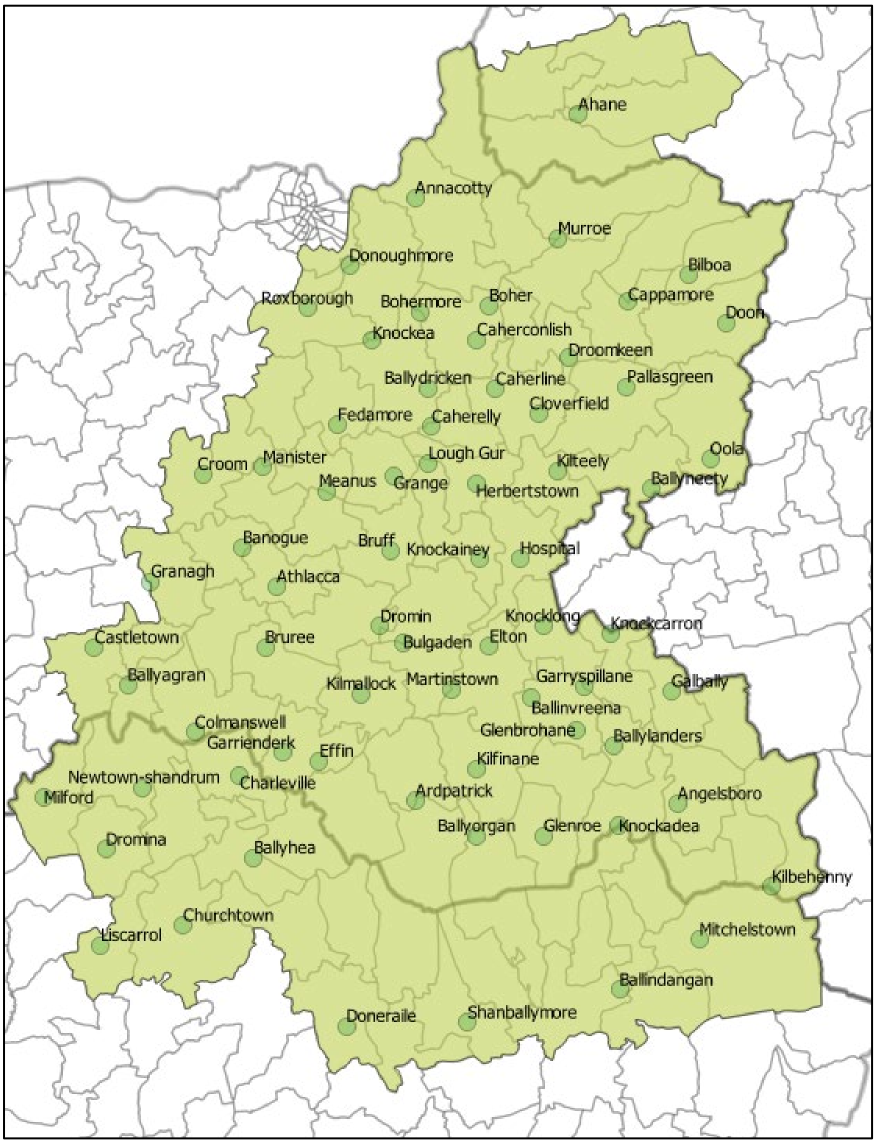

Figure 2: Ballyhoura Region and associated communities in Ballyhoura Development CLG

3.1 Cattle Manure

Agriculture is one of the most important contributors to the economy accounting 9.5% of Irish merchandising exports and compromising 7.1% of total employment. This sector is dominated by beef and dairy exports which are driven by family-farm traditions. This is characterised by a large national herd population spread across all agricultural parts of the country. The national herd has seen a 5.7% growth since 2015. CSO Livestock Surveys for June and December 2021 report that the total number of cattle in Ireland varies between 6.5-7.4 million throughout the year, where variation is due to breeding and slaughtering (higher value reported in 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 2020 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 3,409 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)
- Other cattle (< 2 years and non-dairy, suckler, bulls)

The 2020 Census of Agriculture was not completed until April 2022 due to the COVID-19 pandemic, resulting in very up to date data for this study. Further information on local practises and animal husbandry in the region was gathered through correspondence with local farmers and other stakeholders in the region.

Table 3: Cattle populations in the Ballyhoura region (source: CSO)

Cattle Type	Population
Dairy Cows	43,637
Other Cows	11,966
Other Cattle	99,105

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 4 and
Table 5 respectively.

Table 4-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 5 - Energetic properties of FYM.

Total solids (% wwt)	25.00%
Volatile solids (% wwt)	20.00%
Methane content (m³/kg VS)	0.190
Calorific content (MJ/kg)	1.36
Methane vol. in biogas (%)	60%

In addition to the energetic properties, data on the chemical composition of feedstock is 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 (2022), with Fertiliser replacement value estimated by calculating the chemical fertiliser replaced, with values of 2.18 €/kg N, 3.69 €/kg P and 1.33 €/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 6 - Chemical properties of cattle slurry.

Nitrogen (N, kg/m³)	2.00
Phosphorous (P, kg/m³)	0.80
Potassium (K, kg/m³)	3.5
Ammonium N (NH_4-N, kg/m³)	1.0
C:N ratio	15:1
Fertiliser replacement value (€/m³)	11.97

Table 7 - Chemical properties of FYM.

Nitrogen (N, kg/m³)	1.35
Phosphorous (P, kg/m³)	1.20
Potassium (K, kg/m³)	6.00
Ammonium N (NH_4-N, kg/m³)	0.68
C:N ratio	40:1
Fertiliser replacement value (€/m³)	15.35

Since 2017 the global organic food market has doubled and is continuing to grow as consequence of changes in food consumption trends, as well as environmental and animal welfare concerns. The transition from conventional to organic cattle farming is relatively straightforward compared to other enterprises and has consequently resulted in a large influx of new farmers in recent years. Organic cattle farming is defined as “an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes”. Organic farming has been adapted at a much faster rate in the south and west of the country, particularly in Cork. Figure 3 displays the number of organic producers in Ireland as per February 2017. More up to date values were unavailable.

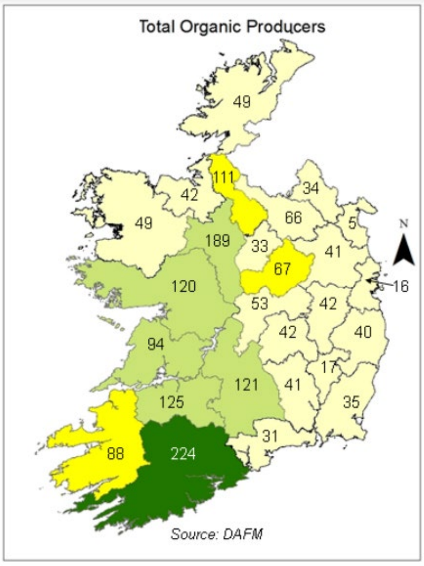

Figure 3 - Organic Producers per County, Ireland, 2017 (Source: DAFM)

The higher standards in housing for the cattle results in large quantities of straw being utilised for bedding and consequently larger volumes of FYM per animal. A random sample of 15 dairy and cattle farms in the Mitchelstown region (including one cattle organic farm) yielded an average of 0.6 m^3/animal compared to the organic cattle farm producing 3 m^3/animal. Organic farms therefore are considered useful suppliers of FYM as a feedstock, particularly in the Cork region.

3.1.3 Quantity and Availability

Using the population of each cattle type in every electoral division (ED), and the specific excretion rate for each type of cattle, the volume of cattle manure per ED is calculated. Each cattle type's excretion rate is given in Table 8 (m^3/week).

Table 8: Cattle Excretion Volumes from Teagasc

Cattle Type	Excretion (m^3/week)
Dairy Cow	0.33
Other Cow	0.29
Bulls	0.25
Other Cattle	0.18

Slurry and FYM can only practically be collected during the months where the cattle are housed indoors. There is a minimum housing period for each farm depending on what zone it is located in. For Tipperary and Cork (in Zone A), the minimum period is 16 weeks while for Limerick and Clare (in Zone B) it is 18 weeks. In practise, the housing periods will trend upwards from this minimum requirement, however the minimum housing period of 16 weeks is deemed a suitably conservative value for establishing manure volumes across a broad region. 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, another cow). Therefore, using the individual cattle populations, minimum housing period, and excretion volumes (Table 9), the total volume of slurry excreted in each ED is established. The spatial distribution of cattle slurry across the regions EDs as well as neighbouring EDs is displayed in Figure 4. Note that 1 m^3 of feedstock is assumed equivalent to 1t.

Table 9: Slurry and FYM proportions by cattle type for Zone A

Cattle type	Slurry (%)	FYM (%)
Dairy Cow	92	8
Other Cow	70	30
Bulls	78	22
Other Cattle	72	28

Using the cited biomethane content of cattle slurry and assuming 100% availability, an estimated biomethane potential across the region is presented in Figure 5. Figure 6 displays the spatial distribution of FYM across the EDs and the corresponding biomethane potential in Figure 7. For this study, it was assumed that during the winter months cattle manure is available in high volumes where slurry is gathered in tanks and FYM is stockpiled and readily accessible for collection. During summertime, when cattle are on pasture it is assumed that available manure will diminish and so the plant will require adequate storage to ensure the feedstock stream is consistent throughout the year. It is also assumed that the raw material cost for either form of cattle manure is 0 €/t since the only value in the feedstock is its nutrient replacement value and after the biogas has been extracted, the digestate can be returned to the farmers as a means of compensation for farm nutrient recycling. Approximately 1.1 million tonnes of cattle slurry and 200 thousand tonnes of FYM is produced in the Ballyhoura region annually which has an accumulative potential of 220 GWh.

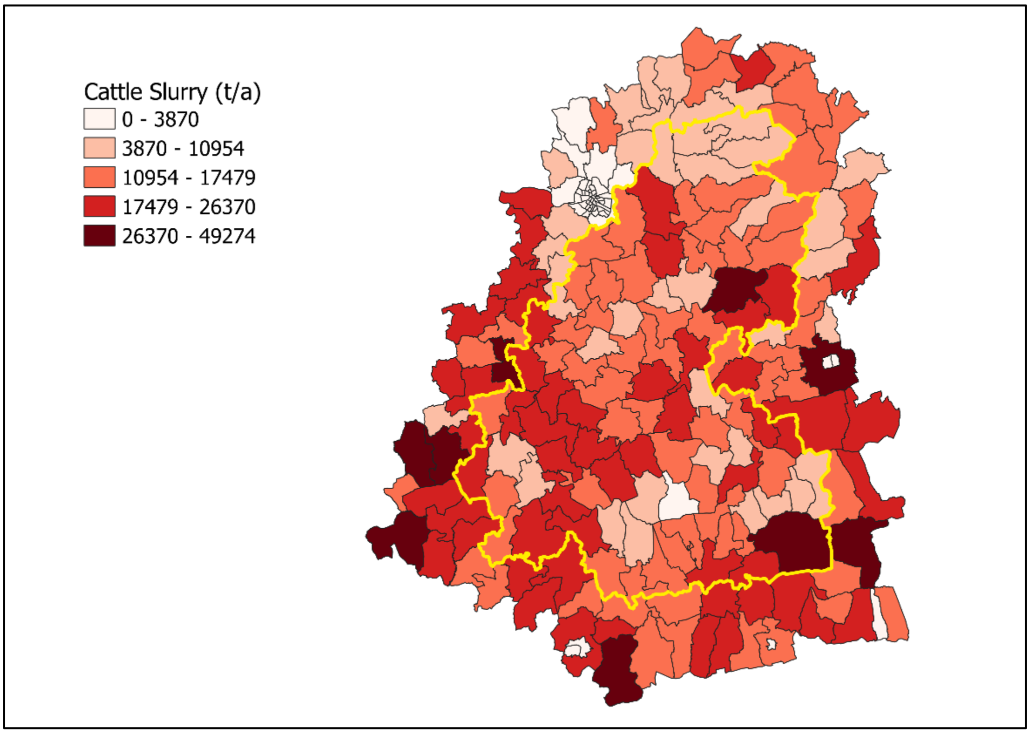

Figure 4 - Cattle slurry quantities in the Ballyhoura and surrounding region.

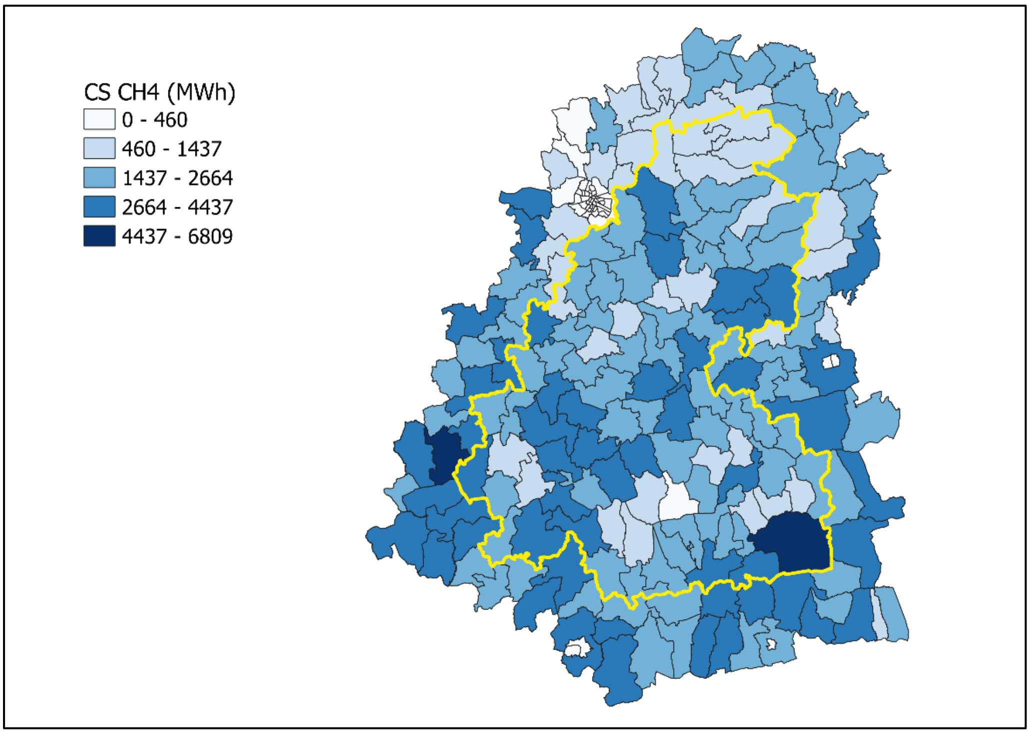

Figure 5 - Biomethane potential from Cattle Slurry in the Ballyhoura region.

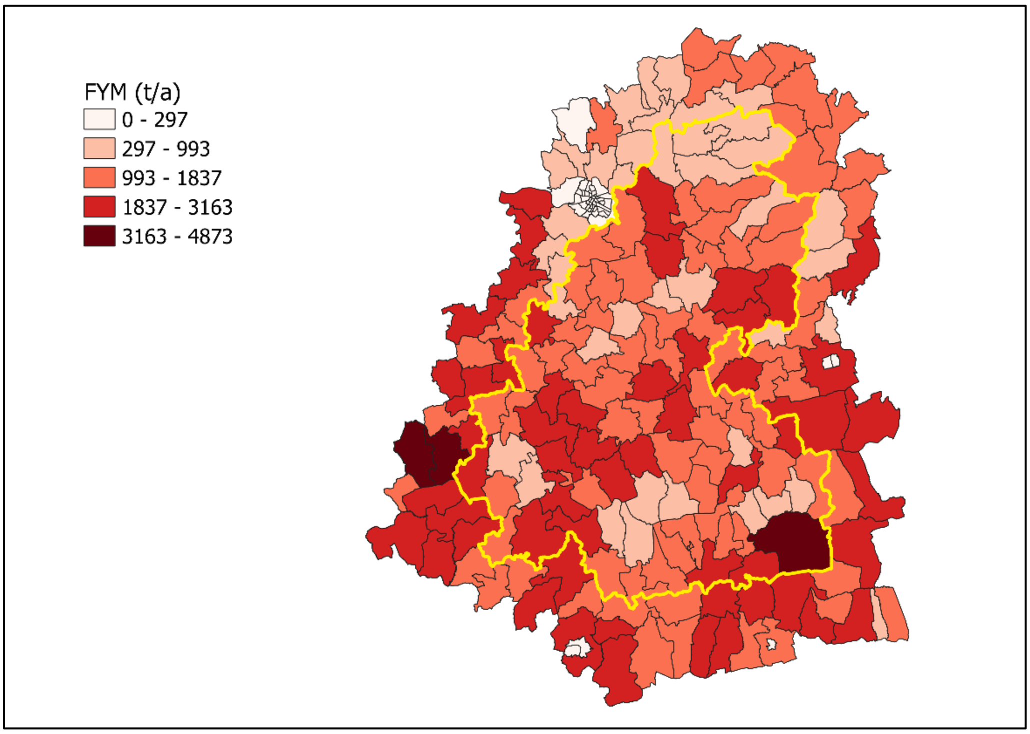

Figure 6 - Distribution of FYM in the Ballyhoura region.

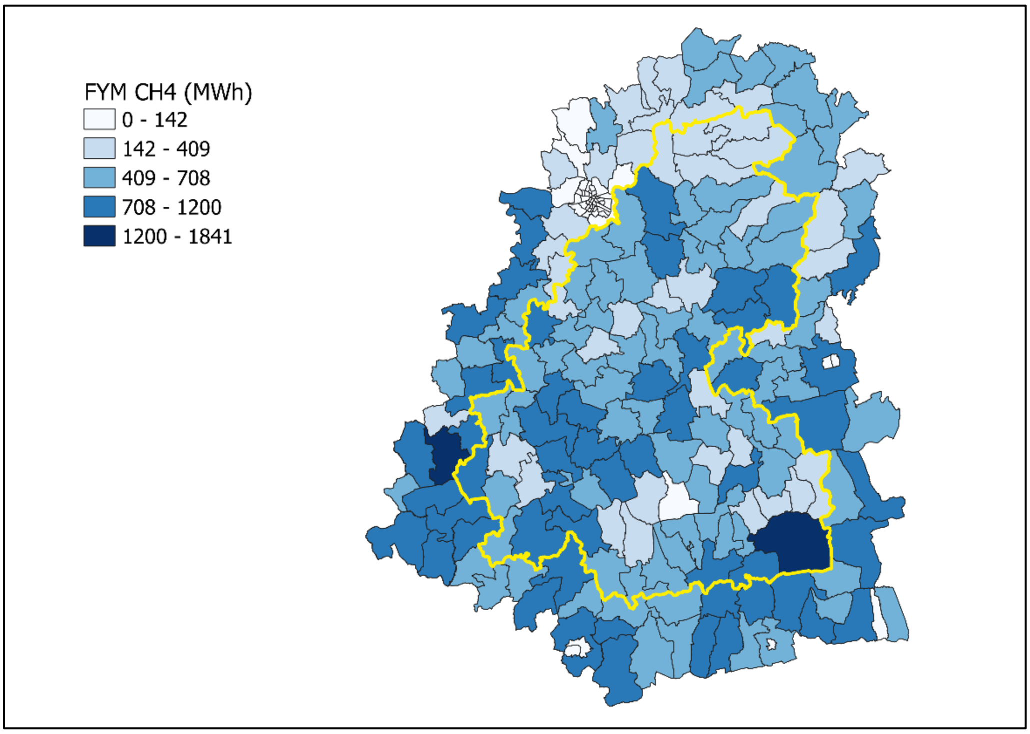

Figure 7 - Biomethane potential of FYM in the Ballyhoura region.

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 valued at €932 million (4% increase since 2020). This important agri-food sector is supported by a large national pig population; according to the latest National Pig Census figures, the total number of pigs in Ireland as of June 2022 stood at 1,694,000, spread amongst 1,675 active herds. 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. Ballyhoura contributes to over 20% of the intensive farming activity in the state, majority of which (71%) occurs in Mitchelstown.

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 AD 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

As described, Irish pig farms are generally clustered into intensive farming units unlike cattle and sheep populations which are generally clustered across thousands of smaller farms. These large pig farms provide a suitable feedstock source for AD since the large pig herds yield large volumes of slurry collected in a single location. In Ireland intensive pig and poultry farms must obtain licenses from the EPA in order to operate. Intensive pig farming practises involve 'the rearing of pigs in an installation where the capacity exceeds (a) 750 places for sows, or (b) 2,000 places for production pigs which are each over 30kg'. Licenced facility operators must 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 35 of them in Cork, Limerick, and Tipperary. The volume of feedstock produced by pigs in each unit is taken from the column name 'Quantity of organic fertiliser produced by the animals housed onsite in the reporting year' in the EPA AER report, reported in m^3 per annum.

Through correspondence with intensive pig farmers in the region these feedstocks availability and end use were confirmed. Since the legal responsibility lies on the pig farmer to dispose of their pig's waste, pig farmers incur costs in transporting the slurry to farms around the region for land spreading. Pig farmers generally do not have land requiring spreading as they do not have animals out for pasture. Small quantities are removed and transported by tractors to neighbouring farms however larger quantities are removed by truck and some trucks are traveling up to 60 km to deliver the slurry to the offloading farm for land spreading. The pig farmer incurs the cost of this transport and so it constitutes an operating cost for the farm.

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 10.

Table 10 - 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 outlined in Table 11 are used in the study.

Table 11 - Chemical properties of pig slurry.

Nitrogen (N, kg/t)	2.10
Phosphorous (P, kg/t)	0.9
Potassium (K, kg/t)	1.90
Ammonium N (NH_4-N, kg/t)	1.05
C:N ratio	10:1
Fertiliser replacement value (€/t)	10.06

3.2.3 Quantity and Availability

Figure 8 displays the source location and scale of intensive pig farms in the Ballyhoura region and surroundings by annual slurry removed (t/a) and Figure 9 displays the corresponding biomethane potential (MWh/a). The cumulative pig slurry quantity from the 10 intensive pig farms in the Ballyhoura region is 251,800 t/a. The largest single farm supply is 73,600 t/a located in Mitchelstown and the smallest is 8,000 t/a. In the region there is over 29 GWh of potential biomethane from pig slurry alone with 21 GWh of the potential in Mitchelstown. The thematic maps confirm the cluster of large pig farms around the Mitchelstown area.

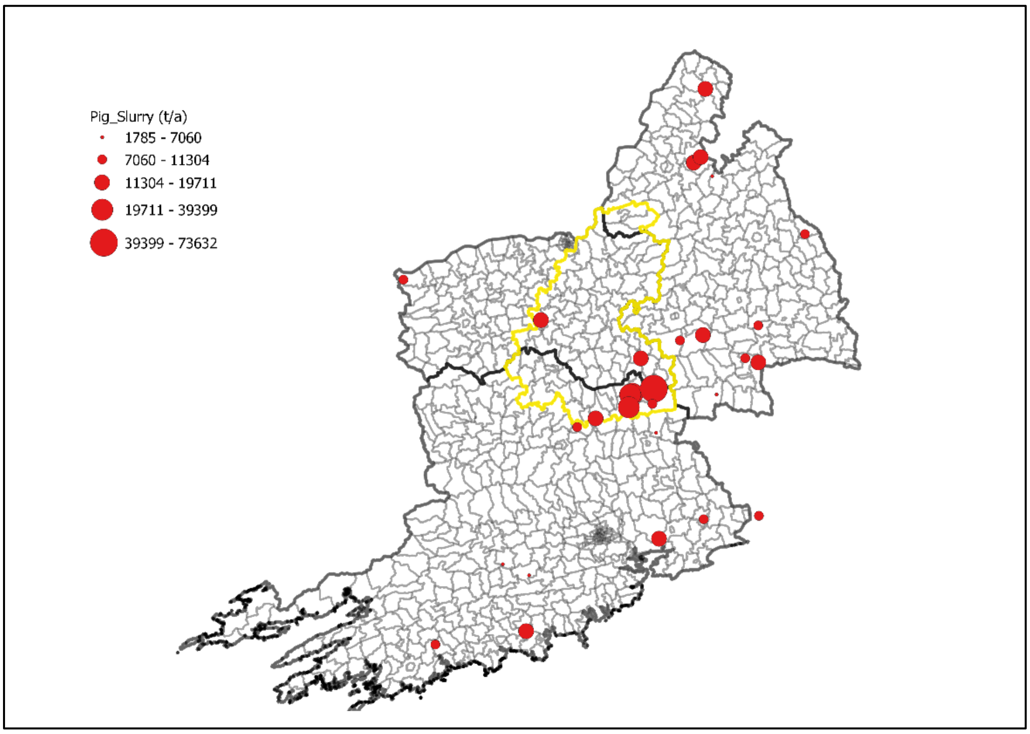

Figure 8 - Pig slurry sources and distribution.

