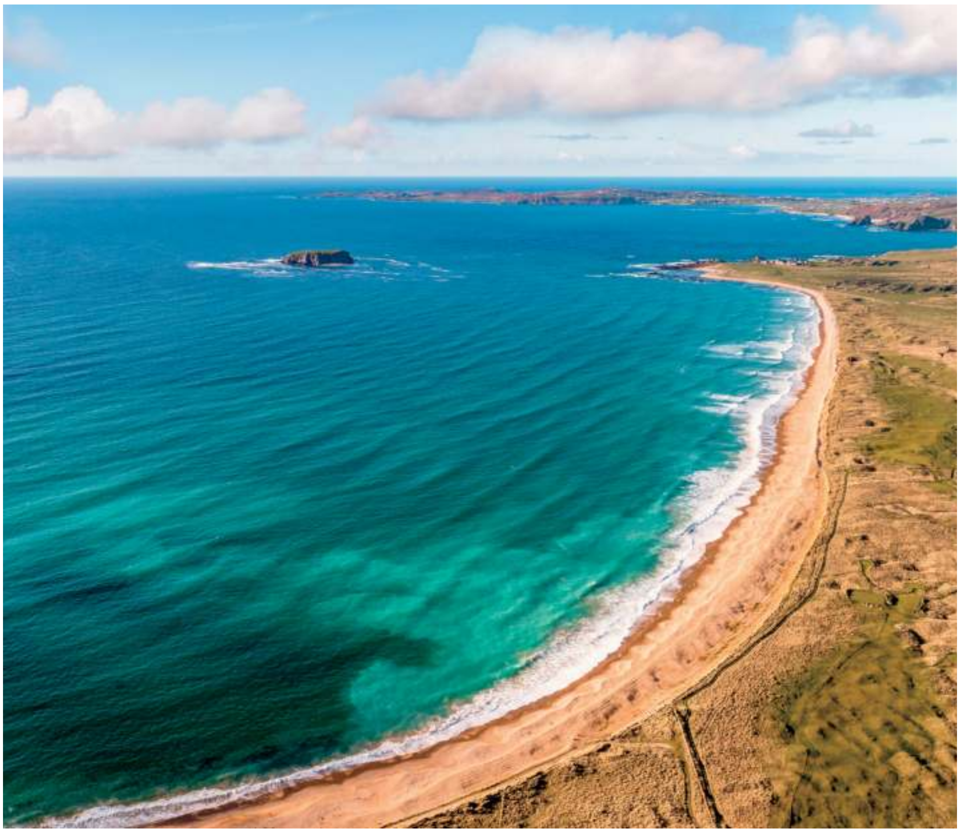
Inishowen Sustainable Energy Community



APRIL 2023

FEASIBILITY STUDY

COMMUNITY-LED BIOGAS POWER PLANT FOR ELECTRICITY AND HEAT GENERATION

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Aim

The Inishowen Sustainable Energy Community, led by the IDP, commissioned a project to develop a strategic plan for Inishowen to become a sustainable, resilient, prosperous, inclusive, and liveable community. The project was undertaken by a consortium composed of ConsortiaCo and Amicitia, with national and international expertise in implementing projects to support renewable energy development, climate action, a just transition, and funding strategies in line with the European Green Deal.

The Inishowen Sustainable Energy Community strategic plan sets out a clear but non-linear path that responds to the community's vision for a more sustainable and prosperous future in a rapidly changing environment.

Five primary projects were identified during the course of the project, which not only address all strategic objectives and priorities for the region but that also have the potential to really accelerate the move towards the Inishowen SEC's overarching vision for the region.

One of the projects mentioned in the strategic plan is the development of a C*ommunity-led Biogas Power Plant for Electricity and Heating Generation*.

The following outlines why this project is deemed particularly relevant for the Inishowen region:

- The project not only uses a renewable source of energy, but it also transforms "by-products" that were considered and treated as waste into energy. This project is based on the principles of the Circular Economy.

- It not only contributes to the generation of electricity (as solar PV and wind farm projects) but also contributes to the generation of heat (used to heat buildings), and to the production of a digestate that can be used as "biofertilizer" (an alternative to the energy-intensive, environmentally damaging production of chemical fertilisers) and biomethane that can be used as a renewable source of gas, fuel of vehicles, and other by-products.

- Since the project generates several different by-products, it has the potential to propel different streams of revenue, or even different small-scale businesses such as the sale of "biofertilizer", and feedstock supply management.