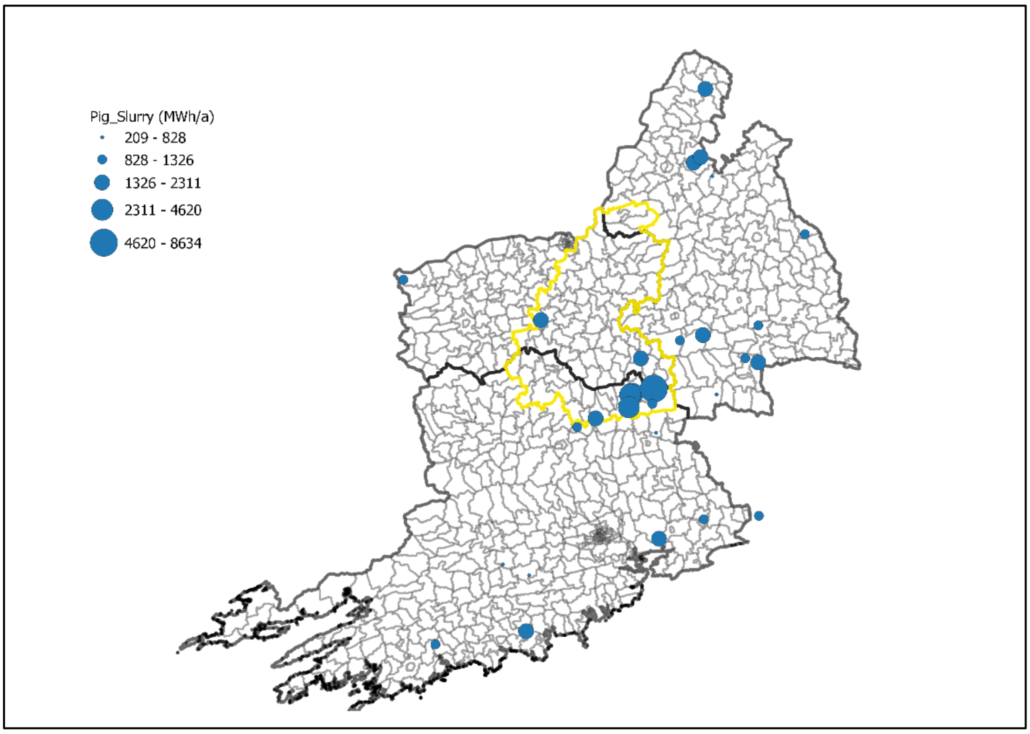

Figure 9 - Pig slurry biomethane potential.

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 biofertilizer. 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 Energy Crops

3.3.1 Grass Silage

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.

Unlike other feedstocks mentioned in this study, the RED II does not allocate CO_2 emissions 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.

3.3.1.1 Source

There is no direct source of information on grass silage and its availability for AD. Instead, from the 2020 Census of Agriculture provides information on land farmed, total grasslands, total cereals on an electoral basis (all in hectares). Farmland dedicated to crops is only given on a regional basis with the privacy and GDPR reasons cited as to the unavailability of this data on an electoral division basis. Farmed grassland can include activities such as areas of pasture, hay, rough grazing, and silage production.

The CSO 2020 census provide data on livestock numbers on an electoral division basis, with the only categories available as follows: total cattle, dairy cows, other cows, other cattle (which constitutes young cattle and bulls), total sheep and total livestock units. These numbers in conjunction with literature on ruminant nutrient and silage feed requirements per animal type are used to determine silage demand, which subtracted from produced silage and accounting for wastage determines the tonnage of available excess silage.

It is a difficult to estimate nationwide availability of grass silage based on several 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 source of grass silage will be required if this feedstock stream is to be utilised.

Further information on grass silage in the Ballyhoura region was provided by farming stakeholders involved the AD project. The consensus is that there is little availability of the feedstock due to high demand for feedstock fodder.

3.3.1.2 Quantity & Availability

The quantities of available silage are calculated based on dedicated land, average yearly yields, and animal feed requirements in each electoral division. Grass silage is typically harvested in Ireland in one or two cuts per year. According to O'Donovan et al. (2011), approximately 79% of silage land is harvested with a single cut and the remaining 21% harvested with two cuts. Less than 1% of land undergoes three cuts and is considered negligible in this study. McEniry et al. (2013) provides maximum grass yield data for grassland under typical nitrates application; 9.8 t DM/ha and 10.51 t DM/ha for one and two cuts respectively, where t DM/ha is tonnes of dry matter per hectare.

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 kg DM/hd/a across different regions (south and east, west and midlands, and northwest) 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 by using figures from O'Mara (2006) for the south and east region, then divided by a factor of 0.7 and 0.65 to select dry matter digestibility for dairy and suckler cattle respectively (0.7 kg/kg DM and 0.65 kg/kg DM). McEniry et al. (2013) provides data in kg DM/hd/for bulls, younger cattle and a variety of sheep types using nationwide averages, assuming a utilisation rate of 0.73 kg/kg DM. The total grass consumption requirements for the different ruminant types are summarised in Table 12

Table 12 - Ruminant grass silage consumption.

Animal Type	Consumption (kg DM/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 is applied to the corresponding 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 and their corresponding fodder demand.

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). Displays the corresponding of excess silage across the EDs (t/a) whilst displays the corresponding methane potential (MWh/a) assuming 100% availability and digestion efficiency.

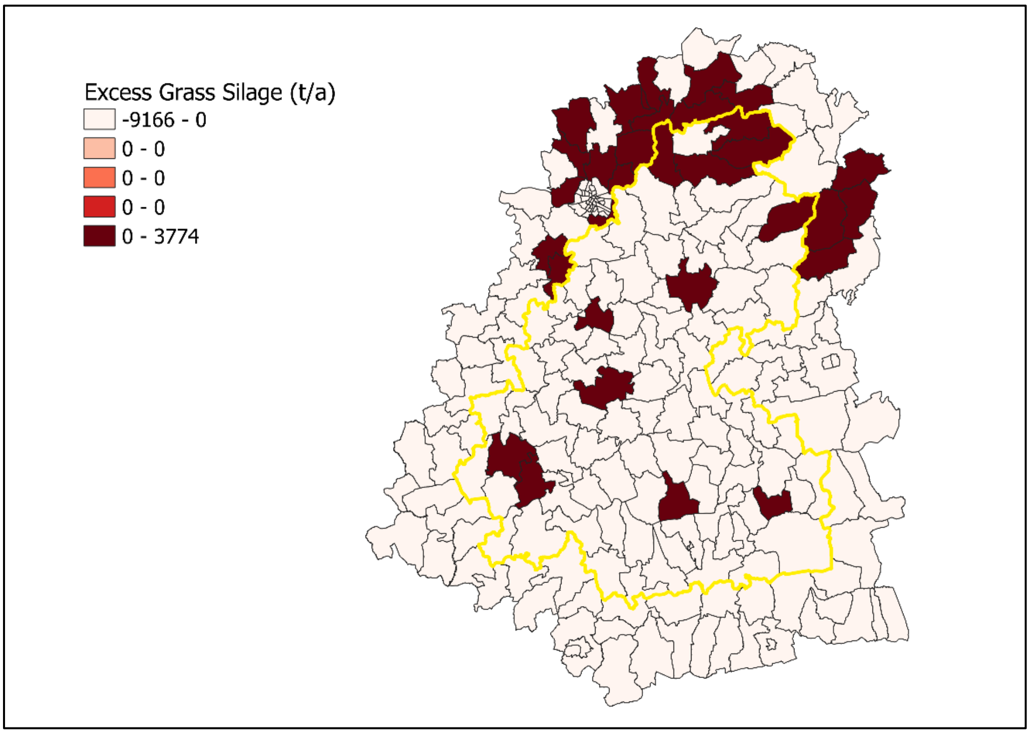

Figure 10 - Areas of excess silage production (production minus demand).

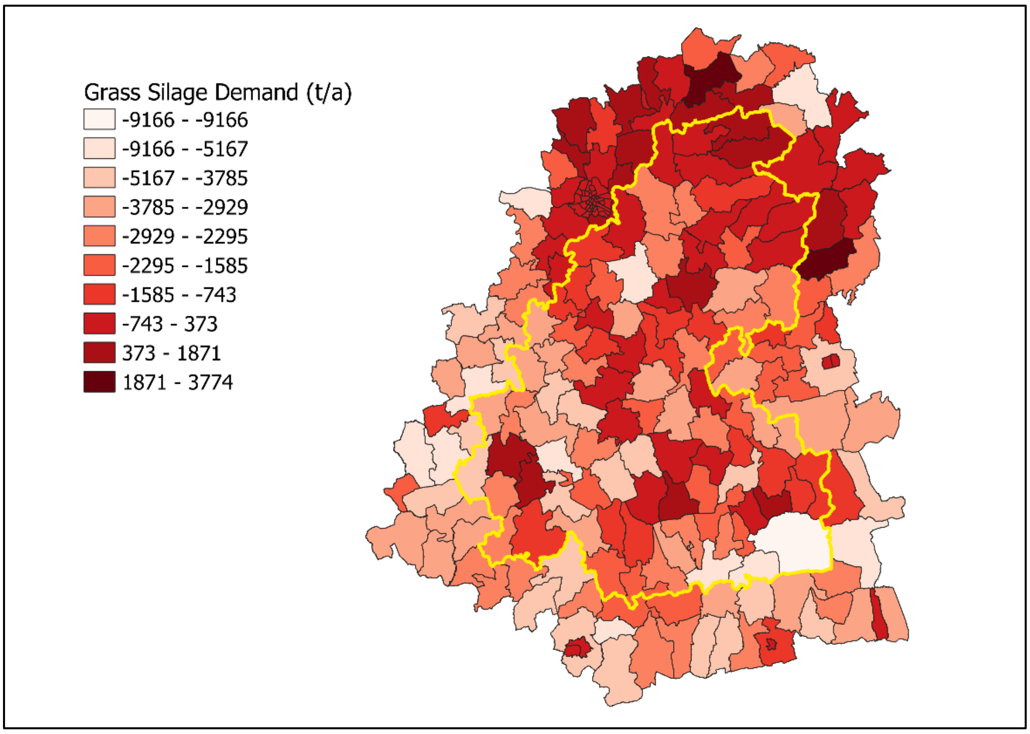

Figure 11 - Silage availability less demand in the Ballyhoura region.

3.3.2 Maize Silage

While there is a variety of energy crops used in AD, maize is the most popular used in European AD projects due to its cost effectiveness, high energy content and low moisture content relative to other agricultural feedstocks. However, due to climatic constraints, maize constitutes a minor amount of all crops grown in Ireland, making less than 4% of harvested crops in 2021 (constituting 14,400 ha) and therefore would not normally be considered as a feedstock for AD. Despite this, the majority of maize is grown in the south of the country due to more favourable climatic conditions (increased average temperatures and daylight). Significant amounts are grown in the vicinity and within the Ballyhoura region (few hundred acres as reported by farming stakeholders).

Like grass silage and other energy crops, the RED II does not allocate CO_2 emissions bonuses to maize. 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 and further details on maize silage emissions are presented in 3.6.5.

3.3.2.1 Source

Much like grass silage, there is little available data on the availability and regional quantities from the CSO and Teagasc. Maize is primarily grown in the south and east of the country where growing conditions are much more favourable. In 2021, some 14,400 ha of maize silage was cultivated in the Republic, with 3,500 ha grown in the south-west (Cork and Kerry).

3.3.2.2 Characteristics

The composition of maize silage depends largely on species, type, fertiliser application, soil type, seasonal weather conditions, ensiling and harvesting practices. Many types of maize include class 600, 700, LG31235, P8200 to name a few, all having various yields, starch, and energy content. Energetic properties and nutrient contents of maize are summarised in Table 13 and Table 14 respectively.

Table 13 - Energetic properties of Maize silage.

Total solids (% wwt)	35%
Volatile solids (% wwt)	33%
Methane content (m^3/kg VS)	0.35
Calorific content (MJ/kg)	4.16
Methane vol. in biogas (%)	60%

Table 14 - Maize fertiliser properties.

Nitrogen (N, kg/t)	3.2
Phosphorous (P, kg/t)	2.3
Potassium (K, kg/t)	8.8
Ammonium N (NH_4-N, kg/t)	0.06
C:N ratio	36
Fertiliser replacement value (€/t)	29.18

3.3.2.3 Quantities & Availability

Due to GDPR regulation, the CSO in the 2020 Census of Agriculture does not provide an electoral division (ED) breakdown of crops harvested; only the quantities of total cereals harvested are provided in the census data on an ED basis. However, Maize does not qualify as a cereal but rather an arable crop making it difficult to assess quantities locally available. From CSO farmed areas data acquired in 2021 (provides regional breakdown on agricultural activities) shows that of the 14,400 ha of maize grown in the country, 38% is grown in the south-west and mid-west. From the stakeholder engagement, it is grown by beef and dairy farmers as supplementary fodder, and it's reported that several hundred acres are grown in the vicinity of Mitchelstown. It is difficult to quantify from official sources on the quantities grown in the region. At present the quantities of maize grown are insufficient to supply any new AD development given the local demand for fodder. Supply of maize to a local AD project would require the contracting of farmers to switch their current land use to maize production which could prove difficult (possible lack expertise and equipment) and costly as it would have to be profitable for them to do so.

3.4 Organic Waste

The organic fraction of municipal solid waste (OFMSW, or biowaste) includes multiple waste streams, predominately food waste, and organic by-products from food production activities. OFMSW can make for a very attractive feedstock 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. Unlike cattle manure, for example, OFMSW is available year-round, with some seasonal variation expected due to consumer habits and tourism. In Ireland, plants receiving OFMSW will generally receive a gate fee of 50-80 €/t. In the case of food waste, for example, the waste collectors are willing to pay this as they will incur an equivalent charge for landfill disposal, further enhancing 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. The EPA estimates that in 2019 of the 530,000 tonnes of waste accepted for composting or AD, 80% was treated in Ireland while 20% was transferred to facilities in Northern Ireland as a result of more favourable gate fees. Approximately 240,000 tonnes of this waste underwent AD. A gap exists for more AD plants in the South, which if established appropriately, would attract these large feedstock streams currently being transported over long distances.

3.4.1 Dairy Processing

The dairy industry is central to the Irish economy producing goods including butter, cheese, milk, yogurt, and ice cream. In 2020, dairy product global exports accounted for 36% (5.1 billion) of all agri-food exports. Ireland has 25 large dairy processing facilities with several located in Ballyhoura and its neighbouring towns. Notably, Kerry Group have a large processing facility in Charleville, while Dairygold have a large one in Mitchelstown. Facilities that produce large amounts of waste either discharge it to municipal wastewater treatment plants or treat it on site if they have their own WWTP. The waste must be treated to meet discharge limits in advance of releasing wastewater into regional water bodies. Depending on the wastewater treatment process carried out onsite varying quantities of solid organic wastes are generated. These are referred to as dairy processing sludge (DPS) which is categorised as a biosolid in the EU and so can be disposed of through spreading on agricultural land. The addition of an anaerobic digester can improve the efficiency of the treatment process resulting in lower quantities of DPS at the end of the process. A 45,000 m^3 anaerobic digester was constructed at Dairygold's site in Mitchelstown in 2012 which pre-treats the process wastewater from the production facility in advance of entering the pre-existing biological nutrient removal (BNR) system. The produced biogas is used on site in a dual fuel boiler for heating the reactor and any surplus is supplies the plant's boiler. Kerrygold treats its processing waste on site and the resulting sludge is either recycled or transported to agricultural land for spreading.

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 are1.26 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 15 - 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 16 - Chemical properties of dairy processing waste.

Nitrogen (N, kg/t)	4.90
Phosphorous (P, kg/t)	3.35
Potassium (K, kg/t)	0.66
Ammonium N (NH_4-N, kg/t)	2.45
C:N ratio	14:8:1
Fertiliser replacement value (€/t)	23.9

For food processing waste, licenced dairy processing facilities are obliged to report waste streams to the EPA through AER submissions; these reports are used to assess potential feedstock streams. Due to the diverse nature of techniques applied and materials processed in dairy processing the nature of waste material and reporting methods can vary substantially between facilities. European Waste Codes (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 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. Based on Dairygold's Annual Environmental EPA report (2017) the site produces 22,000 tonnes per annum of waste suitable for the onsite anaerobic digester, which has a biomethane potential amount of 8.4 GWh per annum (based on BORRG calorific value). Kerry Group in Charleville produces significantly less EWC: 02 05 02 classified waste, approximately 9,000 tonnes per annum based on their 2018 EPA Annual Environmental report. If this waste was treated anaerobically, it could produce large quantities of biogas which amount to a biomethane potential of approximately 3.3 GWh per annum. This potential is currently not being captured for biogas/biomethane production.

3.4.2 Slaughterhouse Waste

The meat sector in Ireland has grown significantly over the last few decades and is now the fifth largest net beef exporter globally. Large meat processing facilities are generally located rurally, with a number situated around the Ballyhoura region and its surroundings. Slaughterhouse produce large quantities of waste consisting mainly of 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). The waste streams produced from slaughterhouses must be reported to the EPA through AER submissions, defining the nature of each stream generated by the facility through the use of EWCs as discussed in section 3.4.The waste streams reported from Irish facilities include 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 17 with data from Browne et al. (2013), O'Shea et al. (2016), and BORRG.

Table 17 - Energetic properties of 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 dairy processing waste is taken from Browne et al. (2013) and Teagasc and shown in Table 18 along with the estimated fertiliser replacement value.

Table 18 - Chemical properties of slaughterhouse waste.

Nitrogen (N, kg/t)	2.8 (paunch), 5.38 (WWTP sludge)
Phosphorous (P, kg/t)	0.273 (paunch and WWTP sludge)
Potassium (K, kg/t)	0.78 (paunch and WWTP sludge)
Ammonium N (NH_4-N, kg/t)	1.4 (paunch), 2.7 (WWTP sludge)
C:N ratio	16.6:1 (paunch) 10.4:1 (WWTP sludge)
Fertiliser replacement value (€/t)	15.46

Through correspondence with ABP Food Group & Dawn Meats, it was determined that cumulatively their facilities in and adjacent to the region have a cumulative potential of 7.5 GWh/a. This potential includes their total sludge and paunch that is currently transported for storage and land spreading or to AD plants in Cork (Youghal), Waterford (Portlaw) or in Northern Ireland. The current distance these feedstocks are transported is due to insufficient storage facilities along with a lack of AD plants in the region.

3.4.3 Domestic Brown Bin Waste

Up to 40% (by weight) of domestic waste produced is organic waste, which decomposes to produce large amounts of methane. Organic waste is an excellent feedstock for AD because of its high energy density, which allows for low volumes to produce relatively high quantities of biomethane along with a high quality digestate. 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. This is represented in CSO data where they provide information on the average kgs of brown bin waste collected per capita per local area authority. As depicted in Figure 12, the rural counties tend to use the brown bin less per capita compared to the urban settings.

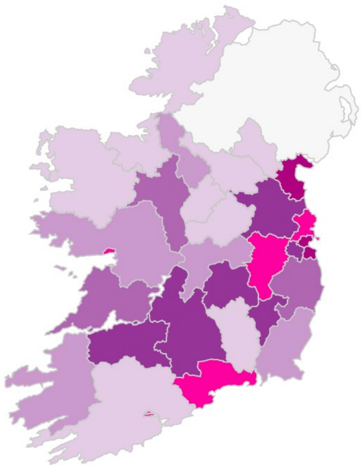

Figure 12: Kilograms of Brown Bin Waste per Capita per local authority[1]

The average in Cork County (excluding Cork City) is in the lowest tier, averaging at approx. 13 kg per capita. In comparison the average collection in Limerick and Tipperary is much higher at 35 kg per capita. The Ballyhoura region is comprised of majority Limerick towns with the remainder being in North Cork. A weighted average of the region yields an average of 29.9 kg per capita.

Ballyhoura Development CLG estimate the population of the region to be 78,191. Based on these estimates, in the Ballyhoura region alone there is 2,400 tonnes of brown bin waste collected. Brown bin waste is a viable option since there is a dominant waste collector in the region which would allow for a single contract as well as single stream of waste. This quantity informs on theoretical maximum potential rather than practical available material. The potential of domestic waste in neighbouring Tipperary is not included which would significantly improve the theoretical output. Further correspondence with local authorities and waste management administration bodies is necessary to infer more realistic estimates of domestic waste for AD, with waste from commercial premises (hotels, restaurants, canteens) analysed alongside domestic portions.

[1] https://www.cso.ie/en/releasesandpublications/ep/p-sdg11/irelandsunsdgs-goal11sustainablecitiesandcommunities2021/environment/

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 to determine the energy potential of the waste. The biomethane potential of the domestic waste in the region is approximately 1.8 GWh which is significant relative to the quantity of waste.

3.5 Minor Feedstocks

3.5.1 Poultry

Poultry manure can be separated into two categories; broiler and layer manure. Layer refers to animals used specifically for the production of eggs and other chickens while broiler refers to animals produced for meat consumption. The latter, although a manure, comes with stringent management and disposal ABP regulations due to pathology concerns, specifically botulism. Therefore, any manure or resultant digestate can only be spread on lands designated for tillage. This is further discussed in section 3.7 and specifically applies to manure from broiler rearing facilities and not layers.

Poultry manure, both layer and broiler, is attractive as a feedstock due to its high biomethane content and density, the best of the animal manures for AD. This allows feedstock to be sourced further afield as there is less water content than other manures and more energy per mass unit.

Table 19 - Energetic properties of poultry manure.

Parameter	Broiler	Layer
Total solids (% wwt)	60%	30%
Volatile solids (% wwt)	45%	23%
Methane content (m^3/kg VS)	0.30	0.33
Calorific content (MJ/kg)	4.86	2.63
Methane vol. in biogas (%)	60%	60%

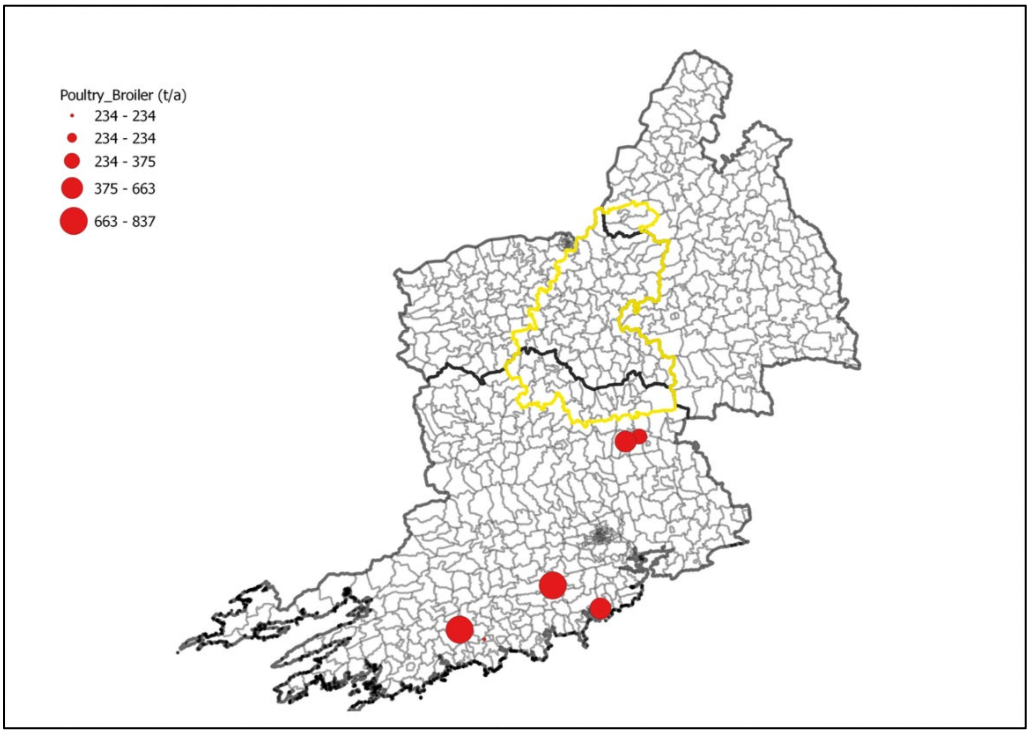

Figure 13 - Distribution of poultry licensed facilities.

From Figure 13, there are 5 no. licensed broiler facilities within Cork, with only two in close proximity to the Ballyhoura region. The quantities of manure are small for an industrial biomethane operation, with less than 2,500 tonnes available per annum and only just over 1,000 tonnes available within 20 km of the region. The restrictions to land spreading of the digestate could prove costly due to transporting the material over larger distances for appropriate disposal, a costly consequence for the addition of a small amount of feedstock. Additionally, there are no licensed layer facilities in the general Munster region or in the vicinity of the Ballyhoura region. Data on smaller installations is unavailable at the time of writing this report.

3.5.2 Equine

Equine manure is an excellent and attractive AD feedstock similar in composition to FYM, but with a higher biomethane potential. This is due to farm management involved, typically horses are kept in stables with straw beddings in which equine excrement is mixed. On average, a 1,000 lbs (453 kg) horse will produce 50 lbs (23 kg) of manure daily. Collection of this feedstock is only viable when the animals are stabled, however, not all horses require housing even during winter months. For the purposes of this study, it will be assumed that horses are housed during a 16-week period during winter, as done with cattle related feedstocks. The quality of horse manure can prove difficult in sourcing as woodchips or sawdust typically substitutes straw for the animals bedding. Wood and derived products have poor digestibility during AD due to its strong lignocellulose and should be avoided.

Table 20 - Properties of horse manure.

Parameter	Horse Manure
Total solids (% wwt)	25.6%
Volatile solids (% wwt)	23.2%
Methane content (m^3/kg VS)	0.41
Calorific content (MJ/kg)	3.45
Methane vol. in biogas (%)	60%

Data on equine livestock is limited at best. CSO data on equines is only available on a regional basis for the 2020 census. In 2010, there was 106,020 horses and ponies in the state with 18,406 in the mid-west and 13,576 of that in the south-west. That number fell to 82,900 in 2021, with 16,100 in the mid-west and 10,000 in the south-west. A review of the region reveals many studs in the vicinity of south Mitchelstown and Fermoy. As there is no data on an ED level, 2010 CSO data modified using regional horse numbers, roughly a 20% reduction over the decade. Based on this, estimates show there is little horse manure in the region with some 6,200 tonnes available (less than 5.9 GWh).

3.5.3 Wastewater Treatment Plant

Wastewater treatment plants (WWTPs) are required to reduce the negative impacts wastewater systems have on regional water bodies. Wastewater passes through a series of treatment steps using physical, biological, and chemical processes to remove solids, break down organic materials and kill pathogens in the water. The treated water is released into streams or rivers. Sludge is a by-product of wastewater treatment comprising of a mix of organic matter from human waste, food waste, microorganisms, chemicals, and inorganic solids with water binding these materials together. Anaerobic digestion of wastewater is generally required to treat sludge to fulfil wastewater standard discharge requirements helping reduce the energy required to treat the wastewater.

In the Ballyhoura region there are four UWWTPs (Urban Wastewater Treatment Plants), in Milford, Charleville, Mitchelstown and Kilmallock of which Mitchelstown is the largest. Mitchelstown's WWTP has a Plant Capacity PE (population equivalent) of 5,600 with a treatment type of 3P – Tertiary P removal. This WWTP has been at capacity for several years which has consequently limited growth of the town over the last few years. In 2019, Mitchelstown failed to meet the EU sewage treatment standards. In 2021, Irish Water announced plans to upgrade the capacity at the plant amounting to an increase of approximately 800 PE. The system at Mitchelstown will therefore be expanded increasing the biogas potential of the plant. Due to its low energy density, this potential feedstock has more benefit for use in situ, for example to power the treatment plant creating a closed-circuit system.

Using the data provided in the UISCE AER 2019 report the biomethane potential of the Mitchelstown Wastewater Treatment plant was calculated to be less than 1 GWh per annum. Wastewater has low C:N ratios (< 8:1) and pHs of higher than 7 resulting in low biogas production. This is because a substrate with low C:N ratios generally has high ammonium concentrations which inhibits microbial growth and the anaerobic digestion. Higher levels of N tend to have high pH values which can result in free ammonia dominating which is considerably more inhibitory compared to the ammonium ion. Wastewater has potential to be a useful feedstock if a digestor requires a higher water content, which occurs frequently in CTSR since a high percentage of water is required for operation. Processes benefit from using wastewater instead of fresh water since it increases the reactors biomethane potential. However, the low energy density (approx. 0.0045 MJ/kg of wastewater) makes it unattractive to transport and more suitable as a feedstock for in situ AD at the WWTP for energy recovery. While only Mitchelstown WWTP was assessed, based on the above calculation and the electricity demands of these sites, it was inferred that there will be limited biomethane potential at WWTP plants in the region and so this potential feedstock was not further explored in this study.

3.6 Sustainability of Feedstock Streams

The revised Renewable Energy Directive 2018 (RED II, 2018/2001/EU) is a component of the 'Clean Energy for all Europeans' package. It is a binding legal framework that defines criteria for EU based renewable energy projects from wind and solar to biogas. An EU member state can only include carbon savings from a project if it adheres to the minimum GHG savings relative to fossil fuel equivalents. In this study, the plant is designed to adhere to the RED II criteria as plants failing to meet these targets will be excluded by the state from further development in the future. At present these savings are 70% ~~60%~~ however from 2026 onwards this value will increase to 80% GHG savings.

The GHG savings are determined through comparison of the life cycle emissions from the biogas plant against conventional energy source emissions in gCO_2/MJ. The biogas projects life cycle analysis (LCA) is completed based on the emissions associated with individual feedstock streams and emissions associated with plants operations. The feedstocks associated emissions in advance of processing by the plant are outlined in this section; calculations of emissions associated with feedstock processing and plant operation are discussed later in the report.

3.6.1 Greenhouse Gas Model of Feedstocks

The rules for calculating the GHG impact of biomass substrates and mixtures in comparison to their fossil fuel comparators in gCO_2/MJ are outlined in Annex VI of the RED II. Section A provides 'Typical and default values of greenhouse gas emissions savings for biomass fuels if produced with no net-carbon emissions from land-use change'. Section B Subsection C outlines the method for calculating the GHG impact of the produced biogas/biomethane for the co-digestion of substates in a biogas plant:

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

- 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:

$$S_n = \frac{P_n \times I_n}{\sum_1^n P_n \times I_n}$$

- P_n = the energy content of feedstock n in MJ/kg of wet feedstock
- I_n = the proportion of each individual feedstock in the total mixture by weight (%)

The volatile solids destruction (VSD) represents the efficiency of the digestion process to extract the total available energy from the feedstocks (typically 80-90%). The energy content of each feedstock is adjusted based on the VSD. The remaining components of the GHG equation are dependent on the particular 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

To deliver feedstocks to the biogas plant, trucks/tractors burn fuel. The associated emissions impact the overall GHG savings of the plant and vary based on the vehicle used, feedstock transported and the required travel distance. Here, it is assumed the vehicles employed are HGV trucks with a specific diesel consumption of 2.66 MJ/t km (i.e. energy required to move 1 tonne over 1 km) (SEAI, 2020). The total diesel requirement is determined in MJ based on the payload in tonnes and the transport distance in kilometres. The unladen journey to collect feedstocks is also included in the calculation and is taken as 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 calorific values of each feedstock are then employed to determine the gCO_2/MJ. The higher the energy density of the feedstock. The lower CO_2 emissions generated as a result of a higher energy yield per kg delivered. The alternative use of biomethane as a biofuel in HGV transport was not considered in this feasibility study, which would result in lower transport emissions. This is shown in Figure 14.

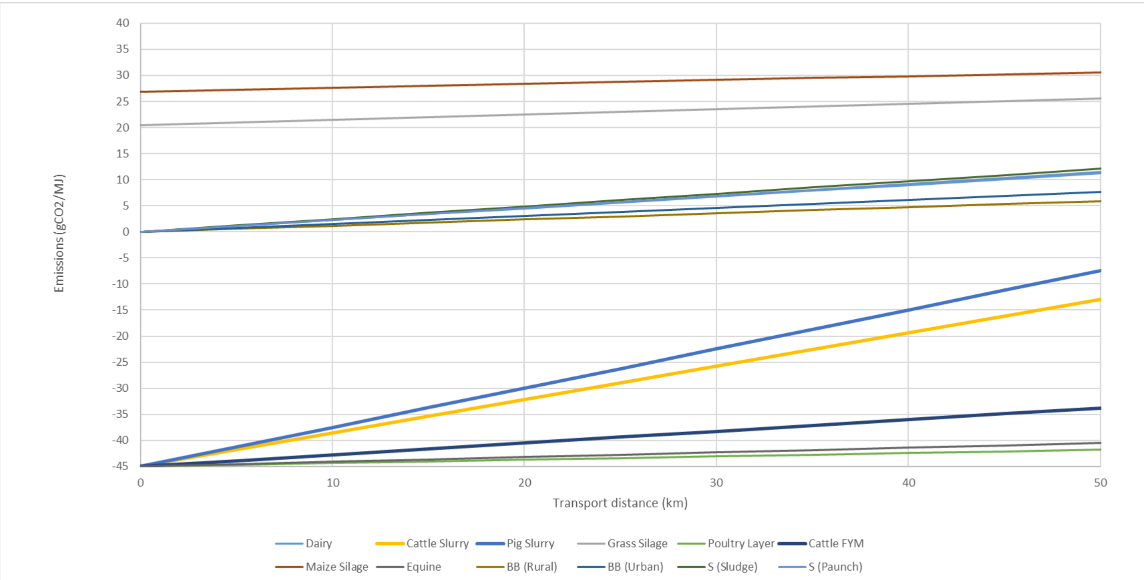

Figure 14: Feedstock emissions per unit energy as a function of distance (gCO_2/MJ).

3.6.3 Agricultural Manure Emissions

The GHG emissions from agriculture manures and slurries, specifically cattle manures and pig slurry, are determinable based on the combination of the credits assigned to the emissions prevented due to improved manure management and emissions from the transport of the feedstock. In the absence of biogas plants, manure is stored on farms prior to land spreading, releasing gases into the atmosphere as a result of bacterial activity. Methane makes up the majority of gas released along with nitrogen compounds including nitrogen compounds (N_2O,

NH_3 and nitrogen oxides (NO_x)). The introduction of AD to the manure management results in the collection of methane in the form of biogas, which can be used in CHP or upgraded to biomethane.

Annex VI of the Red II Directive outlines that a 'bonus of 45 gCO_2eq/MJ shall be attributed for improved agricultural and manure management in the case where animal manure is used as a substrate for the production of biogas and biomethane'. The bonus makes up the e_{save} component of the GHG equation outlined above. This credit therefore minimises the contribution of animal manures to the biogas plant GHG emissions, resulting in a negative emissions value for transportation over short distances. Manure is therefore an attractive substate for co-digestion generally with other more energetic feedstocks that have penalising emissions values such as maise and silage. The total GHG emissions impact of agricultural manures is displayed in Figure 15.

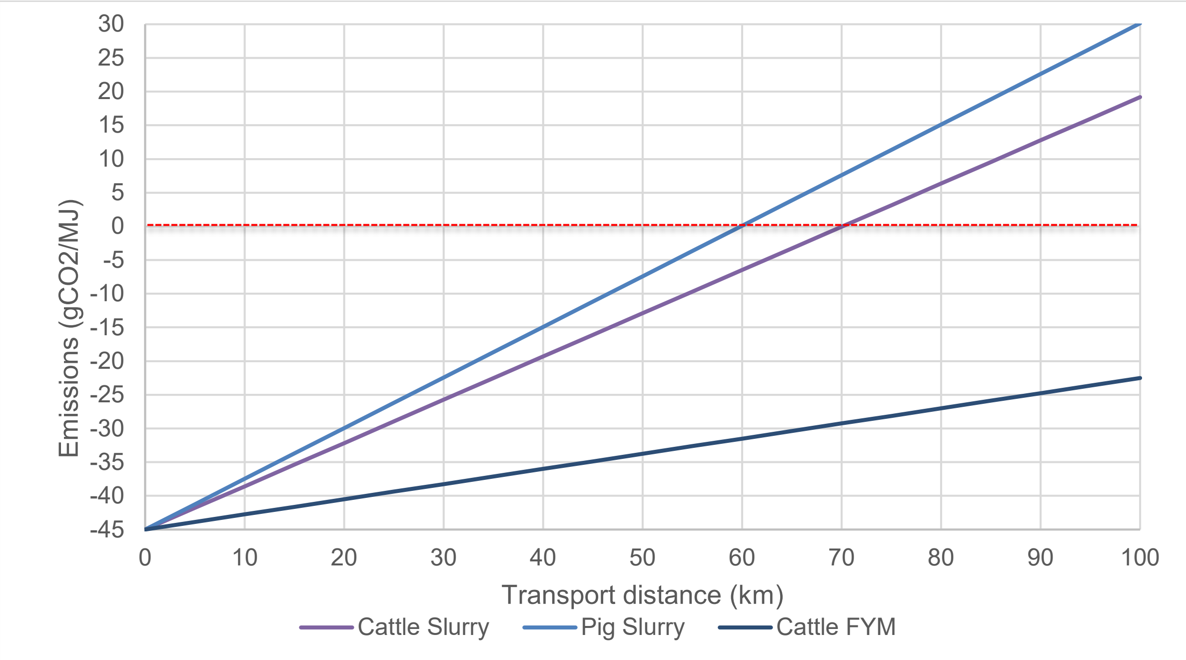

Figure 15 - Emissions of transporting manure feedstocks.

3.6.4 OFMSW Emissions

Municipal solid waste is exempt from the RED II sustainability criteria. Giuntiolio et al. (2015) outline in a report from the Joint Research Centre of the European Commission that this rule is applicable to sewage sludge from wastewater treatment plants but other forms of biowaste (brown bin, dairy processing, and slaughterhouse waste) are subject to sustainability accounting. However, the RED II outlines no credit for OFMSW materials meaning the feedstock's associated emissions are derived solely from transport.

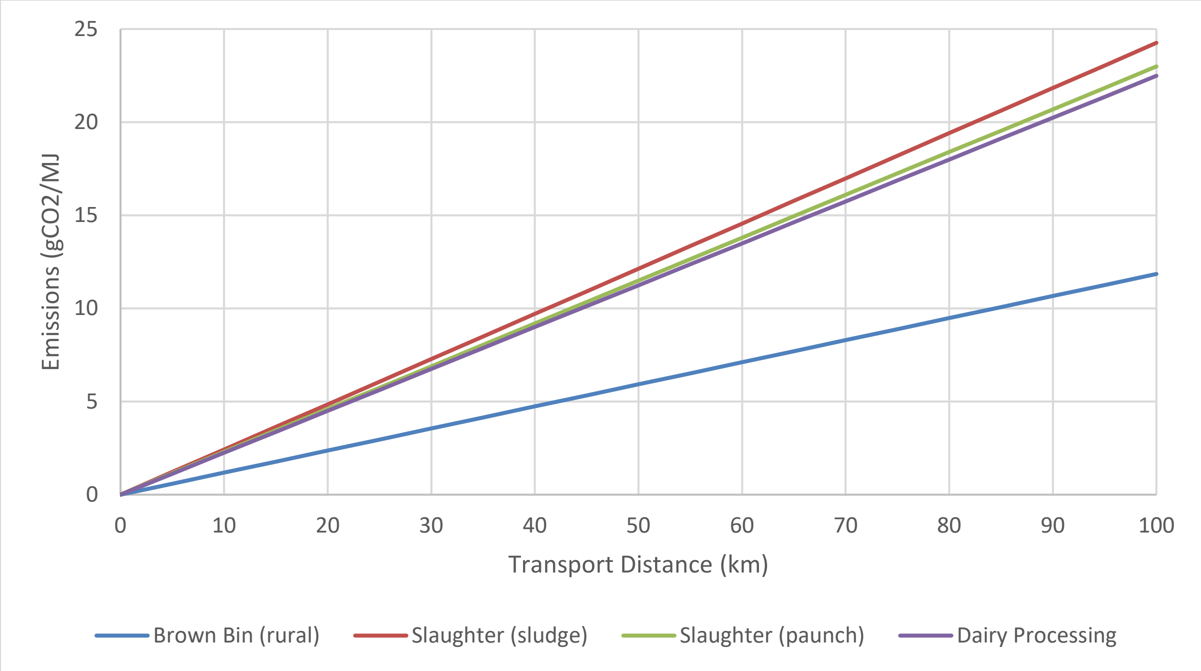

Figure 16 - Emissions from OFMSW

3.6.5 Grass & Maize Emissions

The calculation of GHG emissions for silages and energy crops are the most involved of all feedstock streams as emissions sources must be tracked across the whole production chain. GHG emissions must be considered for seed production, transport, land preparation, harvesting and cultivation operations, production and application emissions associated with fertilisers utilised. Resultant GHG emissions from crops are highly varied and sensitive to many factors. The model presented in this study will attempt to provide a high-level estimate that is sufficiently accurate for the purposes of assessing the plant's viability.

Note: the use and application of sustainable feedstocks outlined in the KPMG/Devenish/GNI Sustainable Biomethane report, peer reviewed by Teagasc was not included in this feasibility report. The report is referencing suggested current available feedstock in the region.

Korres et al. (2010) provides emissions data on the production of grass silage and each associated agronomic activity, including seed production, ploughing, sowing, harrowing, rolling that occur only in a reseeding year (8 years for grass), in addition to annual emissions from silage harvesting, ensiling and fertiliser spreading. The energy consumption for these activities are presented in Table 21.

Table 21 - Emissions due to agronomic activities.

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

Contrary to grass silage, maize fields must be reworked and reseeded on an annual basis, seeing increased energy consumption. Casey et al. (2006) determine that some 71 kg/ha of diesel is consumed in field operations. Also unique to maize, is the use of plastic covering used during the germination stage, requiring some 49.4 kg/ha of plastic which produces some 3 – 3.5 kgCO_2/kg plastic.

Fertiliser production GHG emissions (Wells 2001) must be calculated for energy crops. The quantities consumed largely depend on the crop's nutrient requirements and soil fertility (characterised by the soil index). Teagasc provides fertiliser guidelines for maize and grass based on soil index. Additionally, Teagasc carried out soil sampling in the Cork region (2020) for various farm types (general, dairy, suckler, tillage), presenting percentage of soil indexes for P, K and pH, and showing that 24% of tillage farms are at optimum fertility but only 14-16% of dairy and drystock farms are. Using this data in combination with nutrient guidelines, average fertiliser use is calculated with **assumption that all the requirements are met by inorganic fertiliser and pH adjusted with lime**. The resultant GHG emissions from fertiliser production are presented in Table 22.

Table 22 - Emissions due to fertiliser production for each crop (Wells 2001).

Nutrient	**Emissions (kgCO_2/kg Fert)**	**Grass Silage (kg/ha)**	**GS (kgCO_2/kg)**	**Maize Silage (kg/ha)**	**MS (kgCO_2/ha)**
Nitrogen (N)	3.25	125.0	406.2	126.2	410.3
Phosphorous (P)	0.90	24.8	22.3	48.3	43.5
Potassium (K)	0.60	117.3	70.4	217.2	130.3
Lime	0.43	200.0	86.0	141.7	60.9
Total kg CO_2			**584.9**		**645.0**

Further emissions sources from crop production include direct and indirect nitrous oxide emissions (NO_x). 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 this study. Direct NO_x emissions are derived from Nitrogen in fertiliser spreading, grazing animals, crops residues, mineralisation in soil, land use change and draining/management of soils. Indirect emissions are derived from volatilisation and leaching of N fertilisers.

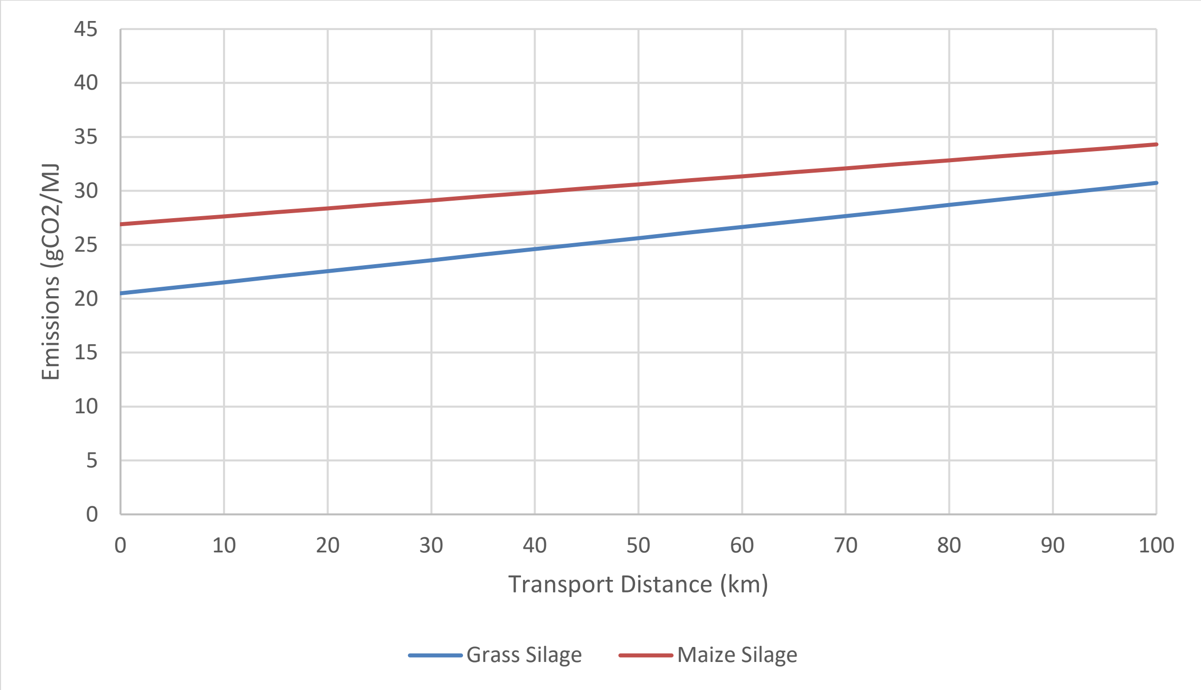

Figure 17 - Emissions from energy crops (grass & maize).

The GHG emissions for grass silage and maize silage are presented in Figure 17, using the referenced farming conditions used in the model as a function of transportation distance. From calculations, grass silage and maize silage production emissions are 20.5 and 26.9 gCO_2/MJ respectively.

3.7 ABP Regulations

Inappropriate treatment of wastes associated with animals including animal manures, sludges, food waste, food production waste or slaughterhouse waste can have devastating impacts on the agriculture and agri-food industries, as a result of the spread of diseases such as BSE and foot and mouth disease. These materials are all potential feedstocks for AD plants and so these associated risks must be correctly managed before removal from the plant, as per the animal by-product (ABP) regulations which are enforced by the Department of Agriculture, Food and Marine (DAFM). The DAFM outline these regulations in 'Approval and operations of biogas plants transforming animal by-products and derived products in Ireland' under the remit of the EU (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.

The feedstocks associated rules vary based on what category of animal-by-product of the regulation it falls into:

- 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

The DAFM outlines nine different classifications for AD plants based on the varying digestion parameters, feedstocks (type and quantity), feedstock source and digestate disposal. Type 1 plants permit the greatest flexibility of feedstocks and digestate may be spread on land in Ireland and EU, making them the most common plant type employed. 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 applicable when a plant only uses 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. The ABP category of the feedstocks considered in this study are outlined in Table 24.

Table 23 - ABP category for feedstocks.

Feedstock	ABP	Notes
Cattle slurry	2	Cat 2 - Manure
Cattle FYM	2	Cat 2 - Manure
Pig slurry	2	Cat 2 - Manure
Equine Manure	2	Cat 2 - Manure
Brown bin waste	3	Cat 3 - Catering waste
Slaughterhouse waste	3	Cat 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
Maize	Non-ABP	No restrictions on energy crops
Wastewater treatment waste	Non-ABP	No restrictions under ABP regulation

All ABP feedstocks outlined require 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.