- The project can contribute not only to the reduction of dioxide carbon (CO_2) emissions but also to mitigate methane CH_4, which would otherwise escape from landfills or manure deposits. Using this methane as a fuel dramatically reduces its climate impact by converting it into "natural CO_2" that can be used, for example, as a by-product of the gasified beverages industry.

- Irish farmers are facing major challenges in the face of the Climate Action Plan targets and need to find integrative solutions which will reduce agriculture's impact on climate change, as well as contributing to farmers' ongoing financial sustainability.

- It is a project that even on a small scale is feasible. It is also easily scalable to medium-large size, enhancing its feasibility further.

In a rural area like Inishowen peninsula, this kind of project can have wider reaching transformation at the community level and can also enable the development of Inishowen Peninsula as a centre of excellence, in essence, contributing to Inishowen becoming a sustainable, self-sufficient, and decarbonized community.

1.2 Scope

The scope of this study is the development of a catalyst project that uses an anaerobic digestion process to digest the agricultural and non-agricultural feedstock for electricity and heating generation.

This study is focused on the development of an initial medium-scale implementation of an anaerobic digestion plant for biogas production to generate electricity and heating. It involves the analysis of the biogas production in an anaerobic digestion plant, considering not only the technological and technical issues, but also the most suitable business models and funding sources, as well as the organisational framework, and the most appropriate governance model required for successful implementation.

Figure 1 - Areas of the scope of the feasibility study.

The use of specific energy crops for biogas production was considered out of scope as this is deemed to be a non-sustainable practice and contrary to the objectives set out in Ireland's Climate Action Plan, as well as European Union policies:

- The use of energy crops does not lead to CH_4 emissions reduction, in contrast to the use of manure or other organic waste.

- Energy crops occupy larger amounts of land, thereby having a higher environmental impact.

- The cultivation of energy crops has higher production costs.

- The cultivation and use of energy crops goes against the 4 R's principle of circularity and does not prioritise the reuse and transformation of waste as a by-product of a transformative process.

For these reasons, the consultancy team does not promote or incentivize the development of biogas production projects in which the main feedstock is energy crops, even if, compared for example with cow manure, their biogas production potential is higher.

1.3 Methodology

The following methodology was used in this study:

1. Analysis and diagnosis of the current context:
    - Global, European, national, and regional policies, targets, and frameworks.
    - collected data, statistics, and territorial information about the Inishowen peninsula.
    - benchmarking of several related projects for inspiration.
    - gathered the perspectives of people with an interest in Inishowen as a thriving community — such as residents, business owners, public institutions responsible, NGOs, including younger people institutions, through surveys, as well as through a number of dynamic and participative co-creative workshops that occurred between 20-23 February 2023.

2. Feedstock analysis.
3. Most suitable anaerobic digestion technology and biogas power plant solution - high level design.
4. Optimal locations for anaerobic digestion plants.
5. Technical economic, environmental, and social impact analysis, and business & governance model.
6. Roadmap and actions for the project development

2 ANALYSIS OF THE CURRENT CONTEXT

2.1 European Union Policy & Targets Framework

The EU has implemented various policies and strategies to ensure that member states can continue to provide secure, affordable, and sustainable energy. Several reduction targets have been highlighted:

- By 2030, the EU aims to reduce its greenhouse gas emissions by at least 40% of 1990 levels, increase the share of renewable energy to 27% consumption, and improve energy efficiency by at least 26%.

- By 2050, the EU aims to reduce its greenhouse gas emission by 80-95% of 1990 levels to achieve significant emission reduction. The EU is currently considering a redefinition of its emissions reduction targets based on achieving net zero by 2050.

Specifically with regard to biogas/biomethane, the EU has outlined the following targets in the **RePowerEU 2030**:

- Target of up to 125 bcm of biogas & biomethane until 2030 (represents an increase of 85% compared with 2020).

- Target of 35 bcm of biomethane production until 2030 (represents an increase of 91,4% compared with 2020).

In an overall realistic and sustainable case, estimated by ICCT, the target must be 17bcm biomethane production until 2030.[1]

2.2 Ireland's Policy & Targets Framework

The Republic of Ireland has also set its own strategy to tackle energy and greenhouse emissions. In 2015, the Department of Communications, Energy & Natural Resources released 'Ireland's Transition to a Low Carbon Energy Future', which set out Ireland's energy strategy from 2015 to 2030.