3.8 Feedstock Comparison

Note: See Table 24 on the next page for feedstock comparison.

Table 24 - Summary of various feedstock.

Feedstock	Total quantity (t/a)	Biomethane potential (GWh/a)	Cost (€/t)	Emissions (gCO_2/MJ over 10 km)	Advantages	Disadvantages
Cattle Manure	1,300,000	218	0	-38.58 (Surry) -42.75 (FYM)	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	440,000	52	0	-37.48	High availability. Concentrated to a relatively small number of sources. Beneficial to pig farmers 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.
Equine Manure	6,200	5.9	0	-44.36	Concentrated to a relatively small number of sources. Qualifies for RED II manure credit. High water content beneficial for co-digestion with dry feedstocks.	Studs tend to be small, large distribution - AD OPEX (transport). Low data availability
OFMSW (Brown Bin)	2,400	13.4	-30	1.2	High energy content minimises AD CAPEX and OPEX. Attracts a gate fee. Systems already in place for feedstock collection via waste management companies, looking for alternative disposal options as landfill capacity limited.	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	8,390	6.5	20-40	20.5	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.	Based on assumptions in using inorganic fertilisers and spreading lime results in High emissions. High cost. Competition with animal feed requirements could lead to unstable supplies and fluctuating costs.
Maize	-	-	70	26.9	Very 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.	Based on assumptions in using inorganic fertilsiers and spreading lime High emissions. High cost. Competition with animal feed requirements could lead to unstable supplies and fluctuating costs.

4.0 OWNERSHIP & STAKEHOLDERS

The project's feasibility relies on guarantees of feedstocks as well as raising large amounts of capital at the beginning of the project, when no revenues have been achieved. AD projects have significant capital costs associated with the required equipment. Therefore investors/lenders are taking on risk. The availability of capital and feedstocks varies based on the project's ownership model. The requirements of organisations vary as they fall under different legislation. In this section the structural differences as well as the advantages and disadvantages of a range of different community led organisations are explored. The historical impact of commercial led projects with community buy-in on the local economy and the project is explored.

4.1 Stakeholder Engagement

A variety of community stakeholders (primarily from the farming sector) were engaged in informing the direction of the study in addition to highlighting any concerns or particular areas of interest to be investigated. Based on this initial engagement, a survey aimed at farmers within the region was drafted as to determine availability of feedstocks, willingness to participate in an AD project, opinions, concerns and views on AD development, in addition to information on their farming practises. The survey has had 40 responses to date.

Per the survey, most farmers were aware of the AD technology (87%) and most responded favourably to participating to a local AD development (90%). The primary motivations for participating in an AD project were assessed. Participants were asked to rank in order of most importance the intended outcomes from participating in a local AD project: 50% cited financial as the primary outcome, 25% cited enhance environmental credits while 2.5% cited both improved work efficiency and community enhanced as the primary desired outcomes. The majority would approve the development of AD within their community with 10% neither disapproving or approving and only 5% disapproving. Only 5% do not use manure or slurry as a fertiliser. For manure and waste management, the methods in order of most employed are: slatted sheds, silo tanks, other, stockpiling, drystacking and slurry lagoons (64%, 10%, 10%, 8%, 5% and 2% respectively). The majority would use digestate as a fertiliser replacement (95%). The majority grow silage for their own feedstocks, with 26% (some both) producing grass silage for sale. Majority (61%) have the potential to grow more silage. The majority (59.5%) would also consider using **multispecies swards** as an alternative silage production.

Note: this feasibility report does not elaborate on the application and use of alternative sustainable feedstocks such as Multispecies sward or red clover ryegrass, currently being promoted by Teagasc and devenish for increased productivity, low or zero nutrient input requirements and low cost of production.

Feedstock availability and quantity findings are presented in Table 25. The combined biomethane potential from feedstocks represented in the survey amount to 1.428 GWh, a fraction of what is required for a small 20 GWh (2.5 MW) plant. Other information collected includes the amount of silage produced for participant's own livestock (28,356 t, approx. 714 ha) and 1,600 t (approx. 40 ha) for sale, 1,132 t of chemical fertiliser used and some 1,897 ha (4688 ac) of total area farmed. The survey shows a lack in the availability of FYM in the region. However, given the abundance of cattle slurry and subsequent storage methods, it would suggest that the respondents constitute mainly of dairy farmers. It is expected that organic farmers have higher proportions of FYM due to differing farming practices to obtain the organic status.

Table 25 - Survey results.

Feedstocks	Cattle Slurry	FYM	Equine	Pig Slurry	Grass Silage
Mass (t)	7,919	200	120	30	350
Energy (MWh)	990	69	104	3	263

Many opinions and concerns were expressed with regards to the potential development of AD in the Ballyhoura region. The main concern is the potential for competition between the AD plant and farmers in terms of land use and grass silage (other crops) being taken for AD feedstocks as opposed to fodder. Other potential issues include securing a constant stream of feedstocks, odour and local objections to its development. However, the survey also yielded many positive views on AD including reduced reliance on chemical fertiliser, employment in the rural community, alternative and diverse income source for farmers.

In conclusion, the farming community see AD as a favourable development on condition benefits (financial or material) can be provided to the farmer and rural community. The RGFI and industry proposed commercial structure places the farmer as central to the development of AD biomethane across Ireland.

4.2 AD Operation & Feedstock Sourcing

Feedstock sourcing and contracting farming stakeholders is discussed in this section. The subsequent section 4.3 will investigates the options on the project organisation and structure.

Sourcing and securing a consistent supply of feedstocks is the most important aspect of an AD plant. While support for AD development, biomethane production and, specifically RGFI and AD developers, are in discussion (RHO, see section 6.3.1); the farmers need incentivises to participate in AD. As previously mentioned, at the time of writing, an emissions ceiling will be enforced for each economic sector in the republic and an agreement between agricultural representatives and the government sets the emissions reduction target to 25% by 2030 for the agricultural sector (Agreed in August 2022). In these discussions, AD was highlighted as a key technology in helping achieve this reduction which, although no supports are in place, for and on behalf of industry RGFI/KPMG have presented key asks of Government with an Integrated Business Case for Biomethane Production in Ireland. These key asks are 50% Capital Funding, Implementation of the Renewable Heat Obligation Scheme by 2023 and favourable commercial lending to support 2.5TWh of biomethane by 2030, i.e 125 AD Plants.

The Integrated Business Case for biomethane production from RGFI show the principle of “Clustering” pays an important role is achieving economic of scale at the optimum scale of 20GWh to meet the Governments objectives of scale, pace, efficiencies and economics. RGFI, KPMG and Project Clover industry participants have been proactivity engaged with Government in the recent 18 months to demonstrate the demand for Biomethane and also the benefits from AD of decarbonising the difficult sectors of agriculture, themal demand and transport.
. Given the outlined legal commitments it is acknowledged that further supports could be required for farmers to participate or switch to AD. However, as mentioned above the Integrated Business case for biomethane production in Ireland is promoting AD as a complimentary and mature technology to decarbonise agriculture and food production.

Potential supports for farmers adopting new farming practises and land management are being explored such as LIFE **carbon farming** pilot scheme which offers €6,000 - €12,000 per livestock farm participating. There are currently 750 farms participating in this pilot scheme across Belgium, France, Germany, Ireland, Italy and Spain[2]. AD may be considered such a practise as it presents a method of improved manure management and methane emissions control as recognised by RED II. Such schemes would encourage the participation of farmers in an AD project if deployed on a national level and give an indication as to how such a support scheme could be implemented.

However, RGFI promotes that the Carbon Farming model should be the most economically advantageous structure to reward the farmers economically, for the environmental improvements and addressing the climate change issues. Farmers should have the option to contract their carbon savings from farm practices and land management to the purchasers of their produce to facilitate in setting of the carbon savings in sustainable food production.

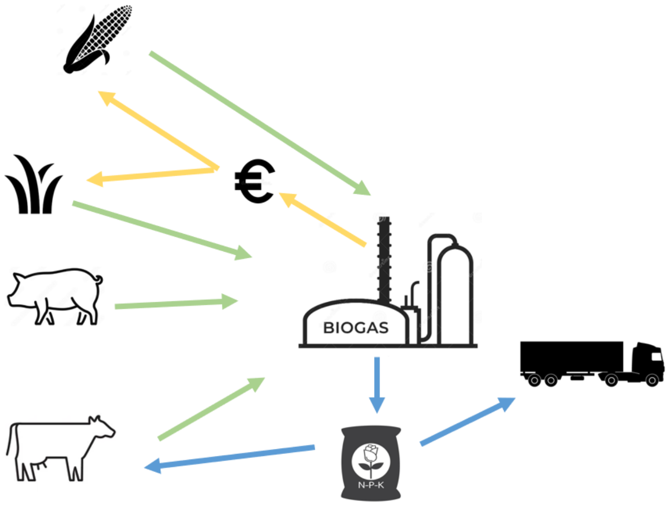

Figure 18 - Schematic of feedstock sourcing.

Consideration must be given to the economics and logistics of the plant, its supply of feedstocks and suppliers. These considerations will form the assumptions when constructing the financial model and feasibility assessment. Energy crops (maize and grass silage) would be bought by the plant with a supply agreement in place providing security of supply and certainty for the farmers production feedstock for the AD plant at a profit, covering the production cost of such feedstocks, giving the plant full ownership of the digestate which can be sold as fertiliser or processed further.

It is assumed that manure feedstocks are provided to the plant at no cost, however, transportation costs (both of collection and disposal) are covered by the plant, including energy crops. Grass silage being the primary fodder for cattle during the housing period during which cattle manure (FYM and slurry) can be collected. This silage requires a fertiliser input to be produced and consequently, the manures produced by the cattle. Typically, this manure is spread as a fertiliser to replenish nutrients in harvested grasslands and so, if supplied to an AD plant, the digestate should be returned as to avoid a nutrient deficit, if any and depending on the crop, such as red clover and ryegrass or multispecies sward, may require very little nutrient application over time., Thus, where cattle derived feedstocks are provided, the nutrient value equivalent is returned.

Pig farming produces vast amounts of slurry in a concentrated area due to the nature of the practise. While this makes collection and management of slurry easier due to its centralised nature, its disposal can be costly and difficult for larger facilities due to limitations on land

[2] https://www.teagasc.ie/environment/climate-change--air-quality/research/life-carbon-farming/

spreading (Nitrates directive) and its high moisture content, requiring larger transport distances and costs. Pig farmers in the Mitchelstown area have informed that 60% of their slurry can be spread in a 40 km radius, with the remainder requiring transport up to 60 km for disposal. The development of an AD plant in proximity to large pig farms (~10 km) where transportation is provided, would greatly benefit pig farmers and provide significant savings in addition to better waste management and work efficiency. It is assumed that pig slurry is provided at no cost and transport is provided by the AD plant, giving full ownership of the digestate to the AD plant.

4.3 Commercial vs Community Projects

Financing a community led project can be more difficult compared to commercial projects. The associated pros and cons to a community of buying in to a commercial project versus operating their own project are explored here. The comparison of a range of projects reveals that development and operating costs are generally higher for community projects while construction costs are normally comparable. As construction costs are generally the most significant costs in renewable energy projects this means these discrepancies are not necessarily detrimental to the project's success. In many instances these cost disparities lie in a community's lack of knowledge in the following areas, among others: planning rules, financial analysis, procedures for licensing, negotiating with manufacturers, securing grid connections, finalising legal contracts with landowners. Commercial developers are more likely to have expertise in these areas.

The open and democratic nature of communities can lead to longer development phases which can directly impact the cost of developing community projects. On the contrary, community projects tend to benefit from volunteer labour time whereas commercial projects are being charged by every project employee/contractor. Negotiation tactics can also cause an increase in community projects costs since communities generally negotiate less aggressively than commercial developers as well as the disadvantage of not having a developed relationship with the supplier, where commercial developers may receive bulk purchase discount. On the contrary, community projects can often be seen as pilot projects and receive discounted equipment on this basis. Communities tend to struggle to access affordable finance as the reputation of community projects has historically been poor. Compared to commercial developers, communities have less assets and cash resources. However, community run projects taking the form of a cooperative for example can access capital through local investments relatively easily due to the benefit of direct engagement with the local community where there is consultation and communication with allowance for locals to become owners.

Sometimes commercial developers offer communities buy ins to projects which can absorb the risk and permissions are obtained by the developer. Alliances with developers makes affordable debt access much easier but results in a reduced share owned by the community and consequently the project benefits experienced locally are also generally reduced, for example loss in income streams or loss of access to reduced local energy costs. A study carried out in Scotland found the local benefits from community energy projects vastly exceeds private owned generation highlighting the importance of communities owning and operating the project to maximise the local benefits. The report found community owned wind farms have paid their communities 34 times more than commercial projects. This loss can directly impact the development of the local economy and consequently other projects in the community. Commercial developers often receive more resistance from locals, who are less conscious of the projects benefits when they have less of a stake in the project.

When members of communities can actively participate in the region's energy transition as owners, this can engender increased cooperation and enhanced acceptance. Communities' acceptance is often referred to as a 'Social Licence to Operate' and is essential in acquiring planning permission promptly as it limits objections being lodged. A SLO is only seen as existing if a project has 'the broad acceptance and on-going approval of the local community in which it operates. Generally, these partnerships are difficult to establish, and communities overall find whole-owned projects to be more work but are much more beneficial in the long term. An interesting avenue exists in co-locating a renewable energy community project adjacent to a commercial project allowing the community to still access supports and reap all the project's whole benefits while both projects benefit from economies of scale. For this project a community ownership is the desired approach, but it is pertinent to consider the difficulties associated with this style of ownership model compared to a commercial developer ownership. Regularly referring to these reoccurring mistakes for the duration of the project can assist in minimising them and their impact on the project's timeline and financing.

4.4 Community Owned Organisation

In this section appropriate community ownership models for the development of AD in the Ballyhoura region are assessed and reviewed. As discussed, the community ownership route engenders local support and allows all the associated benefits of the project to be experienced locally. The Co-Operative and the Company models are outlined having been identified as the two organisation structures to raise equity for a community run project. A weighted scoring system is employed to compare the two organisation structures specific pros and cons relating to an AD plant in the Ballyhoura region.

4.4.1 Cooperative

The European Union has recognised the importance of Renewable Energy Source Cooperatives (REScoops) where their definition of a REScoop is a 'group of citizens that cooperate in the field of renewable energy, developing new production, selling renewable energy or providing services to new initiatives.' The principles associated with co-operatives allow the organisation to foster the community engagement in the project through the democratic membership model, from the organisation's independence, by training, educating, and informing members, through general cooperation with other cooperatives, through operating with concern for the community and through voluntary and open economic participation.

Cooperatives have limited liability meaning owners can only loose what they have invested and so there is no impact to owners' personal wealth beyond their investment in the Co-op. Co-ops must have a minimum of seven members but there is no upper limit on the number of members, and they are run by a board of directors elected by the shareholders. Co-ops are allowed to raise share capital and pay dividends to shareholders. Regardless of a shareholders share in the Co-op; each individual only gets one vote which exists as a mechanism to keep the control evenly spread out. Co-ops allow for capital to be raised relatively inexpensively. They can offer returns competitive to banks interests to incentivise large investments in the Co-op. Co-ops are governed by rules set by the group; however, the Irish Co-Operative Society offers Model Rules to provide a basis for new bodies. In general Co-Ops are run in favour of the layman, with lightweight reporting requirements and simple share offer documents and the registration to the Registry of Friends Societies in the CRO is inexpensive.

4.4.2 Private Limited Company & Designated Activity Company

The Companies Act 2014 lists two types of private companies – companies limited by guarantee (CLG) or companies limited by shares (LTD). The majority of companies in Ireland are LTDs. CLGs are generally set up for non-profit organisations requiring a legal personality, established so that the organisation can employ staff, enter into regular contracts and/or own property. Companies are separate legal entities to their employees, and therefore, only a company can be sued for its obligations and can sue to enforce its rights. LTDs are controlled by shareholders, while CLGs are controlled by their members. Members of a company limited by guarantee, however, do not 'own' the company in the same way that the shareholders of a company limited by shares do. In CLGs, members agree to a specific amount in the event of insolvency while in LTDs insolvency results in the loss of their original investment. The most significant differences between CLGs and LTDs are outlined in Table 26.

Table 26: Comparison of CLGs and LTDs

	Company Limited by Guarantee	Company Limited by Shares
Risk	Limited liability	Limited liability
Documentation	Constitution document with a memorandum and articles of association	Single document constitution
Name	Name must end in “company limited by guarantee". May be exempt if not for profit	Name of company must end in "limited" or "teoranta"
Profit	Profits reinvested	Shareholders receive dividends
Member numbers	No limit on member numbers	It can have between 1 and 149 shareholders
Applicable	Used primarily for NPOs, clubs, societies, community projects	Used primarily for businesses
Owners	No owners	Shareholders ‘own’ the company
Share Capital	Cannot raise share capital	Raise capital by issuing shares
Member fees	Subscription and/or joining fee	N/A
Not for profit status	May be eligible for not-for-profit status	Not eligible for not-for-profit status

A designated activity company (DAC) can either be limited by guarantee or limited by shares. A DAC have a memorandum in their constitutions which state the objects for which the company is incorporated. An objects clause is a provision in a company's constitution stating the purpose and range of activities for which the company is carried on. A DAC is either a Company Limited by Shares or Company Limited by Guarantee with Share Capital. When a DAC is set up as a company limited by shares it raises share capital with main focus company to maximise profit. However, when a DAC is set up as a company limited by guarantee having share capital, the company will be set in motion using some initial capital from the members as initial working capital because of insufficient funding available through grants, subscriptions, fees, or endowments. However, at a later point, once the company is running, working funds are received from the services and render in the form of fees, charges, and subscriptions. Guarantee companies with share capital determine voting power based on shareholdings however they are like CLGs where each member undertakes that, if the company is wound up, that they will contribute to the assets of the company up to a certain amount, as required, not exceeding an amount specified in the memorandum. Companies likely to avail of DAC format include companies that wish to be limited by guarantee whilst having a share capital or companies which are incorporated for a specific purpose for which the shareholders wish for the capacity of the company to be clearly defined

Unlike Co-ops, limited companies are controlled based on share ownership- where more shares equate to more votes and control. Therefore, a small group in a company can hold the majority control. Companies are also limited to between 1 and 149 shareholders which is often unsuitable for communities in terms of exclusion and raising capital from many community members. Raising capital from issuing a public share offer requires compliance with detailed legislation resulting in significant legal and administrative costs.

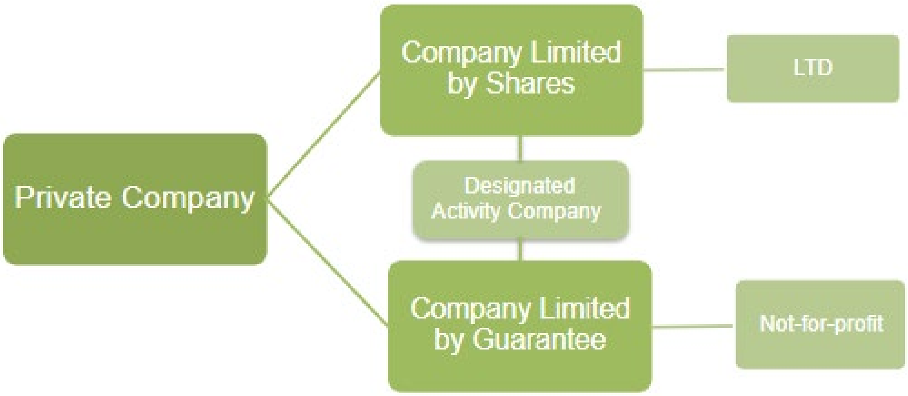

Figure 19: Schematic of types of private companies

4.4.3 Structure Comparison

The different benefits between Co-ops and companies in the context of this project are compared based on a weighted scoring system displayed in Table 27. Through desktop research, regional evaluation, and community engagement it has been hypothesised that the six essential pillars to have an operational plant in the Ballyhoura region, in descending order of significance are Access to Financing, Feedstock Guarantee, Community Engagement, Maximising Profit, Project Expertise, and Project Completion Length. Therefore, as an example 'Access to Financing' is weighted at a six. A score is assigned to each of the two organisation structures based on how well they theoretically perform under each of these criteria, where scoring a 5 implies the criteria will always be met and scoring a 0 means the criteria will never be met by that organisation structure. The total rating is then determined by finding the sum of the products of the weighting and the score of each factor. This analysis revealed that based on the research carried out a Community Led Co-operative is a more suitable ownership model for this project as it scored 5.7% (6/105) better, predominantly due to the assumption that a Co-op will have a much better community engagement and the inclusion of farmers will very likely guarantee a feedstock stream.

Table 27: Scoring Comparison between Co-Op and Private Company

Weighting		Community Led Co-operative		Company Limited by Shares (LTD)/ Designated Activity Limited by Shares (DAC)	
		Score (0-5)	Weighted Impact	Score (0-5)	Weighted Impact
Access to Financing	6	3	18	4	24
Feedstock Guarantee	5	4	20	2	10
Community Engagement	4	5	20	1	4
Maximising Profit	3	2	6	5	15
Project Expertise	2	2	4	4	8
Project Completion Length	1	2	2	3	3
Total rating (out of max 105)		70		64	

been allocated €60 million from the Climate Action Fund to be invested in community climate action projects and initiatives, as well as capacity building. The LIFE programme, the EU's funding body for the environment and climate action was renewed for 2021-2027 with a budget of €5.4 billion. IT has four sub programmes of which 'Clean Energy Transition' is one. Standard Action Projects (SAPs) include projects aimed at developing, demonstrating, and promoting innovative approaches, contribution to the knowledge bank and to the application of best practice, projects supporting EU legislation and projects which will catalyse the large-scale deployment of successful technologies. SAPs can receive co-financing of up to 60% and in 2021 Irish SAPs were also able to apply for CAF funding however, at present, this co-financing scheme is closed.

Along with a grant, some form of debt will be required to make up the balance of the project. Debt involves borrowing money, which is to be repaid, plus interest. Debt can be in the form of loans, bonds, or debentures. 15–20-year contracts for commercial funding have been considered pivotal in the development of the biomethane industry throughout Europe. The Ireland Strategic Investment Fund (ISIF), which is managed and controlled by the National Treasury Management Agency (NTMA), is a sovereign development fund with an aim to invest on a commercial basis to support economic activity and employment in Ireland. It has four main areas of focus which include 'Climate' and 'Food and Agriculture'. To date, the RGFI and Project Clover have secured €24 million of commercial lending from ISIF, subject to terms and conditions to help finance the development of an initial pilot phase of eight 20GWhAD plants. RGFI is working closely with ISIF, has indicated a willingness to facilitate the longer-term roll-out of agri based feedstock AD Biomethane plants, with a proposed €200m dedicated biomethane fund, supporting the wider expansion of Project Clover across Ireland. It is envisaged that this the Ballyhoura proposed AD Biomethane project may be eligible to apply for funding from this fund.

Generally, community owned renewable energy projects struggle in securing finance. Normally, debt financing is expensive, as a result of co-operatives reputation of low investment returns, general unacceptance amongst investors/financial institutions and inability to spread risk. Community run projects are generally not considered legitimate market players leading communities to struggle to avail of debt financing especially in early project stages and often cannot benefit from economies of scales in the early development costs. This type of project has inherent issues that can hinder their financing that are not directly finance related. It is believed that renewable energy co-operative projects can struggle to obtain finance due to political, administrative, legal, and economical factor that impact the validation of the projects financing plan.

5.0 BASIS OF DESIGN

Determining the most economically viable and cost-effective AD biomethane project is dependent on a range of fixed and variable factors. In this section the most optimal components for an AD Biomethane plant in the Ballyhoura region at a high level are identified. Alongside the feedstock analysis described in section 3.0, this section serves as an indicator of the potential for AD Biomethane plants in a range of sites across the Ballyhoura region with ultimate focus on Mitchelstown as the plant location due to its proximity to utilities including the proposed biomethane injection facility along with high volume of local agricultural feedstock streams. A technoeconomic model is then employed to determine a range of potential configurations and their viability.

5.1 Site Location

5.1.1 Considerations

To select an appropriate site for an AD project, there are a number of factors that must be considered, including the following:

- Location relative to available feedstock sources and digestate disposal
- Location with respect to the gas grid for biomethane injection
- Adequate road access for transport access and egress
- 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.
    - It is therefore evident that the selection of an appropriate site requires several interdependent factors in developing an adequate solution.

5.1.2 Candidate Locations

The initial analysis involved identifying eight candidate sites and defining practical feedstock sources at each location. The sites are selected based on proximity to population centres, road networks and geographical disparity allowing the analysis to envelop much of the region. The provisional sites used in this analysis are geographically shown in Figure 20 and are Bruff, Cappamore, Charleville, Croom, Galbally, Kilmallock and Mitchelstown.

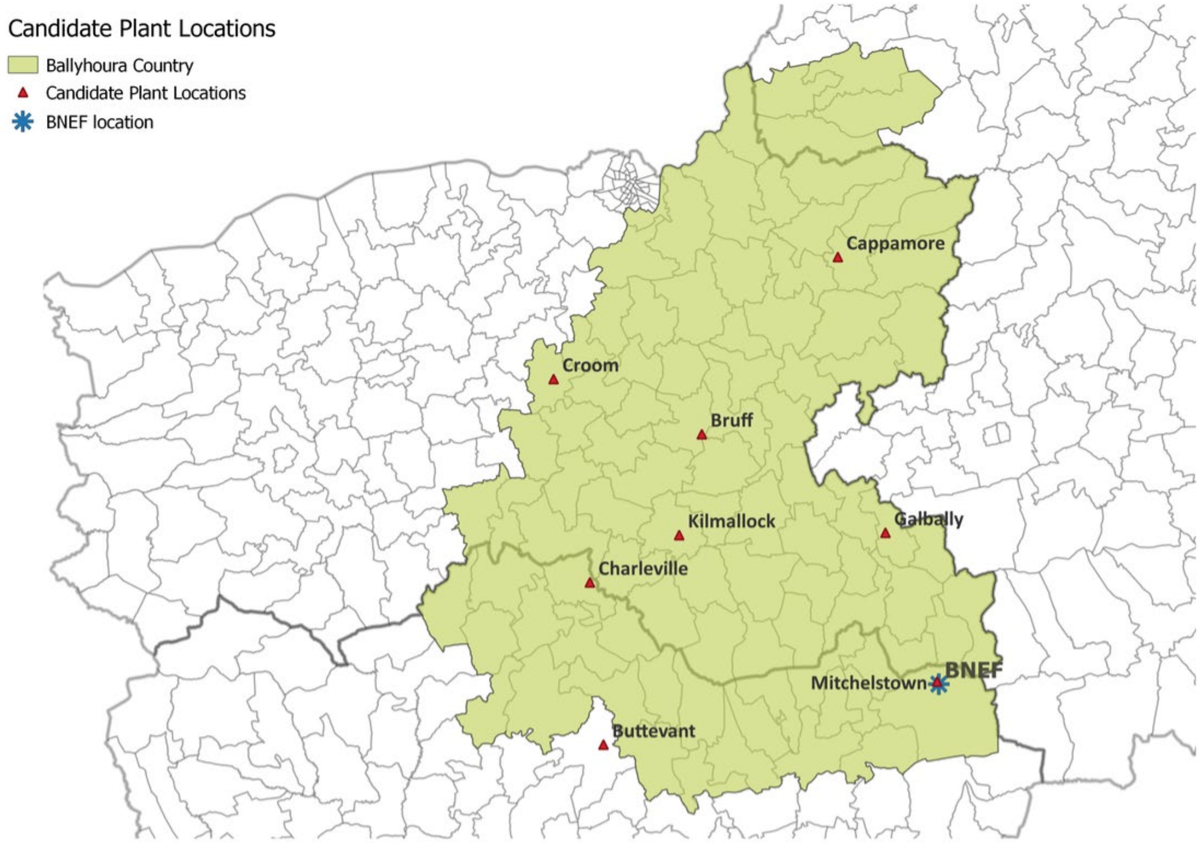

Figure 20: Locations of Candidate Sites

Coordinates for the candidate site locations are provided in Table 28. The locations 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.

Table 28: Candidate Sites

Location name	Latitude (°N)	Longitude (°E)	ITM X (Easting)	ITM Y (Northing)
Bruff	52.4752	8.5334	563734.1	635778.2
Buttevant	52.2337	8.6538	555341.0	609306.0
Cappamore	52.6088	8.3640	575344.2	650895.7
Charleville	52.3579	8.6727	554177.2	623138.7
Croom	52.5135	8.7207	551084.7	640484.8
Galbally	52.3975	8.3026	579405.7	627373.6
Kilmallock	52.3948	8.5612	561801.8	627175.4
Mitchelstown	52.2836	8.2372	583814.4	614685.3

5.1.3 Feedstock Suitability

At each site the quantity captured within a radius of 10 km and 30 km is used to indicate the potential of the location's feedstock stream in terms of tonnage per annum and biomethane potential (GWh). This analysis is limited to feedstocks with specific farm or ED data available (from CSO or EPA) and consequently excludes equine manure and maize.

Table 29: Feedstock quantity within 10 km radius of each site in t/a

Site	Grass Silage	Cattle Slurry	Cattle FYM	Pig Slurry	Poultry - Broiler	Dairy Processing	Animal Slaughter	Brown Bin Waste	Total (excl. Silage)
Bruff	- 61,100	212,780	54,696	-	-	-	-	2,181	269,658
Buttevant	- 35,700	189,051	52,397	-	-	-	-	3,046	244,723
Cappamore	- 35,700	189,051	52,397	-	-	-	-	3,275	337,097
Charleville	- 75,509	259,298	58,340	-	-	8,834	8,254	2,371	337,097
Croom	- 77,509	236,553	57,934	19,711	-	-	-	2,217	316,414
Galbally	- 53,470	197,340	50,438	13,838	-	-	-	1,188	262,805
Kilmallock	- 61,564	226,048	53,495	-	-	8,834	-	2,409	290,787
Mitchelstown	- 69,166	189,009	45,497	193,122	-	22,088	-	1,794	451,511

Table 30: Feedstock quantity within 30 km radius of each site in t/a

Site	Grass Silage	Cattle Slurry	Cattle FYM	Pig Slurry	Poultry - Broiler	Dairy Processing	Animal Slaughter	Brown Bin Waste	Total (excl. Silage)
Bruff	- 458,214	1,783,497	445,180	253,547	-	34,297	8,254	30,216	2,554,991
Buttevant	- 544,815	1,923,565	441,410	249,815	-	33,379	18,319	19,999	2,686,488
Cappamore	- 310,806	1,478,007	392,777	57,341	-	10,083	2,688	29,716	1,970,612
Charleville	- 482,308	1,905,583	457,944	243,025	-	33,379	8,254	25,830	2,674,015
Croom	- 327,713	1,618,634	419,873	33,549	-	11,542	8,254	31,952	2,123,803
Galbally	- 553,831	1,725,594	422,580	288,739	-	34,297	8,254	20,794	2,500,259
Kilmallock	- 543,033	1,840,946	443,156	253,547	-	34,297	8,254	29,567	2,609,767
Mitchelstown	- 610,231	1,687,714	400,706	282,873	1,038	34,297	18,319	17,797	2,442,744

Table 31: Feedstock Biomethane Potential within 10 km radius of each site in GWh/a

Site	Grass Silage	Cattle Slurry	Cattle FYM	Pig Slurry	Poultry - Broiler	Dairy Processing	Animal Slaughter	Brown Bin Waste	Total (excl. Silage)
Bruff	-51.09	29.41	20.66	0.00	0.00	0.00	0.00	1.57	51.6
Buttevant	-41.18	26.49	16.74	1.31	0.00	0.00	2.03	2.05	48.6
Cappamore	-29.85	26.13	19.79	0.00	0.00	0.00	0.00	2.12	48.0
Charleville	-63.13	35.83	22.04	0.00	0.00	3.37	2.03	1.58	64.9
Croom	-64.81	32.69	21.89	2.31	0.00	0.00	0.00	1.55	58.4
Galbally	-44.71	27.27	19.05	1.62	0.00	0.00	0.00	0.89	48.8
Kilmallock	-51.47	31.24	20.21	0.00	0.00	3.37	0.00	1.60	56.4
Mitchelstown	-57.83	26.12	17.19	22.65	0.00	8.42	0.00	1.14	75.5

Table 32: Feedstock Biomethane Potential within 30 km radius of each site in GWh/a

Site	Grass Silage	Cattle Slurry	Cattle FYM	Pig Slurry	Poultry - Broiler	Dairy Processing	Animal Slaughter	Brown Bin Waste	Total (excl. Silage)
Bruff	-383.12	246.47	168.18	29.73	0.00	13.07	3.04	19.31	479.8
Buttevant	-455.53	265.83	166.76	29.29	0.00	12.72	2.95	13.48	
Cappamore	-259.87	204.25	148.38	6.72	0.00	3.84	1.99	18.81	384.0
Charleville	-403.26	263.34	173.00	28.50	0.00	12.72	3.04	16.85	497.4
Croom	-274.00	223.69	158.62	3.93	0.00	4.40	3.04	20.28	414.0
Galbally	-463.06	238.47	159.64	33.86	0.00	13.07	2.03	13.98	461.1
Kilmallock	-454.04	254.41	167.41	29.73	0.00	13.07	3.04	18.99	486.6
Mitchelstown	-510.22	233.23	151.38	33.17	1.40	13.07	2.95	12.26	447.5

From

Table 29 to Table 32 it can be seen that dairy and suckler farming activity in the region result in large quantities of biological waste in the form of cattle slurry and FYM. Cattle slurry constitutes between 61% and 82% of the region's tonnage per annum. Therefore, quantities of cattle slurry far exceed that of FYM. However when analysed in terms of biomethane potential (Table 30), the relative contribution of cattle slurry to the total biomethane content in a 10 km radius drops considerable due to a low energy content (0.49 MJ/kg), indicating that significant quantities are required to be transported to the facility to harvest the feedstocks potential and produce biomethane at scale. FYM has a much higher energy content as it is drier (1.37 MJ/kg), and a higher C:N ratio due to the straw content which is useful for co-digestion with manure substrates. The large quantities of cattle slurry are quite evenly spread across the region, with Charleville and Buttevant having the largest biomethane potential from cattle slurry. The assumptions used here ignore the high levels of organic farming practices recorded in North Cork (section 3.1.2), which increase the biomethane potential of the FYM in Mitchelstown, Buttevant and Charleville.

On the contrary, the pig slurry tonnage is not evenly spread, with majority located on the east of the region, around Mitchelstown. It has a low energy content, and so while it contributes to about 20% of the tonnage in the eastern side of the region, it only provides about 13% of the biomethane potential. In all other regions the biomethane potential of pig slurry is less than 5%. The quantity of silage available in the region is considered negative since insufficient quantities of silage are produced within the region which results in net imports across the region. There are only approximately 10 broiler facilities in Munster and only three within a 30 km radius of Mitchelstown. Due to the high energy content, the small volume of waste available has a relatively significant large potential, however due to concerns over botulism and salmonella, this potential was not considered further.

5.1.4 Selected Location

All candidate sites have significant potential, predominately from cattle slurry and FYM. However, aforementioned benefits of pig waste for AD plants (including intensive farming, slurry disposal) make it a reliable feedstock once available within short distances of the plant. Mitchelstown has several large pig farms close to it, large quantities of FYM available and a strong utility network including the planned BNEF and injection point adjacent to Corracunna AGI to the east of Mitchelstown. The total biomethane potential (excluding silage) within 10 km of the proposed site was the largest for Mitchelstown and therefore it was chosen for the proposed plant location and is solely considered for the remainder of this study.

5.2 Plant Parameters

5.2.1 Plant Scale

The scale of an AD plant is either classified based on the volume/mass of feedstocks processed (m^3/a, t/a), or by the maximum energy generating capacity (MW of gas/heat/electricity). Maximising biogas extraction generally involves co-digestion of substrates and in these instances defining scale based on energy generating capacity (MW) is preferred since feedstock throughput is a complex quantity as it can vary greatly depending on the energy density of the individual feedstocks. The capacity of a plant, the maximum amount of energy which can be produced, is generally impeded by the capacity factor of the plant. The capacity factor is typically 90%, where the remainder of the capacity is lost due to required plant shutdown for activities like maintenance. The annual energy generation is defined in MWh/a and is determined by multiplying the generating capacity, capacity factor and the number of hours per year (8760). 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. The plant will aim to be in the 2.5 MW (20 GWh) depending on feedstocks available, should it be possible then larger plants will be considered. This is aligned with the RGFI/KPMG feasibility study of 20Gwh being the optimum scale and where appropriate larger AD biomethane plants possible where the feedstock availability is concentrated in one location.

5.2.2 Solids Content

AD digestion systems are either dry or wet; 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%). Feedstocks with high solids content can be processed using dry AD systems. The OPEX are lower due to lower throughput (handling and heating) and no additional water is required. The feedstocks are stacked, with leachate spayed on them, which percolates through the material, breaking it down over a relatively long retention time. 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 CSTR and pumped through the plant using conventional pumping systems; however, the gas output per unit feedstock is lower and high-water content results in 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 Ballyhoura region (Section3.0), and popularity/market maturity of wet systems in Ireland and the UK, continuously stirred wet AD is considered in the study, requiring a solids content target of 14% or less.

5.2.3 Temperature Regimes

The microorganism in the feedstock that produces methane as a by-product in oxygen limited environments is called a methanogen. A methanogen grows in two temperature categories, mesophilic and thermophilic and therefore these are the two temperature ranges employed in AD. Mesophilic AD systems operate at 35-45°C, with thermophilic digestion occurring at 50-60°C. Thermophilic conditions permit a greater throughput of material and greater pathogen kill than mesophilic, however capital, and operational costs are generally higher. Thermophilic conditions are generally employed in hot countries where the temperature difference between the internal mesophilic and external environment is small, where nuclear energy is powering the plant or where there is an adjacent large heat source available. 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. Given the increased robustness and stability in addition to the relatively low annual ambient temperature of Ireland, a mesophilic regime is chosen for AD in this study.

5.2.4 Digester Design

The digester is a sealed vertical cylindrical tank made of either coated steel or concrete, where the anaerobic bacteria transform the feedstock mixture releasing biogas. As described the wet AD system is appropriate due to the density of the major feedstocks in the Ballyhoura region. Continuously stirred tank reactors (CSTR) are the most commonly employed configuration in wet systems. CSTRs are simply designed and operated where their feedstock is loaded to the top of the tank and then allowed to ‘fall’ slowly to the bottom as it is stirred and digested. Upon reaching the bottom, the digestion process is largely complete and the digestate is removed. In the digester the substrate is continuously stirred and maintained at a specific temperature

(35-40°C for mesophilic operation) using mixing/agitation equipment and heaters, respectively.

The heat employed in a digester depends on the schematic of the system. If the digester is part of a CHP plant generating electricity, then the heat produced is used in 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 is either 'vertical' or 'classical' in design. In the vertical arrangement the mixers are suspended from the roof of the digester, with the heat supplied by heat exchangers external to the digester. These digesters don't have flexible roofs and so the produced biogas is stored in a separate biogas holder. These digesters are distinctive in that the digester height that is greater than its diameter. For the classical arrangement, the mixing equipment is inclined through the sidewall, 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. It also has a smaller footprint which can be beneficial in built up area however they are more expensive to construct and require a separate gas holder and are more complex to operate. The less efficient classical style digester is generally used in smaller on-farm projects, commonly seen around Europe. It is suited to agricultural feedstocks, and relatively easier operation and maintain whereas the vertical design requires full-time technical staff to service a more complex system.

5.3 Feedstock & Digestate Management

Feedstock Storage

Certain feedstocks may have time sensitive availability which requires careful management as to maintain a balance and consistent flow of feedstock for the AD process. FYM will not be available during the winter months as animals are housed. FYM will only be available once animals are returned to pasture. For the Ballyhoura region, this implies a 16-week minimum housing period during which the feedstock will not be available. Similarly, grass silage and other crops are harvested during the spring and summer each year and will require the appropriate onsite storage or ensiling. It is assumed the silage and maize require storage for a year's worth of feedstock and FYM requires 4 months' worth of onsite storage. Pig slurry is available year-round due to the nature of pig farming and therefore it is assumed it is stored on farm and collected as required.

Processing & Odour Control

A major concern and objection by the wider community with regards to the development of AD projects is the association made between AD plants and odorous animal manures. The land spreading of raw slurries and manure produces odours that often disturb the public, even a great distance away from the site; despite AD reducing odours of these substrates, the incoming feedstock could produce odours.

Odour control and management can be implemented if particularly odorous feedstocks (pig slurry, chicken manure) are used. The AD feeder and loading area can be housed within a facility or warehouse (reception building). The most common solution for treating odour is to maintain an internal negative pressure which siphons air into carbon filter. The filter contains activated carbon which captures volatile molecules. This will, however, increase capital costs and operational costs, particularly CAPEX due to construction.

Land-Spreading

While the AD process extracts methane (Hydrocarbons) from the ingoing feedstock, the nutrient contents (specifically N-P-K) are conserved and remain in the digestate, a homogenised material, meaning it can be spread on land as an alternative to manure or chemical fertilisers. Land spreading is restricted by the aforementioned ABP regulations in addition to the Nitrates directive act. This imposes a period of prohibited spreading of fertilising products on land during the winter months, dependant on location and fertiliser type. The period of prohibited fertiliser application is presented in Table 33 with the zones shown in Figure 21. Thus, any AD development should accommodate for storage of digestate and feedstock during a 3–4-month winter period.

Table 33 - 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

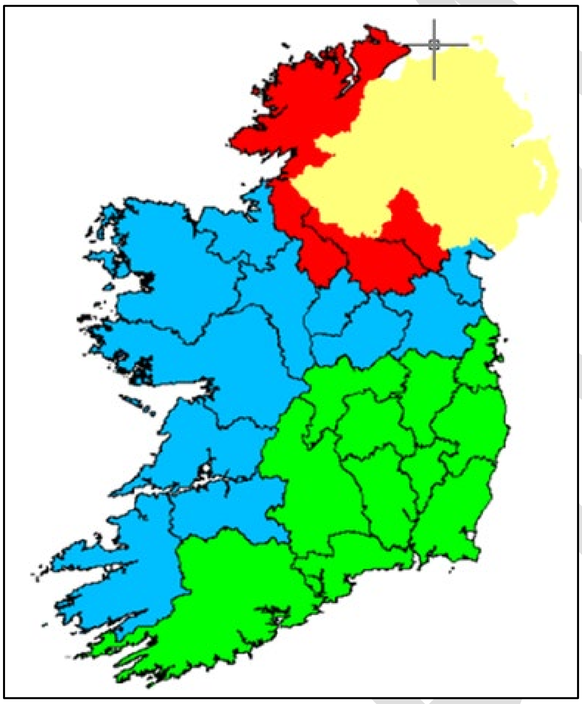

Figure 21 - Zoned areas (A green, B blue, C red)

Digestate Storage

Given that land spreading is prohibited during the winter months as outlined previously, consideration must be made to digestate and the subsequent derived bio fertiliser. The digestate will have a thick slurry like consistency, expected to be some 9% Dry Matter (DM). Storage for such material would include closed silos and tanks.

Closed Silos and tanks present a more robust method of storage, however, requiring much more in the way of materials, labour and design, in addition to being limited in maximum size (largest typically 5,000 m^3). Advantages they present include space efficiency and minimised risk of spillage or contamination or dilution by rainwater and subsequent recovery of biogas .

It is expected that the digestate will undergo separation upon exiting the digestion process into either a solid and liquid fraction. The solid and liquid fractions are expected to have dry matter content of 25-34% DM and 1-4% DM respectively. The liquid fraction can be stored in the previously outlined methods. The solid fraction although still quite wet will be of cake or compost like consistency (similar DM content to silages) can be stored much like the feedstocks as discussed previously.

Post-fertiliser upgrading (further discussed in section 5.4), the volume of material requiring storage is greatly reduced. The liquid fraction is expected to be reduced by approximately 50% as it consists of the reject water from reverse osmosis. This nutrient rich liquid can be stored in a silo or tank (possibly IBCs). The solid fraction post upgrading will return three products; a wet organic potting soil, a gypsum sludge and struvite sludge. These make up 73%, 17% and 10% of the upgraded solid digestate respectively. The potting soil can be stored and dried much like a compost, held in a simple drystack. Once dry, potting soil can be used directly by the farmers if desired, although it is likely to be of more use to a compost plant or producer of garden soil supplies and products. The gypsum sludge produced will require drying, possibly requiring a mechanical crushing to achieve a pelletised or granular form for ease of handling, storage, transportation and spreading. Likewise, struvite precipitates from the solution in a settling tank and requires drying but is otherwise in a “pelletised”/granular form due to the setting process. The gypsum and struvite can be stored in simple mounds or in tonne bags (as shown in Figure 22) on condition that they are sheltered from water and elements (as they are partly soluble). Like the potting soil, they can be directly used by the farmers or sold to nutrients wholesaler for garden or horticulture applications for further processing and distribution.

Figure 22 - Struvite stored in 1m³ bags (de Vries et al, 2017).

Processing

Digestate although having many benefits over usual manures and raw slurries as fertiliser such as less nitrous oxide emissions, less odours and less plant burn, it can be further processed to concentrate nutrients, improve quality, improve purity and reduce the amount of material to be transported. These upgraded materials no longer classify as wastes and become an actual marketable bio fertiliser product that can be sold throughout the EU.

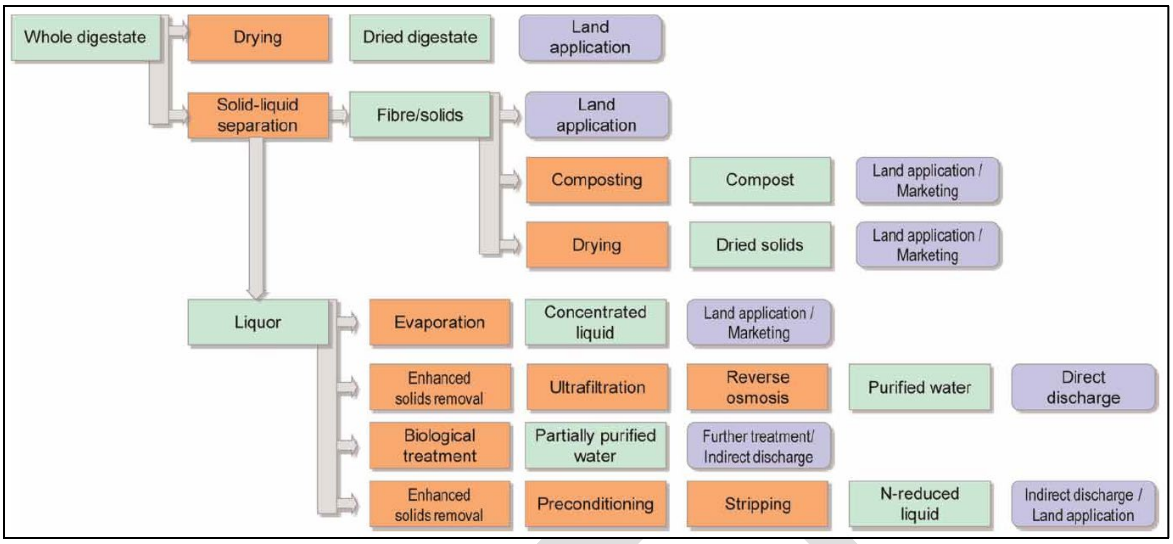

Figure 23 – Examples of digestate processing (source: Fuchs and Drosg, 2013)

Various methods of nutrient recovery and extraction are discussed in the subsequent section.

5.4 Biofertiliser Upgrading

This section discusses digestate management and further processing techniques to reduce the volume of digestate to be disposed and producing a high-quality fertiliser that can be valorised and sold, once compliant with the Fertiliser Products regulation

5.4.1 Phase Separation

After the digestate has exited the digester and undergone pasteurisation, roughly 94% of the material entering the digester will remain and will require disposal. While the AD process extracts methane (Hydrocarbons) from the ingoing feedstock, the nutrient contents (specifically N-P-K) are conserved and remain in the digestate. The digestate (typically 9% TS) undergoes a phase separation step, typically done by either a screw press or centrifugal decanter. The resultant outputs are a Nitrogen Potassium rich digestate liquor (<1% TS) and a solid fibre cake which is rich in Phosphorous and contains most of the remaining organic matter (25% TS); allowing for better distribution and spreading to lands only requiring a particular nutrient. These materials can undergo further processing to extract nutrients and improve their purity and concentrations while reducing the amount of material to be disposed from site and consequentially the associated transport costs.