The government has stated that it "will support the ambition emerging within the European Union to achieve a net zero target by 2050" and have "sought a pathway to 2030 which would be consistent with a net zero target by 2050". Some of the key measures to help create a framework and support change include:

- Development of a Green Procurement Strategy
- Targets of 50% Energy Efficiency and 30% greenhouse gas emissions reduction

[1] IFEU (May 2022).Biomethane in Europe.

- A trajectory for the price of carbon and the creation of incentives which avoid locking in carbon intensive technologies
- Compact, connected, and sustainable development across all towns and villages.
- Competitive funding rounds to promote research and innovation to meet the climate challenge.

The relaunch of the Support Scheme for Renewable Heat (SSRH) provides financial support to help businesses move to renewable heating which is very significant for the expansion of biogas projects.

2.3 North-West Regional Energy Strategy

The North-West Region has developed a report aiming to evaluate the energy opportunities and local measures that are available to both Donegal and Derry councils within the North-West Region to encourage the growth of a sustainable low-carbon economy. To do this, a clear strategy and roadmap have been developed which show the local measures that can be taken to decarbonise the Region by 2045.

One of those measures is precisely related to biogas production, by addressing the need for the identification of opportunities to invest in energy from natural and industrial waste.

2.4 Inishowen SEC's Energy Masterplan

The Energy Master Plan for Inishowen Sustainable Energy Community, released in May 2021, gave an overview energy consumption and the renewable energy potential on the Inishowen Peninsula, the state of grant funding opportunities, as well as the projects that can avail grant opportunities. One of the solutions pointed out in the Inishowen SEC's Energy Master Plan as having potential for energy production is biogas production through an anaerobic digestion process (AD). Accordingly, this study aims to analyse the feasibility of biogas production from agricultural and non-agricultural feedstock.

3 ANALYSIS OF THE STUDY AREA

The study area comprises the Inishowen Peninsula, located in the County of Donegal, and situated in the northernmost part of the island of Ireland.

The peninsula measures 884.33 square kilometres (218,523 acres) and is bordered to the north by the Atlantic Ocean, to the east by Lough Foyle and to the west by Lough Swilly. It is the largest peninsula in Ireland and is known for its picturesque scenery and rich history. Most of Inishowen's population inhabit the peripheral coastal areas, while the interior landscape consists of low mountains, mostly covered in bogland. Inishowen has several harbours, some of which are used for commercial fishing purposes, including Greencastle, Bunagee and Leenan. A seasonal ferry service crosses the Foyle, connecting Greencastle with Magilligan in County Derry, while other crosses the Swilly, connecting Buncrana with Rathmullan. Inishowen is unique because of its location and circumstances.

Figure 2 - Areas of Inishowen Peninsula (study area)

The total population is 39,330 and its largest town is Buncrana, with a population of 6.785 in its urban area (CENSUS, 2016). It has a "comparatively higher dependence (11%) on primary economic activities. Building and construction activity is more important to the local economy (average 8%) compared with the national average (5%). These sectors (agriculture, forestry, fishing, building and construction) are particularly vulnerable to the changes that will be needed to meet climate action targets and thus the transitions required here are likely to have significant impacts"[2].

There are 2,688 farmers in Inishowen. The land within the peninsula is quite varied and a wide range of agricultural enterprises are carried out. The area is dominated by High Nature Value farmland (HNV). The average size of a farm in Inishowen is 27 hectares according to the Sligo Leitrim Donegal Advisory Region, 2015 and in keeping with the national trend, many farmers have off-farm income.

---

[2] Exploring Place-based Opportunities for Policy and Practice in Transition | Research Paper, July 2022; Page11

Sustainable tourism also plays a key role in Inishowen Peninsula's development and in December 2022, a plan to drive and sustain tourism on the Inishowen Peninsula - *Inishowen Peninsula Destination and Experience Development Plan* – was launched, which aims to create a sustainable tourism destination by extending the tourism season and spreading business across all parts of the region over the next five years.

Progress in the region is further impacted by the significant numbers of the local population that cross the border for work or education. This is particularly acute in the Inishowen region which impacts the vitality of a region and leads to an over-reliance on private cars as a mode of transport.

"The north-west of Ireland has for many decades had weaker economic prosperity relative to the rest of the country and has been reclassified by the European Commission from a 'More Developed Region' to a 'Transition Region' for the Post 2020 (2021-2027) funding period (NWRA, 2020). There is a history of underinvestment in the area, low educational attainment, and high unemployment, and acknowledging this is the first step to examining a place-based approach to just transition in Donegal and the Northwest city region. However, there is also significant potential, and the Regional Spatial and Economic Strategy 2020-2032 identifies sustainability as the fifth pillar of growth and central ingredient for successful places[3]."