From Bauer et al (2009), the proportion of nutrients allocated to both the solid and liquid phases of digestate are explored. The results are presented for separation via screw press although other methods include belt press and centrifugal decanter. Given that a liquid and solid fraction remain post separation, different methods will be required for further processing and nutrient extraction.

Table 34 - Separation of nutrients into liquid and solid fractions.

Parameter	Liquid Phase	Solid Phase
Mass (t)	79%	21%
TS (%)	38%	62%
Total N	69%	31%
Total P	48%	52%
Total K	72%	28%

5.4.2 Liquid Fraction Upgrading

The liquid post-separation contains the majority of the Nitrogen and Potassium contents of the digestate. However, the vast content of the mass is water which requires large transport and spreading costs while not being the item of interest or value. At such quantities it is worthwhile investigating dewatering and nutrient extraction methods. Dewatering typically involves Dissolved Air Flotation (DAF), Membrane filtration, Reverse Osmosis (RO) and Ion Exchange (summarised in Figure 24).

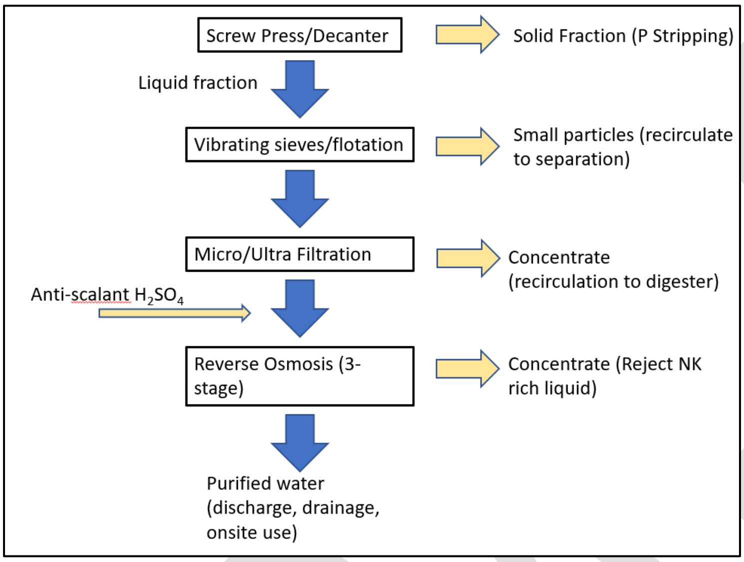

Figure 24 - Overview of digestate liquid fraction upgrading.

DAF is used as the initial separation process is not full efficient in removing solids from the liquid digestate with many smaller suspended solids making it into the liquid. DAF removes these by pushing compressed air through the liquid which has had polymer flocculants added (to aid solids to float), causing microbubbles to attach to remaining solids causing them to float to the surface. These can then be removed via a skimming device and re-circulated back into the digester for further anaerobic breakdown.

RO occurs via the solvent diffusion across the membrane (solution-diffusion membranes) that can be non-porous or uses nano-scale pores whereby the predominant mechanism of permeation is driven by the difference in solubility or diffusivity of the substances. The process can remove down to 0.001 μm and can even remove dissolved salts and molecules. It is typically configured as to have three stages to maximise nutrient extraction and typically rejects 30-40% of the water content (See Table 35). The rejected liquid concentrate will contain 95% of the nutrients which can be spread as an NK fertiliser. The clean water that is produced passes into an ion exchange stage as to remove any remaining impurities prior to discharge.

Table 35 - Nutrient proportions from liquid digestate in water and liquid concentrate.

Parameter	Concentrate	Water
Mass	30%	70%
N	95%	5%
P	95%	5%
K	94%	6%

This process, while increasing energy and maintenance costs, does have the benefit of significantly reducing the amount of material and digestate that would otherwise have to be transported off site for disposal providing significant savings in transport costs and emission in addition to storage (Approximately 55% reduction in mass). The savings are gained from the removal of excess water content from the digestate which can be discharged to WWT. From discussion with suppliers, the power consumption of the whole liquid treatment process amounts to 14 kWh/m^3 of digestate treated.

5.4.3 Solid Fraction Upgrading

The separation process typically produces a cakelike substrate of 25-30% DM, making up 20% of the processed digestate's overall mass and containing the majority of the phosphorous content and organic matter. Treatment of solid waste is somewhat uncommon. Phosphorous stripping or struvite extraction provides one method, although this typically done in the context of treating vast quantities of water in a WWT process. However, recently this process is being introduced to AD plants where digestate disposal is a hurdle to its financial viability. The process is novel and bespoke with the consequence that equipment and suppliers may not be readily available on the market. Regardless, a trial process at a plant in the Netherlands (Groot Zevert) has been documented, giving insight into materials, equipment and inputs required in addition to data on its technical and financial performance.

Phosphorous is an essential element in fertiliser and is a finite, non-renewable resource making its recovery from manures and wastewater effluent highly desirable. The main extraction method involves struvite precipitation (the process shown in Figure 25), whereby struvite is a mineral composed of ammonia, phosphates and magnesium ($MgNH_4PO_4$). Post-separation, the solid digestate is rewetted and has an acid (usually sulphuric acid H_2SO_4) added to drop the mixtures pH in a first acidification stage. Dissolving phosphorous out of the solid into liquid sludge after a certain Hydraulic Retention Time (HRT), the mixture undergoes a separation stage via screw press where the acidified liquid fraction is sent to a settling tank while the remaining solid fraction enters a secondary acidification stage. This stage extracts any remaining phosphorous from the solid which then enters a second separation step leaving a P-poor organic material behind, with the liquid recirculated back to the first acidification stage tank.

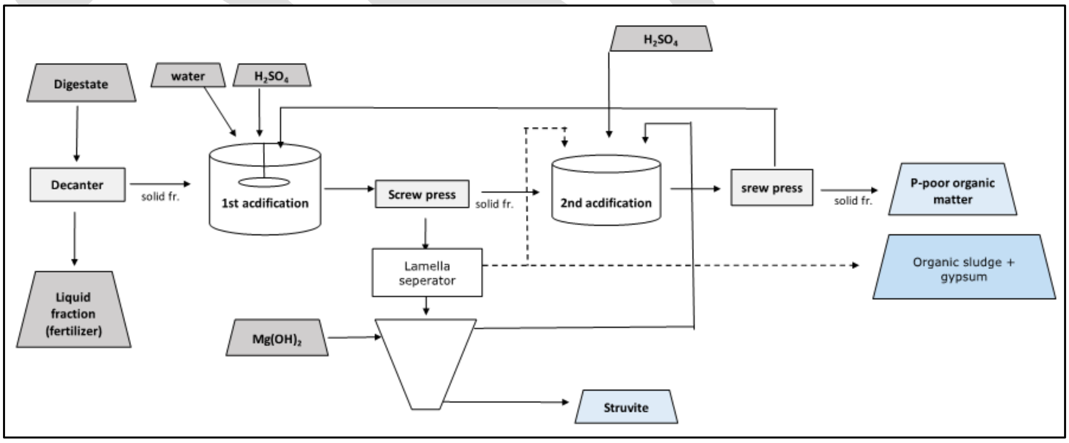

Figure 25 - Process for treatment of solid digestate (Inge Regelink et al 2019).

The solution in the settling tank is screened, removing any sludge that may form and sending it into the secondary acidification stage. Post screening, the liquid is passed into a reactor where a base (either Magnesium oxide $Mg(OH)_2$) is added to increase the solution's pH causing the formation and precipitation of struvite crystals. These would have to undergo drying and dewatering.

The P-poor material can be used as a soil conditioner or potting soil. Struvite can be used as a slow-release phosphorous fertiliser. Depending on the efficiency of the process, the process produces an organic sludge containing gypsum, depending on the acids and bases used reacting with organic matter, which can be dewatered into an organic P fertiliser.

Table 36 displays the expected yields from the process. The amount of gypsum sludge produced depends on the amount of calcium in the digestate as it combines with sulphuric acid. Although the sludge can be used as a fertiliser, it is desirable to minimise it as to maximise struvite yield which is of a higher quality. The process uses some 37 kg of sulphuric acid, 11 kg of magnesium oxide and 20 kWh of electricity per tonne of solid digestate processed. As detailed in section 3.6, GHG emissions must be tracked from all operations taking place at the plant. Emissions from sulphuric acid and magnesium oxide are 0.140 kg CO_2 /kg and 1.060 kg CO_2 /kg respectively.

Table 36 - Proportion of nutrients from solid digestate into corresponding products.

Parameter	Topping Soil	Struvite	Gypsum Sludge
Mass	73%	10%	17%
N	85%	10%	5%
P	10%	87%	3%
K	70%	5%	25%

This process is included with the AD plant configurations and assess their impact on the economic viability as discussed in section 6.3. Unlike the liquid treatment process, the are no transport or storage savings provided as all solid material would have to be disposed of. The process produces more concentrated nutrients and organic solids allowing for better management, producing more marketable products for sale. Savings from P stripping are usually gained when there is a prohibition on the spreading of certain nutrients (Phosphorous) on nearby lands where disposal distances are large and the volume of material is large, resulting in high transport costs.

5.5 Biogas End Use

Various applications for valorising the biogas produced are discussed and compared in this section.

5.5.1 Heat Only

Some AD plants are set up to produce biogas for the production of heat only in situ. The digester and pasteurisation unit are maintained at the operating temperature using a portion of this heat. The remaining heat is available for use in domestic heating or industrial processes. The process is efficient where approximately 80-90% of useful energy is converted. The feasibility and success of this system is dependent on an adequate local heat load with commercial offtake agreement, as well as 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 only biogas end-use, with such systems uncompetitive against conventional heating systems.

5.5.2 Electricity Only & CHP

The biogas produced can be burned to generate and export electricity, however this process is relatively inefficient with only approximately 30-35% of useful energy converted as the system does not take advantage of the significant quantity of the energy available through heat recovery. The introduction of CHP (Combined Heat & Power) generation units allows for the simultaneous production of electricity and heat where the load extracts waste heat from the process yielding efficiencies of 80-90%, where a useful heat load is located close to the plant location. To date AD plants in Ireland have availed of the Renewable Energy Feed-In Tariff (REFIT) which guaranteed renewable electricity generators a minimum price for each unit of electricity exported to the grid over a 15-year period. Under REFIT 3 large/small non-CHP and CHP units are receiving 10-12 c/kWh and 13-16 c/kWh respectively. This scheme closed in 2015 and was replaced by the Renewable Electricity Support Scheme (RESS) which invites renewable energy projects to bid for and receive a guaranteed price for the electricity they generate. Biogas CHP is not competitive with wind and solar PV in the RESS, with no biogas projects awarded contracts in either the RESS 1 (2020) or the RESS 2 (2022) auction. The guaranteed prices are 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.

5.5.3 Biomethane Upgrading & Injection

Biomethane is derived from biogas by separation of the CO_2 and CH_4 using specialised upgrading technologies, leaving high purity CH_4 that has identical properties to the grid gas. The biomethane can be injected into the network via either a pipeline with a connection at the plant or a “virtual pipeline” (which involves HGVs transporting gas trailers) to a centralised injection site referred to as the BNEF. The upgrading process is efficient with approximately 92% of the energy in the raw biogas in the final energy delivered. Across Europe Biomethane is seen as a vital tool for decarbonising the heat and transport sectors. The European Commission identified Ireland as having the highest potential in Europe per capita to produce biomethane.

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 to be biomethane. Along with RGFI and working closely together, GNI is proactive in driving and promoting an indigenous biomethane industry in association with Renewable Gas Forum Ireland and Renewable Energy Ireland, Renewable Energy Ireland GNI have initiated project GRAZE which is funded by the Climate Action Fund and aims to promote biomethane production and adoption via the development of CGI (Centralised Grid Injection) or BNEF and operation of CNG facilities. Their development will provide the infrastructure to collect biomethane from private AD plants (expected to develop in regions of intense agriculture) for injection into the national grid. Currently, a CGI is being developed in the Corracunna townland close to Mitchelstown, Co. Cork in addition to operating 2 no. biomethane transport trailers. These trailers are available to operate as a virtual pipeline whereby biomethane is compressed to 250 bar into specialised trailer units which can carry around ~11 ,000 Sm^3 from the AD plant to the CGI facility (Figure 26). Prior to acceptance and injection, the biomethane undergoes the following steps:

- **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

Figure 26 - Example of trailer that would make up virtual pipeline (source: Galileo Technologies).

At the present time, the Renewable Heat Obligation Scheme to socialise the funding gap, is progressing with the Government of Ireland having approved to proceed to the design phase and public consultation in November 2022, with the view of Implementation of voluntary obligation in 2023 and becoming mandatory in 2025. This is an enduring solution that will support biomethane production, providing certainty and confidence for investors' . The Renewable Heat Obligation (RHO) scheme, is expected to mirror the Biofuels Obligation Scheme (transport sector), obligating fuel suppliers to ensure that a specific proportion of the fuel they supply for heat is renewable. It will apply to all heat sector fuel suppliers supplying more than 400 GWh of energy. 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, current support scheme landscape and existing/developing infrastructure to facilitate grid injection, upgrading of biogas to biomethane is the technology pathway of choice for this study.

Biogenic CO_2Over 500,000 tonnes of CO_2 are required annually in the UK and Ireland for a range of applications including carbonation of soft and alcoholic beverages, in greenhouses to stimulate photosynthesis, in animal slaughter and in food preservation. At present, the majority of the food grade CO_2 employed, is recovered from industrial processes where CO_2 is a by-product and if not captured, is released to the atmosphere. A major industrial process in the UK is the production of Ammonia on a large scale to make nitric acid which is used to produce nitrate fertilisers such as ammonia nitrate and urea. The process of combining airborne nitrogen with hydrogen in methane, to produce ammonia, emits 1.3 tonnes of CO_2 for every tonne of ammonia produced, which is largely captured and sold. However, in recent years, due to the global energy climate and ageing assets, UK based ammonia production has become an increasingly volatile industry, undergoing a transformation, along with widespread plant shutdowns as result of economic and mechanical issues. The UK's domestic production of CO_2 has consequently seen reoccurring shortages over the last several years. Ireland has no local sources of CO_2 production, which results in a range of industries relying on CO_2 imports, particularly from the UK, to operate.

Biogas contains an average of 45% CO_2 and 55% CH_4 (with other trace elements including nitrogen, hydrogen sulphide and ammonia). When biogas undergoes 'upgrading' to biomethane, it is separated, generally with membranes, into CH_4 and biogenic CO_2. This results in food grade liquid biogenic CO_2 being readily available for collection and distribution, creating another potential revenue stream for the plant. In the UK there is evidence appearing of a move towards diversifying the CO_2 production facilities, so to rely on multiple smaller sources of biogenic CO2, in particular through recovery from biomethane production. This diversification allows for a more reliable and greener stream of CO_2 production. Based on the estimated biomethane production for each plant option, an estimated biogenic CO_2 production was calculated.

The Biogenic CO_2 stream coming from the Biomethane Upgrading Process (BUP) has a purity of >99.6 %. To convert the gaseous biogenic CO_2 to a food grade liquid CO_2, a double acting, oil free, water-cooled compressor is required. The biogenic CO_2 at normal operating conditions is gaseous and can be liquified under pressure at a temperature below 31 °C (the critical point). If compressed and cooled below this critical point, a colourless fluid is produced with approximately the same density as water. This is depicted in Figure 27, in the phase diagram for biogenic CO_2. Typical biogenic CO_2 compressors operate with an output pressure of between 19 and 40 bar. The LCO_2 (liquified CO_2) is then pumped into a vertical vacuum insulated biogenic CO_2 tank. To transport the LCO_2, a CO_2 semi-trailer is employed, which is filled via CO_2 transfer pumps. The associated capital and operating costs and revenue stream are outlined in section 6.3.2.

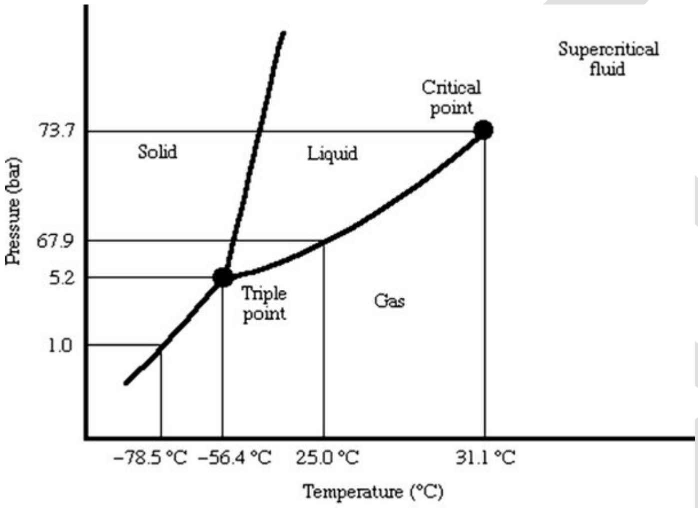

Figure 27: CO_2 Phase Diagram

5.6 Preliminary Plant Design

5.6.1 Design Assumption

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 (7,446 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 biofertilizer
- Gas revenue of 10 –12 c/kWh.

5.6.2 Plant Description

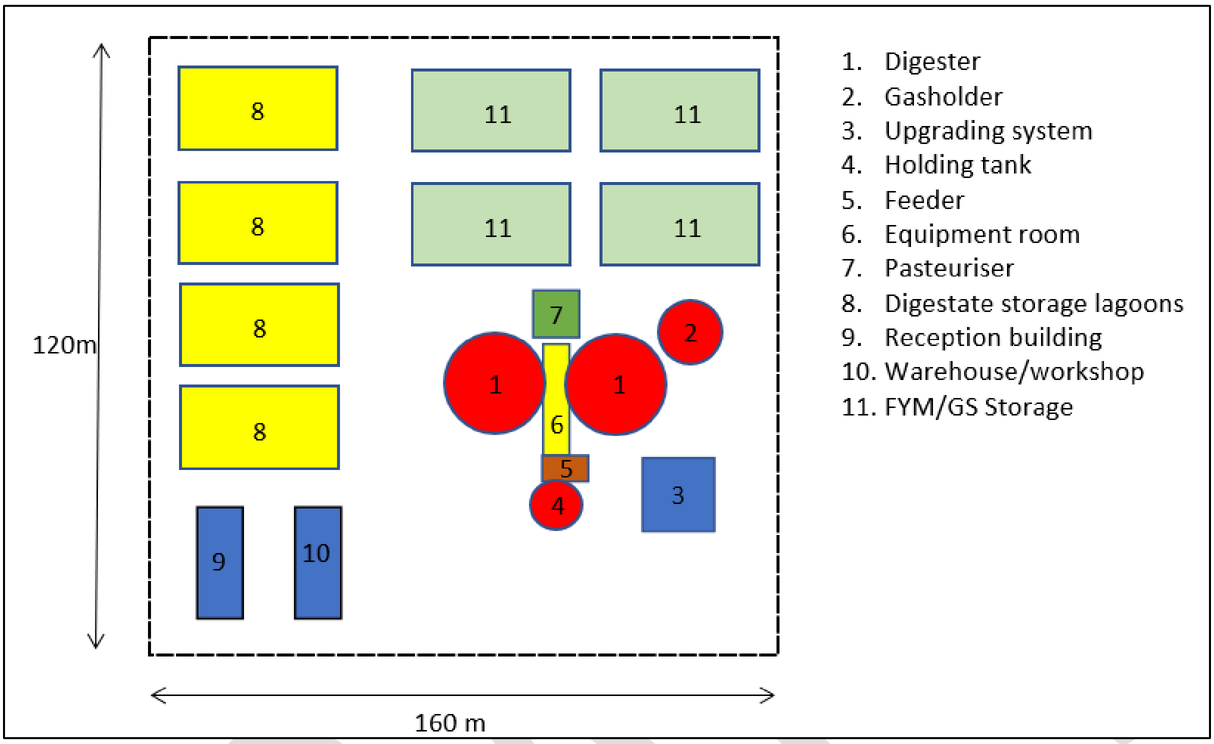

Figure 28 - Basic AD plant site layout including storage.

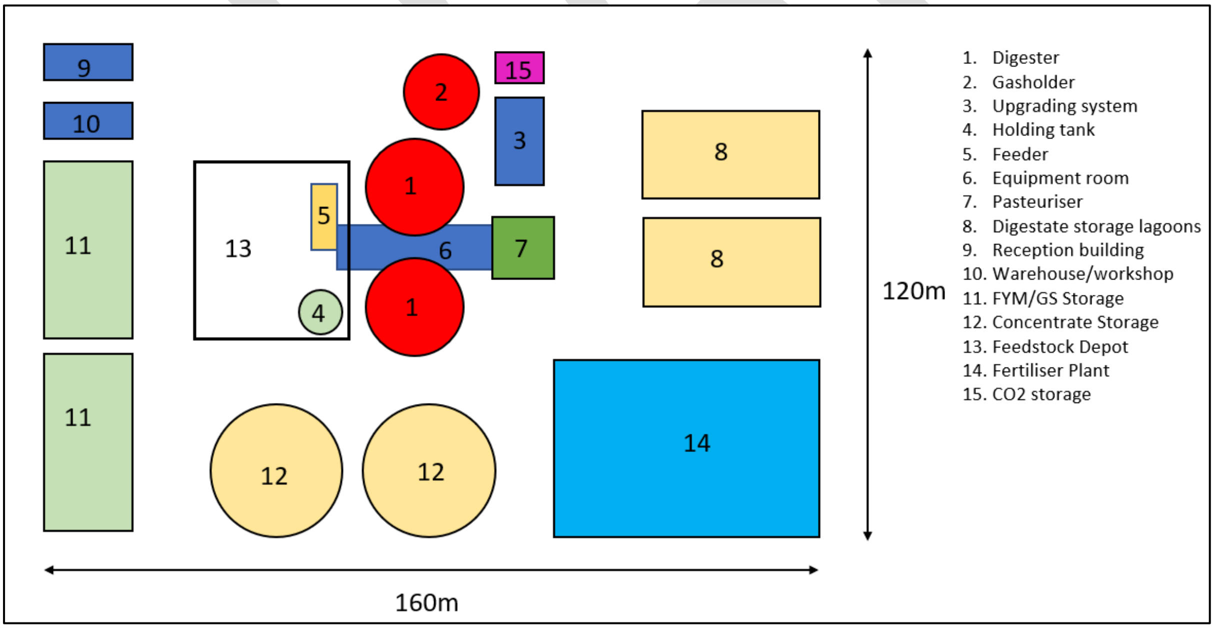

Figure 29 - Plant layout with fertiliser upgrading plant.

No two AD facilities are alike despite sharing the same processes and equipment. The plant layout and design are bespoken as to maximise biogas extraction from the specific input, in addition to compliance with local biogas/AD plant regulations. While considering the design assumptions presented, there still exists many variations of plant configuration and equipment, which can vary according to the following parameters:

- 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
- Processing and nutrient extraction of digestate
- Handling and processing of by product biogenic CO_2

RGFI/KPMG business case for AD biomethane production Cluster Report findings are that there benefits to a standardise approach to design and clustering of AD plants for economics of scale and procurement process to achieve competitive tendering for 20GWh AD biomethane plants and subsequently the operations and maintenance contracts.

The main components of the biogas plant and biomethane upgrading facility are displayed in a flow chart format in Figure 30 and Figure 31 respectively.

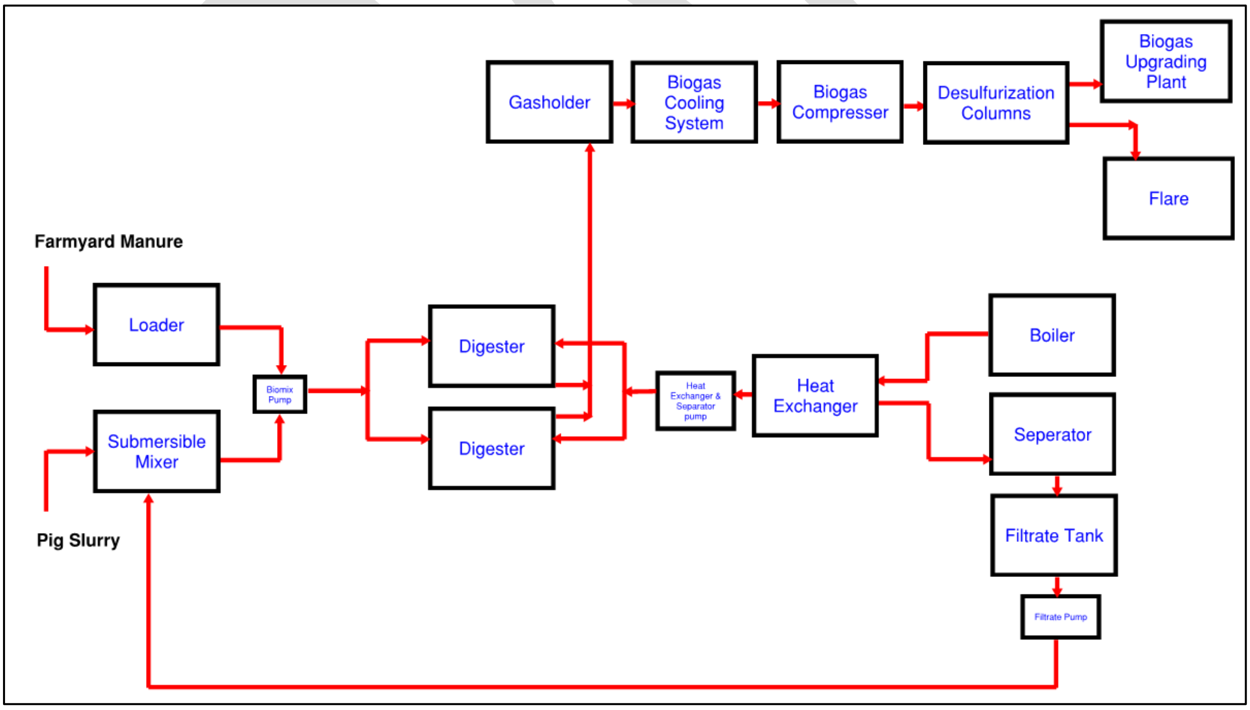

Figure 30: Flow Chart of Biogas Plant Components

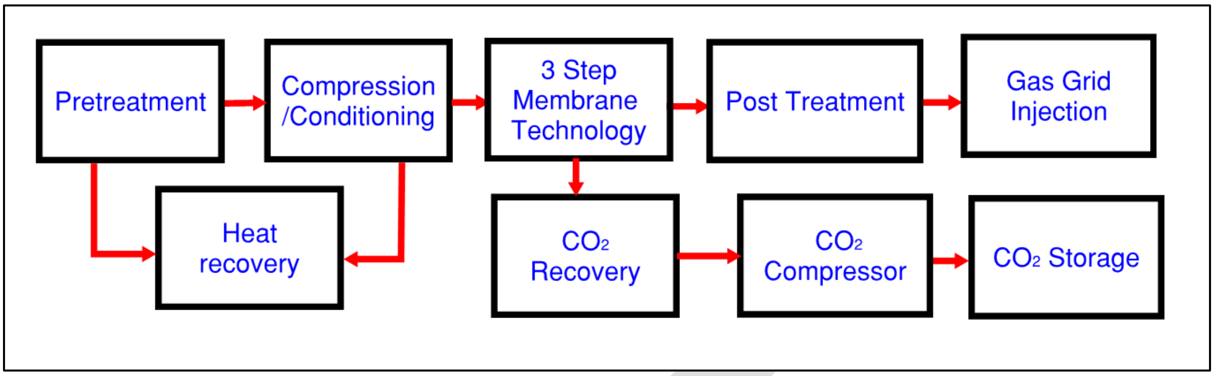

Figure 31: Flow Chart of Biomethane Upgrading Facility Components

5.6.3 Plant Configurations

Co-digestion of multiple feedstocks presents the optimal way of achieving and maintaining optimal digestion parameters such as C:N ratios, ammonia levels, solids content, etc. Optimisation of these parameters ensures growth of methanogenic bacteria and thus maximise biogas/biomethane yields. Optimising digestion parameters has additional benefits of producing a higher grade digestate with better nutrient concentration, one that is more homogenous and contains less VFAs and, thus, less odours. Presented are plant configurations utilising a variety of available feedstocks as assessed in section 3.0 and utilising various plant scales. The feedstock mixtures presented were selected as to optimise parameters, prioritise the most abundant and secure feedstocks as well as to maximise stakeholder participation by not focusing on feedstocks from one farm type, industry, or sector. Plant A and B would involve cattle and pig farmers participation only. Plant B represents an annual output of 20 GWh as described in 'RGFI/KPMG Integrated Business Case 2019' an full economic assessment in compliance with public spending code and presented to Government in 2019 to advise on the pathways for biomethane production and futher support by the GNI Sustainability of Biomethane production in Ireland' report 2021[3]. Through incorporation of maize (anecdotally produced in high quantities), Plant C reduces its FYM requirement by 10% and the total system throughput by more than 40%. Plant D includes silage, as recommended in the aforementioned GNI report[3]. Table 37 is an extract from Table 44 which outlines the plant characteristics in more detail. All of the configurations outlined exceed the RED II requirements from 2026 of a minimum of 80% GHG savings relative to fossil fuel equivalents.

Table 37 - Various plant configurations.

Plant	Feedstock Configuration	Output (MW)	Output (GWh)	Throughput (t/a)	RED II GHG Savings (%)
Plant A	65% Pig Slurry, 35% FYM	5	40	210,000	108.6
Plant B	50% Pig Slurry, 50% FYM	2.8	20	100,000	103.4
Plant C	65% Pig Slurry, 25% FYM, 10% Maize	5	40	150,000	82.3
Plant D	65% Pig Slurry, 25% FYM, 10% Silage	5	40	175,000	86.2

[3] https://www.gasnetworks.ie/biomethane-sustainability-report-2021.pdf

As discussed in section 5.4, further processing of digestate can yield some benefits to plant operation (liquid treatment) or break it down into several marketable products for specialised applications (solid treatment). The liquid treatment of digestate essentially provides separation of the digestate into liquid and solid fractions, in addition to dewatering the liquid fraction. The result is 55% less material requires disposal, reducing transport, spreading cost and emissions significantly. This process is particularly useful with very moisture heavy slurry feedstocks, the benefit of its application in the plant configurations can be seen in Table 38. The extracted water can simply be piped to a WWTP or discharged (see section 5.7.4).

Table 38 - Comparison between material to be transported offsite between upgraded and non-upgraded digestate.

Plant	Feedstock Configuration	Throughput (t/a)	Digestate (t/a)	Digestate if Biofertiliser Upgraded (t/a)
Plant A	65% Pig Slurry, 35% FYM	210,000	193,000	86,000
Plant B	50% Pig Slurry, 50% FYM	100,000	90,000	40,000
Plant C	65% Pig Slurry, 25% FYM, 10% Maize	150,000	118,000	53,000
Plant D	65% Pig Slurry, 25% FYM, 10% Silage	175,000	159,000	71,000

5.7 Environmental Sustainability & Planning

5.7.1 Protected Areas

Any development, especially industrial, will face planning challenges with regards to potential environmental impact. Large industrial developments such as AD plants should be located away from environmentally sensitive areas, irrespective of their protected status. In the selection of an appropriate site for AD projects, these areas are avoided.

The National Parks & Wildlife Service (NPWS) is responsible for the designation of conservation sites in Ireland, which is required under European and national legislation and aims to conserve habitats and species. The NPWS works with farmers, other landowners and users, in addition to national and local authorities, to achieve an appropriate balance between land use for farming and other human activities, with the need to conserve natural ecosystems. These sites are designated as Special Protection Areas (SPA), Special Areas of Conservation (SAC) and National Heritage Areas (NHA).

Figure 32 shows the restricted areas for development according to the NPWS. In Limerick, there are 3 no. SPA, 12 no. SAC and 4 no. NHA. In Cork, there are 18 no. SPA, 30 no. SAC and 8 no. NHA. In Tipperary, there are 4 no. SPA, 23 no. SAC and 12 no. NHA. From the map, there are four main environmentally sensitive areas to avoid in the Ballyhoura region; namely the Galtee mountains in east, the Balyhoura mountain area where significant number of protected habitats are present (east of Charleville), the Grageen Fen and Bog area in North Tipperary and East Limerick, and the several small lakes north of Bruff.

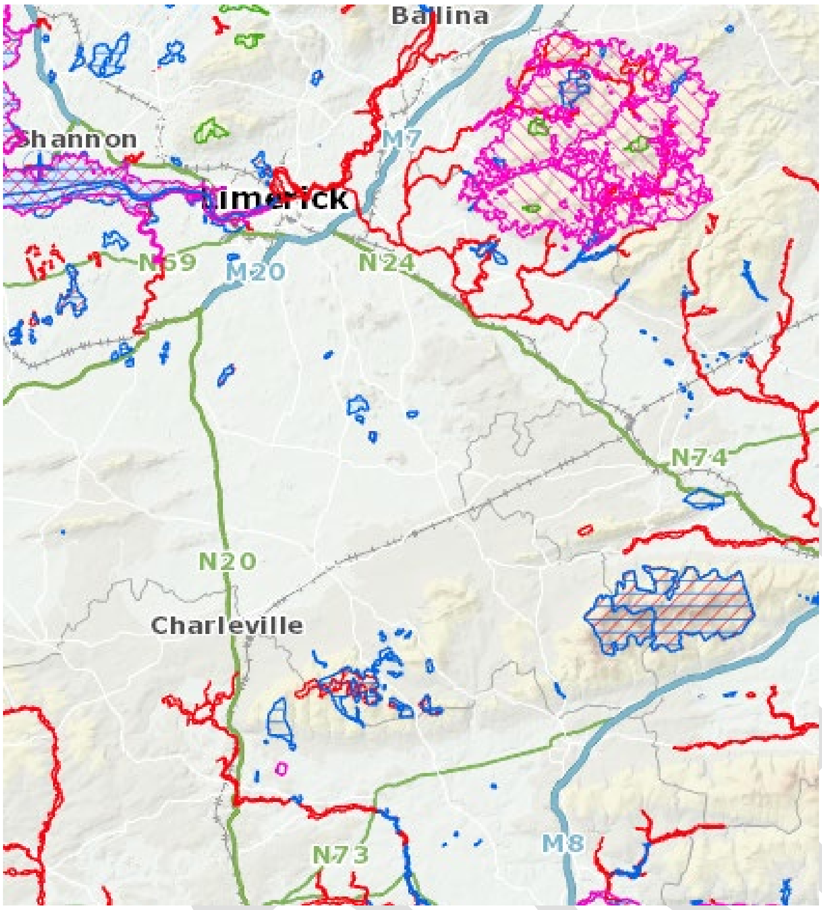

Figure 32 - NPWS designated areas (SPAs, SACs, NHAs)

5.7.2 County Development Plan

The Cork County development plant lays out planning objectives for a variety of regions within the county, with North Cork being relevant to the Ballyhoura study.

The County Development Plan 2022 – 2028 (CDP) sets out that the County Council will facilitate the development of renewable energy projects as part of its climatic objectives in line with national Climate Action Plan.

Mitchelstown is highlighted as a major town for further development with strategic goals for further economic and industrial development in the CDP. Areas zoned for industrial development as shown in the land use zoned map from the Cork CDP in Figure 33.

Zone MH-I-01 reserved for industrial development is noted as being visually sensitive and will require that any development is correctly and sensitively sited, designed and landscaped. MH-I-02 is reserved for expansion of the existing food processing industries located nearby, namely the Dairy Gold Food Ingredients Processing complex. The sites are 23.26 ha and 12.02 ha respectively.

MH-I-03 is located adjacent to an existing industrial area containing several businesses and industries. This site is zoned for industrial development and amounts to 6.81 ha of land.

MH-I-04 and MH-I-05, located north of Mitchelstown, are both zoned for industrial development with MH-I-04 reserved for medium to large scale industry. The CDP notes that access to MH-I-05 will be from the regional road to its west. The sites are 17.31 ha and 15.76 ha respectively.

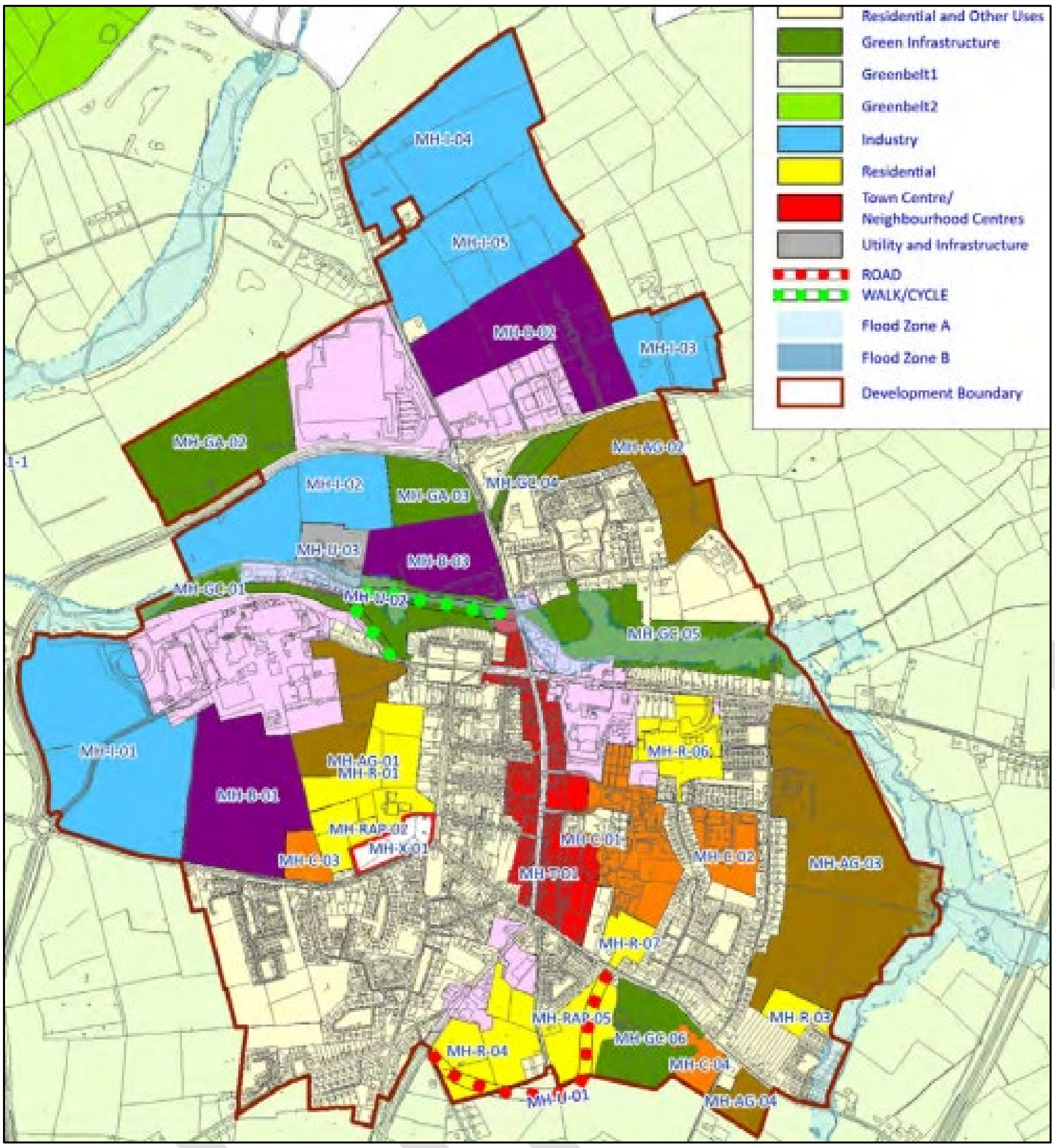

Figure 33 - Mitchelstown Land use zoned areas.

5.7.3 Utilities

For an electrical connection, a review of the ESB network for a potential connection was conducted, consulting the ESB network capacity map. The map shows all existing substations, installed infrastructure, capacity and available demand. The plant electric requirements are determined from the various AD plant and equipment supplier quotes and technical specifications. The plant would require a connection of 600 to 700 kW. Figure 34 shows the available capacity from the various substations in the town. The connection map shows that of the two MV substations in Mitchelstown, none have any available capacity; requiring an upgrade to the existing MV substation which can be done upon application to the ESB.

Requesting MV connection and upgrade will incur connection charges. These are outlined in the ESB's Statement of Charges, in which MV connection charges can range from MICs of 100 kVA to 5 MVA. For a 700 kVA AD plant, the MV Business Demand Customer connection charge is €16,860 (for a three phase 10 or 20 kV connection). However, there are additional charges based on the type of connection either via MV overhead lines or underground cables (also requires trenching charges. The connection type and works required will be decided by the ESB upon application, based on existing available infrastructure (existing substations, overhead and underground powerlines), required capacity and most economical connection. Network charges for 3 phase (>5MVA) MV overhead line are €12.60/m, while MV underground 3 phase (70/185s) cable cost €22.50/m, with additional trenching charges at €206.50/m and €74.10 for trenches through roads/paths and grass respectively.

For the purposes of this study a cost of €200,000 has been allowed for in the capital budget. At minimum, an MV overhead connection is made to the AD plant from the substation 3 km away, the total charges can amount to €55,000 (including connection charge). At worst, if underground cables from MV substation 3 km away are required, the connection charge could be up to €250,000.

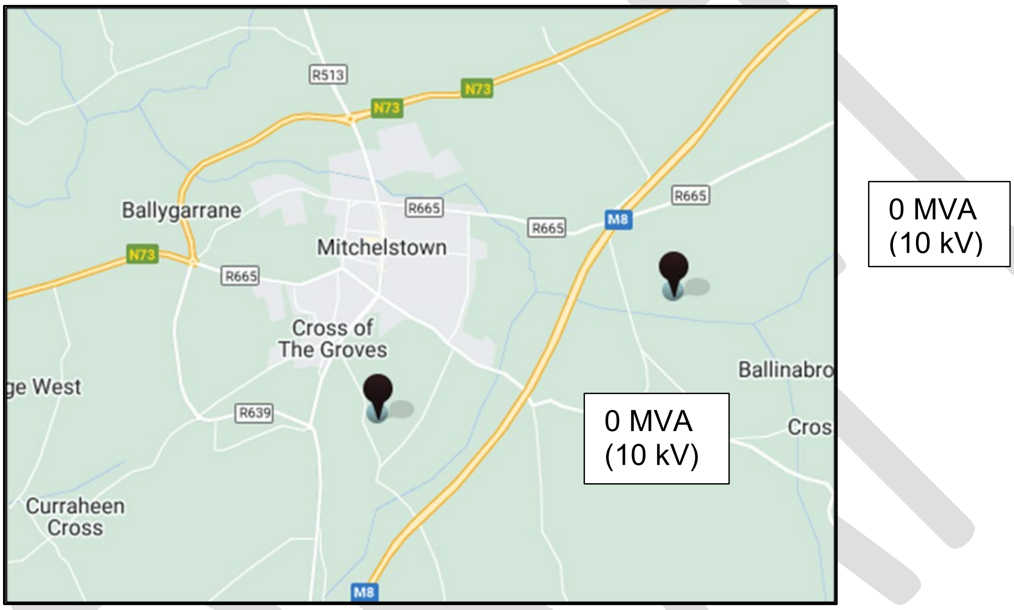

Figure 34 - Map showing available MV electrical capacity in Mitchelstown.

While kerosene or oil is typically, alternatively bioLPG can be used in meeting the AD plant's heating requirements, the presence of a gas grid provides a cheaper alternative. Mitchelstown is serviced by the gas network with transmission lines into the town with AGIs stations and an extensive distribution network throughout the town which extends out west servicing nearby communities of the Demense and Glanworth.

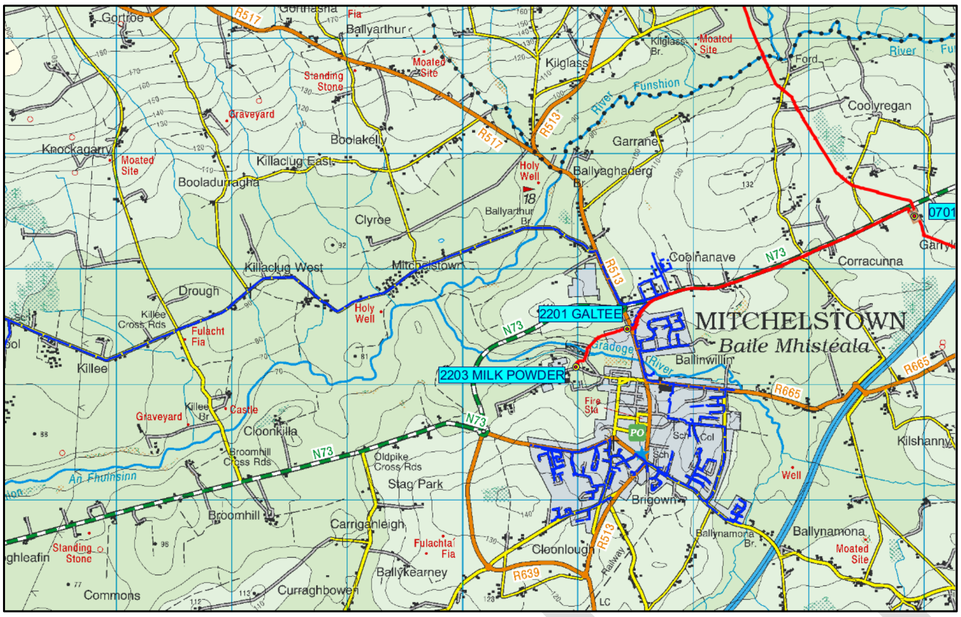

Figure 35 - Gas network in Mitchelstown and surrounding areas.

5.7.4 Planning & Licensing

The recommended AD biomethane plants generally require planning permission, and an ABP license and a waste permit or licence depending on the biodegradable materials going into the plants. These licenses and the associated potential barriers are outlined below.

Anaerobic digestion plants must operate under a waste permit 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. Generally, AD plants with a capacity exceeding 25,000 tonnes per annum require an Environmental Impact Assessment to be carried out and an Environmental Impact Assessment Report (EIAR) to be written under the amended Environmental Impact Assessment Directive (2014/52/EU). The EIAR assesses the existing/potential impacts of the proposed facility on the environment under the following sections: population and human health, biodiversity, land, soil, water air and climate, material assets, cultural heritage and the landscape. The EIAR must clearly detail how the development will not impact the environment or the mitigation measures that eliminate risks. The EIAR must include consultation with relevant Statutory Bodies and a public consultation (site notice/newspaper notice) must be carried out. The EIAR is submitted as part of the application for planning permission allowing the relevant authority to fully understand the environmental effects of the proposed plant.

Local engagement, consultation, information, and education are essential from an early stage in development to ensure the proposals, process and terminology are fully comprehended to avoid planning objections. Local's concerns around AD are commonly around noise, odour, visual impact, and transport.

The Department of Agriculture, Forestry and the Marine (DAFM) have set out conditions (detailed in CN11) that AD and biogas plants operating in the Republic must abide as to satisfy compliance with EU Animal By-Product regulations. These include structural and equipment requirements, secure fencing to perimeter, secure and monitored access to plant, plant operational requirements, record keeping requirements, microbial testing and pre-requisite programmes.

Odour

Odour abatement is achieved through the introduction of housing and an internal negative pressure as discussed in section 5.7.4. This is cited as a common objection and concern amongst the public with regards to AD. The local authority may even request information on projected plant odours via the Request for Further Information (RFI) stage of the planning process. Thus, detailing an abatement methodology in the planning process is likely to improve chances of a successful submission.

Water Discharge

If the plant is to discharge water to the public sewers (or public WWTP) after a liquid treatment process, a license must be obtained from Irish Water or the EPA (depending on scale). This falls under the Trade effluents which require regulation and apply to landfills, waste transfer stations, waste processing, treatment, and storage facilities. Carefully monitoring and testing of water emissions and its nutrient contents will be required (CBOD, BOD, Phosphorous, Ammonia, Potassium, total solids).

Traffic

An AD plant processing animal slurries/energy crops requires transport of feedstock to and digestate away from the plant. An increase in traffic is expected, however effective scheduling and route planning would direct trucks to national roads/motorways and avoid busy areas and rush hours to ensure there is the least disruption to the existing road network.

Noise

Noise assessments of plants are carried out at planning stages. It is anticipated that the most significant noise impact will occur during the construction phase. During normal operation, the delivery and collection will have the biggest effect on noise levels (loading/unloading, reversing alarms). Plant equipment, such as boilers and feed pumps effect noise levels. A review of previous planning for AD plants in the state has revealed that noise is not a significant barrier in obtaining planning permission since all processing generally occurs indoors or in fully enclosed units and strict operational hours are enforced for delivery vehicles to avoid noise impact early in the morning or late at night.

Biodiversity

A detailed landscape plan for maintaining or maximising local biodiversity is now essential for proposed projects to obtain planning permission. This includes planting local natural species, creating areas for biodiversity and conservation and creating wildlife corridors around/ through the facility. Planting trees also benefits the region by screening the facility.

Table 39: Proposed Configurations with Associated System Characteristics

Model	Feedstock Composition	Output (MW)	Output (GWh)	Throughput (t/a)	Maximum Distance (excl. Maize & Silage)	Trucks Required	Digestor Size	Digestate Produced (t/a)	RED II GHG Savings (%)
Plant A	65% Pig Slurry, 35% FYM	5	40	210,000	30	8	2 X 8,400 m^3	190,000	108.6
Plant B	50% Pig Slurry, 50% FYM	2.8	20	100,000	25	4	2 X 3,900 m^3	90,000	103.4
Plant C	65% Pig Slurry, 25% FYM, 10% Maize	5	40	150,000	25	5	2 X 6,100 m^3	135,000	82.3
Plant D	65% Pig Slurry, 25% FYM, 10% Silage	5	40	175,000	25	7	2 X 6,900 m^3	160,000	86.2

Table 40: Colour Coding employed in Financial Analysis Section to differentiate between Models

Plant X	Base Case Model (Biomethane production and sale of Liquid Carbon Dioxide)
Plant X	Base Model with Additional Liquid Biofertiliser Upgrading
Plant X	Base Model with Additional Liquid & Solid Biofertiliser Upgrading

6.0 Financial Assessment

A preliminary financial model for the four proposed configurations referred to as the 'base cases' (Table 39) is formed from the capital and operating costs and plant revenue from the sale of gas as well as the by-product Biogenic CO_2. The feasibilities of these models are analysed based on their Internal Rate of Return (IRR) which is calculated using the inflows and outflows of cash. The IRR metric is a guideline for evaluating whether a project or investment is worth pursuing and if the IRR is greater than 0% the business is generating a profit in its lifetime. Depending on the type of investor and investment, different IRRs are considered acceptable.

All of models discussed in this section, assume an electricity and gas price based on current SEAI values however these values are linked and volatile and so the impact of a range of increases and decreases in these values are explored in 6.2.1. An 8-12 c/kWh estimate revenue for biomethane is based on a recent public consultation from the DECC, which explicitly references biomethane supports for an imminent RHO scheme, ranging from 8 c/kWh for energy-dense food waste that may also command gate fees, to 12 c/kWh for agri-manures/slurries. For plant revenue in the models, biomethane prices of 12 c/kWh are investigated. Table 49 and Table 50 display the impact lower prices (10 or 11 c/kWh) have on the model by evaluating the resultant IRR. The expected revenues associated with selling the food grade Biogenic CO_2 and biofertilizer are discussed in sections 6.3.2 and 6.3.3, respectively.

Table 41: Financial Model Outputs: Base Cases Configurations (Including CO_2 system)

Base Case	Plant A	Plant B	Plant C	Plant D
	5 MW - 65% Pig Slurry, 35% FYM	2.5 MW - 50% Pig Slurry, 50% FYM	5 MW - 65% Pig Slurry, 25% FYM, 10% Maize	5 MW - 65% Pig Slurry, 25% FYM, 10% Silage
CAPEX (€)	19,900,000	12,500,000	17,290,000	18,930,000
OPEX (€)	3,300,000	2,180,000	3,800,000	3,520,000
Revenue (€)	5,370,000	3,000,000	5,370,000	5,370,000
IRR (%)	6.6%	-2.2%	3.3%	4.7%

The secondary financial models for each of the options are extended to include the capital and operating costs and the associated revenue stream of the inclusion of a liquid biofertilizer upgrade facility, as well as both a liquid and solid biofertilizer upgrading facility, since these processes are optional and the digestate can instead be redistributed for land spreading. These models are analysed in tables colour coded as described in Table 40. The high-level impact of upgrading only the liquid fraction is explored in Table 42 while the impact upgrading both the liquid and solid fraction is shown in Table 43. These processes can be carried out independently and AD plants sometimes only carry out the liquid upgrading process due to high capital and operating costs associated with the combination of the processes.

Table 42: Financial Model Outputs: With Liquid Biofertilizer Upgrade

Including Liquid Biofertilizer Upgrading	Plant A	Plant B	Plant C	Plant D
	5 MW - 65% Pig Slurry, 35% FYM	2.5 MW - 50% Pig Slurry, 50% FYM	5 MW - 65% Pig Slurry, 25% FYM, 10% Maize	5 MW - 65% Pig Slurry, 25% FYM, 10% Silage
CAPEX (€)	21,560,000	13,750,000	18,560,000	20,420,000
OPEX (€)	4,020,000	2,515,000	4,330,000	4,120,000
Revenue (€)	6,850,000	3,530,000	6,390,000	6,740,000
IRR (%)	9.8%	0.4%	6.6%	9.2%

Table 43: Financial Model Outputs: With Liquid Biofertilizer and Solid Biofertilizer Upgrade

Including Liquid & Solid Biofertilizer Upgrading	Plant A	Plant B	Plant C	Plant D
	5 MW - 65% Pig Slurry, 35% FYM	2.5 MW - 50% Pig Slurry, 50% FYM	5 MW - 65% Pig Slurry, 25% FYM, 10% Maize	5 MW - 65% Pig Slurry, 25% FYM, 10% Silage
CAPEX (€)	23,171,000	14,677,000	20,759,000	22,046,000
OPEX (€)	4,680,000	2,835,000	4,810,000	4,660,000
Revenue (€)	6,850,000	3,530,000	6,390,000	6,740,000
IRR (%)	4.3%	-5.8%	1.0%	4.2%

From Table 41 it is evident Plant A followed by Plant D will generate the greatest return over a 15-year period (IRR). Plant B makes a loss over its lifetime and so should not be further considered. This is representative of the impact economies of scale can have on AD projects. Plant C is impeded by its high OPEX (cost of maize feedstock) and so results in a lower return despite having a lower CAPEX than Plant A and Plant D. When the biofertilizer liquid upgrading system is considered and subsequently the solid and liquid upgrading system in tandem (Table 42 & Table 43), Plant D and Plant A are equally viable. When only the liquid fraction is upgraded Plant A and Plant D's IRR are increased to 9.8% and 9.2% respectively. Upgrading the liquid fraction of Plant A, C, and D makes them all more attractive investments, primarily due to the reduction in transport and storage costs. Upgrading the solid fraction decreases Plant A and Plant C’s return to less than the base case due to further increased capital and operating costs while revenue remains constant. The IRR therefore varies significantly based on whether the biofertilizer is upgraded and to what extent.

6.1 Capital Costs

Due to the highly variable and bespoken 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 bring together various major pieces of equipment or costs. Various quotes from suppliers on the costs of the components in a CSTR AD plant have been obtained to compile an estimate as shown in Table 44.
The costs below are broken down into the 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. Flow diagrams of the system components are shown in Figure 30 and Figure 31. 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, engineering and contingency which are estimated.

Table 44: Capital Cost Breakdown of Configurations

CAPEX item	Plant A	Plant B	Plant C	Plant D
Digester equipment	€10,500,000	€6,200,000	€8,330,000	€9,690,000
Biomethane Upgrading Equipment (€) incl. CO_2 Capture	€3,500,000	€2,210,000	€3,500,000	€3,500,000
Civil Works & Construction	€2,580,000	€2,000,000	€2,580,000	€2,580,000
Other	€3,320,000	€2,090,000	€2,880,000	€3,160,000
Total (Base Case)	**€19,900,000**	**€12,500,000**	**€17,290,000**	**€18,930,000**
Additional CAPEX item for Upgrading Equipment	**Plant A**	**Plant B**	**Plant C**	**Plant D**
Liquid Biofertilizer Upgrading Equipment	€4,200,000	€2,400,000	€3,000,000	€3,900,000
Storage Savings	(€2,540,000)	(€1,150,000)	(1,530,000)	(2,410,000)
Net CAPEX Liquid Biofertilizer Equipment	€1,660,000	€1,250,000	€1,470,000	€1,490,000
Additional Cost Solid Biofertilizer Upgrading Equipment	€1,611,000	€927,000	€1,995,000	€1,626,000
Total	**€23,171,000**	**€14,677,000**	**€20,759,000**	**€22,046,000**

6.2 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 (maize/silage), personnel, and operator wages as well as general maintenance.

6.2.1 Energy Requirements

The components of a biogas plant and the upgrader have a continuous electrical load, while the digester and pasteuriser have a continuous heat load. For an electricity connection a MV connection is assumed to the nearest substation(s) with adequate capacity and the availability of a connection to a suitable point on the gas network is assumed with the proposed site location making consideration for proximity to these utility connection points (Section 5.7.3).

The models outlined assume an electricity price of 18.55 c/kWh and a gas price of 7.48 c/kWh based on SEAI's commercial/industrial fuel price comparisons for April 2022 assuming the plant falls into the electricity Band ID (>=2000 < 20,000 MWh per annum) and the gas Band I2 (>=278 <2,778 MWh per annum). A sensitivity analysis was carried out to highlight the impact these varying prices have on the IRR of each configuration (Table 45). The analysis looks at a ±10% and ± 20% changes in gas and electricity prices compared to current commercial pricing. In Ireland, the electricity and gas markets are intrinsically linked since the electricity network uses gas for generation and stabilisation, therefore a change in one is generally reflected in the other. Plants A, C, and D all remain feasible at the higher energy prices but are considerably less attractive investments. Plant B's return is still insignificant with a 20% drop in energy prices. Plant A and D are very favourable investments at lower energy prices.

It should be noted that the majority of Irish electricity is produced with natural gas, therefore the price of gas directly impacts the cost of electricity. In 2020, the SEAI reports that 57.1% of all energy inputs in electricity generation was from natural gas, thus, are strongly correlated and result in gas price fluctuations greatly affecting the electricity price.

Table 45: Sensitivity analysis of Plant Configurations based on Energy Prices

			Plant A	**Plant B**	**Plant C**	**Plant D**
	Gas Prices (c/kWh)	**Electricity Prices (c/kWh)**	**IRR (%)**			
-20%	5.98	14.84	8.5%	1.8%	4.5%	7.3%
-10%	6.73	16.70	7.2%	0.2%	3.9%	6.1%
SEAI, April 2022	*7.48*	*18.55*	*5.9%*	*-1.6%*	3.3%	*4.7%*
+10%	8.23	20.40	4.5%	-3.6%	2.7%	3.3%
+20%	8.98	22.26	3.1%	-5.8%	2.1%	1.8%

6.2.2 Other Operational Costs

In general, the larger the throughput, the larger the operating costs such as electricity and transport within the system. It is assumed there is no cost other than transportation associated with feedstocks such as cow and pig manures, however, costs are unavoidable in instances where silage or maize are employed in the system. These costs are substantial, impacting the OPEX of the system. This, along with the other operating costs are outlined below in Table 46.

Table 46: Operating Cost Breakdown of Configurations

OPEX item	Plant A	Plant B	Plant C	Plant D
Feedstock (€)	0	0	1,090,000	530,000
Electrical (€)	1,500,000	1,000,000	1,290,000	1,430,000
Heating (€)	300,000	150,000	210,000	200,000
Transport (€)	600,000	290,000	410,000	500,000
Other (Salaries, Maintenance) (€)	900,000	740,000	828,000	860,000
Total (€) (Base case)	**3,300,000**	**2,180,000**	**3,800,000**	**3,520,000**
Additional OPEX item for Upgrading Equipment	**Plant A**	**Plant B**	**Plant C**	**Plant D**
Liquid Biofertiliser Upgrading Equipment (€)	720,000	335,000	530,000	600,000
Solid Biofertiliser Upgrading Equipment (€)	660,000	320,000	480,000	540,000
Total (€)	**4,680,000**	**2,835,000**	**4,810,000**	**4,660,000**

6.3 Revenue Streams

Table 47: Revenue Streams

Revenue Streams	Plant A	Plant B	Plant C	Plant D
Sale of Biomethane Sale of CO_2	4,800,000 570,000	2,700,000 300,000	4,800,000 570,000	4,800,000 570,000
Total (€) Base Case	5,370,000	3,000,000	5,370,000	5,370,000
Additional revenue for Upgrading Equipment	**Plant A**	**Plant B**	**Plant C**	**Plant D**
Sale of Liquid Biofertiliser	950,000	340,000	750,000	1,010,000
Sale of Solid Biofertiliser	530,000	190,000	270,000	360,000
Total (€)	6,850,000	3,530,000	6,390,000	6,740,000

6.3.1 Renewable Heat Obligation

The main incentive and support for a biomethane producing facility falls under the proposed RHO scheme. which is due for public consultation on the design, structure and administration . 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. A heat obligation rate will be reviewed and set for each year, defining the proportion of renewable sourced energy that must be supplied in the heat sector with plans to allow parties who have not supplied sufficient proportions of renewable energy to trade with another supplier who has exceeded the supply requirement. The scheme then offers support to those suppliers on a c/kWh basis. As discussed, the RHO seeks to allocate 8-12 c/kWh for renewable fuel.

Based on the plant configurations presented, the expected biomethane yields from such plants are shown in Table 48Table 48.

Table 48 - Plant inputs and outputs.

Plant Configuration	Feedstock Input (t/a)	Biomethane Output (m^3/a)	Biomethane Output (kWh)
Plant A	210,000	3,900,000	39,433,333
Plant B	100,000	2,200,000	22,244,444
Plant C	150,000	3,900,000	39,433,333
Plant D	170,000	3,900,000	39,433,333

Assuming a gas price of 10 – 12 c/kWh is allocated, the above configurations would yield the following revenue and IRR over a 15-year plant lifetime as shown in Table 49 to Table 50. The resulting plant IRRs at 10 and 11 c/kWh show the significance of the RHO and the need for plants operating on agricultural feedstocks to receive the higher end of the proposed range for viability.

Table 49 - Financial model based on calculated costs and revenue at 10 c/kWh support.

Plant Configuration	Annual Revenue	IRR (%)
Plant A	€ 4,560,000	-1%
Plant B	€ 2,530,000	-11%
Plant C	€ 4,563,018	-6%
Plant D	€ 4,560,000	-1%

Table 50 - Financial model based on calculated costs and revenue at 11 c/kWh support.

Plant Configuration	Annual Revenue	IRR
Plant A	€ 4,960,000	3%
Plant B	€ 2,760,000	-6%
Plant C	€ 4,962,293	-1%
Plant D	€ 4,960,000	3%

Table 51 - Financial model based on calculated costs and revenue at 12 c/kWh support.

Plant Configuration	Annual Revenue	IRR
Plant A	€ 5,350,000	6%
Plant B	€ 2,980,000	-2%
Plant C	€ 5,361,568	3%
Plant D	€ 5,350,000	5%

6.3.2 Liquid Carbon Dioxide Biogenic CO_2

Section 5.5.4 outlines how food grade Biogenic CO_2 presents an additional income stream for an AD operation that is upgrading biogas to biomethane, since it is a by-product of the process, however, to valorise the product additional equipment and operations are required. The capital cost is made up of a water-cooled compressor and static vertical, vacuum insulated storage tank with capacity for more than two days of Biogenic CO_2 production. An assumed revenue of €120 per tonne is used in this analysis. The actual value of a tonne of food grade biogenic carbon dioxide is expected to be higher (>€200 per tonne), however, it is assumed the buyer will inherit the testing and transport costs thus reducing the value of the Biogenic CO_2. This reduces additional capital and operating costs incurred by the AD plant. There are companies, such as Biocarbonics (UK) that operate fleets with the sole purpose of buying, collecting, and delivering Biogenic CO_2 to the end users from AD plants. This is achieved through long term offtake agreements for 100% of the produced Biogenic CO_2. These companies provide the required analytical systems to certify the product for the food grade market. Presented in Table 52, are the Biogenic CO_2 yields and corresponding revenues for the various plant configurations. This process was included in the base case since it significantly increases the expected revenue without hugely impacting the various configuration's CAPEX.

Table 52: Food grade liquid Biogenic CO_2 produced by the plant

Plant Configuration	Biomethane Output (m^3/a)	CO_2 Output (m^3/a)	CO_2 Output (t/a)	CO_2 Revenue (€/a)
Plant A, C, D	3,900,000	2,600,000	4,700	475,000
Plant B	2,200,000	1,400,000	2,600	265,000

6.3.3 Biofertilizer

As discussed in section 5.4, the digestate can be further processed as to reduce quantities of material to dispose and produce a valuable marketable product. Two candidate processes are explored: a solid fraction upgrading stream and liquid fraction upgrading stream. Their primary benefit is not only producing these fertilisers but also reducing the amount of material transported and disposed, reducing the associated costs and emissions. The impact on the AD plants economic performance is presented in Table 53 and Table 54.

A portion of the nutrients taken from the digestate, and its derivatives will have to be returned to farmers providing feedstocks that required a fertiliser input, as the contrary would result in a nutrient deficit to the feedstock supplier. The feedstocks in question include energy crops (grass, maize, etc), cattle FYM and slurry. The fertiliser returned is to be of the same value (based of the nutrient value) of the feedstock provided to the plant (€20 of FYM for €20 of products).

Table 53 - Performance of plants with liquid processing.

Plant Configuration	Annual Revenue	IRR (%)	GHG (%)
Plant A	€6,850,000	9.8	103
Plant B	€3,530,000	0.4	100
Plant C	€6,390,000	6.6	78
Plant D	€6,740,000	9.2	82

Table 54 - Performance of plants with both liquid and solid processing.

Plant Configuration	Annual Revenue	IRR (%)	GHG (%)
Plant A	€6,850,000	4.3	95
Plant B	€3,530,000	-5.8	95
Plant C	€6,390,000	1.0	72
Plant D	€6,740,000	4.2	75

The addition of a fertiliser upgrading facility impacts both the IRR (examined in section 6.0) and the GHG savings of the plant. The RED II minimum 80% GHG savings target was met for all base case configurations, however, was not met in some cases when fertiliser upgrading was included. Plant C with any upgrading and Plant D with both solid and liquid upgrading fall short of the 80% savings requirement. As a result, these configurations are not considered feasible options. Plant D with only liquid upgrading (greatest return of all configurations), exceeds the minimum requirement by a small margin making it is a feasible option, however, a more detailed calculation would be required in the detailed design stage to ensure this requirement is always met. Plant C with only liquid upgrading (78% GHG savings) may become feasible if the process is optimised for energy savings. Plant A and B always meet the requirement due to the absence of energy crops in their mix and reliance on agricultural manures.

7.0 Project Risks

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).

7.1.1 Feedstock Security

The most detrimental risk to an AD plant is a failure in its feedstock supply. Large quantities (typically, more than 100-200 thousand 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 the 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 (e.g. replacing poultry manure with cattle slurry), quantities and throughput need to increase to meet desired production, resulting in higher energy, heat and transport requirements.

7.1.1 Planning Risks

Through correspondence with local stakeholders, it is apparent that communication is a major pillar of this type of project and may determine the outcome of the project. In the past, proposed AD projects have received widespread objection in the region as a result of insufficient local communication and the spreading of misinformation. The concerns surrounding odour and site location, land valuation impacts and silage competition must be discussed with the community with the intention of broadening the regions knowledge on the technology.

7.1.2 Digester Loading & Retention

Inconsistent feeding

Inconsistent and interrupted supply of feedstocks will fluctuate and diminish biogas production rates, 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.

7.1.3 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.

7.1.4 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.

8.0 Conclusion

The feasibility of an agriculture-based AD plant in the Ballyhoura region, specifically in Mitchelstown, has been confirmed in this study. Mitchelstown was chosen based on proximity to the BNEF and its specific feedstock profile. Based on the region loads and supports it has been proposed the biogas will be upgraded to biomethane. A CO-OP is the recommended company structure based on the specifics of this project. There are large quantities of manures/slurries in the region while the potential of sufficient maize and silage has been confirmed anecdotally. The larger the proportion of animal waste in the process the greater the carbon savings however energy crops have a high energy density resulting in a smaller throughput.

Of the suggested four feedstock mixes explored, Plant B (2.5 MW - Pig Slurry, FYM) is not feasible while the other three produce a return – Plant A (5 MW - Pig Slurry, FYM) – 6.6%, Plant C (5 MW Pig Slurry, FYM, Maize) – 3.3%, Plant D (5 MW Pig Slurry, FYM, Silage) – 4.7%. The feasibility of Plants A, C and D vary depending on feedstock streams, expected returns and whether the digestate is upgraded and if so, to what level. Upgrading the liquid fraction of the biofertilizer increased the IRR of the plants, however upgrading the solid section reduces the returns. Solid fertiliser upgrading process is not worthwhile until a market for the derived products develops and can be established.

Plant A is the most feasible of all the plants when the liquid section is upgraded with a return of 9.8%. The suitable degree of biofertilizer upgrading depends on the feedstocks employed and if no biofertilizer upgrading occurs Plant A (5 MW, no energy crops) is the most profitable base case plant with a 6.6% return. All financial models include sale of the by-product food grade Biogenic CO_2 due to its low CAPEX and strong potential revenue stream.

All plants meet the minimum RED II target of 80% GHG savings in their base case. However, Plants C and D do not meet the required target when implementing both solid and liquid biofertilizer upgrading while Plants A, B and D meet the criteria with liquid fertiliser upgrading only.

However, from the analysis carried out, survey results and further discussions with regional stakeholders, concern has been expressed over the quantities available FYM in the region as the plant will require very large quantities (upwards of 50,000 tonnes). While CSO data would suggest large quantities of young cattle in the region, most survey respondents and project stakeholders were dairy farmers producing only slurry. FYM is vital due to its higher biogas potential and CN ratio for optimised co-digestion with slurry. Thus, sourcing FYM should prioritise organic farmers, who, based on available data and reports, produce FYM exclusively due to the required nature of the practise to obtain organic status. However, information pertaining to organic farmers whereabouts and operations is unavailable. Maximising FYM minimises feedstock and operating costs while maximising biogas production and GHG savings. Should FYM quantities be lacking, grass silage grown by contracted stakeholders can fulfil the remaining demand given its high carbon and biogas content, however, this will incur additional costs for its production and sourcing.

The main risk to this project is inadequate support from government (ie. Capital funding and RHO price level to low), however, other risks identified include feedstock security, digester loading and retention, temperature, ammonia inhibition and local objections. These need to be considered further in the next stages of the project to ensure successful progression.

Despite the recent geopolitical crisis and its impact on energy prices, in particular natural gas and its derivatives, successful development of AD throughout the Republic of Ireland will be determined by the level of support forthcoming from the Government on Capital funding and incoming RHO scheme. Given the commitments made by the Irish government to achieve a 51% reduction in GHG emissions by 2030, the agreement between government and the agricultural sector to reduce the sector's emissions by 25% and the highlighting of anaerobic digestion as a key decarbonising technology in this regard; the outlook of the incoming RHO and AD support is positive.

9.0 Next Steps

The project can be further developed at minimal cost pending a decision on the RHO scheme, include the following steps:

- Establishment of the project's organisational structure.
- Securing of feedstocks and drafting of contracts for feedstock supply.
- Engagement with the local community and local stakeholders as to inform on the subject of AD, its benefits and tackling potential sources of misinformation and objection.
- Proceed with font-end engineering design (FEED) to firm up capital costs, gas production rates and detail the necessary steps for offtake agreements to manage digestate/biofertilizer and Biogenic CO_2 removal from site.
- Investigation and survey into a specific site in the proposed areas should be conducted to further assess its suitability.
- In conjunction to the FEED, the necessary documents (engineering report, environmental reports, drawings, etc) can be prepared as to submit a full planning application.

Upon successful submission, the planning application is valid for 5 years, a 10-year request can be made to local authority. The significant capital costs to develop the project would be committed following the securing of feedstocks, finance and the introduction of an RHO. And Capital funding support.