However, as stated in the EnVision Inishowen Series Summary report, "people's resilience has evolved to tolerate the burdens of economic, social and health inequality…where the same resilience leads to creativity, locally derived solutions, an appreciation of plurality and diversity, and a capacity to celebrate and appreciate this uniqueness and duality[4]."

Natural assets, where the green and blue economy have an eco-focus, the future potential of young people in terms of innovation and green growth, and an inherent understanding of circumstance – "a circular, productive, rural economy which generates productivity, social inclusion, equality, and stability"[5]

According to a recent report, "there is increased awareness around local greening and quality of life since the arrival of the Covid 19 pandemic. The city-region supports skills needed for the circular economy and links to further and higher education. Just transition is recognised in the plans for the Northwest City region and is seen as the optimal scale for climate action[6]".

---

3 Exploring Place-based Opportunities for Policy and Practice in Transition | Research Paper, July 2022; Page11

4 EnVision Inishowen Series Summary Report, 2021; Page5

5 EnVision Inishowen Series Summary Report, 2021; Page5

6 Exploring Place-based Opportunities for Policy and Practice in Transition | Research Paper, July 2022; Page12

4 ANALYSIS OF THE ANAEROBIC DIGESTION PROCESS

4.1 Brief Description of the Anaerobic Digestion Process

Anaerobic digestion (AD) or biomethanation is a process where organic matter is decomposed by microbiological activity in absence of oxygen. Anaerobic digestion is suitable for treating different feedstock such as animal manure, agricultural waste, organic fraction from municipal solid waste (food waste), fish waste and marine algae.

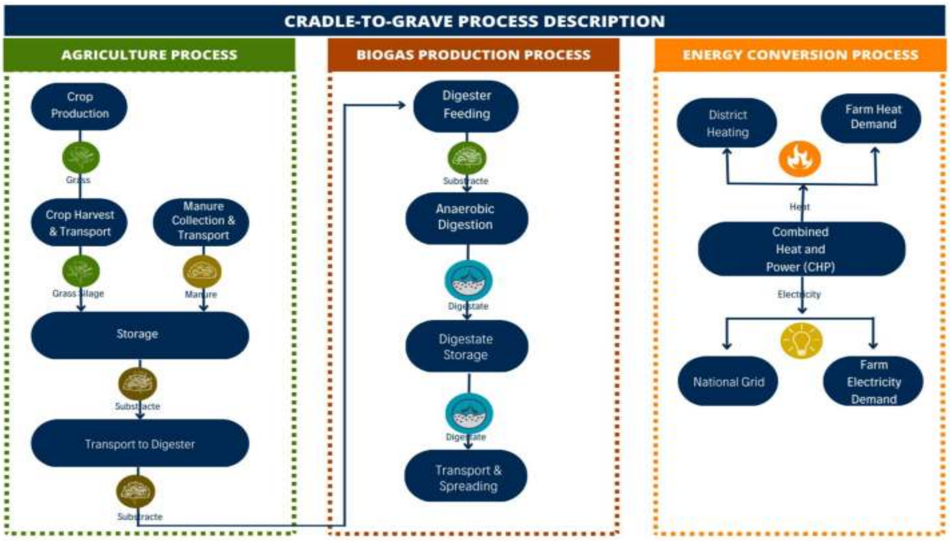


Figure 3 – Cradle-to-grave biogas production description

The anaerobic digestion (AD) process consists of four stages:

- hydrolysis
- acidogenesis
- acetogenesis
- and methanogenesis

<u>Hydrolysis</u>

Hydrolysis is the first stage of the anaerobic digestion process where polymers (complex molecules) of the substrate are decomposed into mono and oligomers (small molecules). In other words, during hydrolysis, carbohydrates, proteins, and lipids are decomposed into glucose, glycerol, purines, and pyridines. Several microorganisms known as facultative anaerobes are involved in the hydrolysis stage.

<u>Acidogenesis</u>

The acidogenesis process or acid-forming stage consists of the degradation of sugars, amino acids, and fatty acids (products from the hydrolysis) into methanogenic substrates (acetic acid, carbon dioxide, and hydrogen) by fermentative bacteria also known as acidogenic bacteria.

The major products from this stage are organic acids, e.g., acetic acid, butyric acid, and propionic acid, alcohols, ammonia, carbon dioxide, and hydrogen.

Acetogenesis

From the last stage, some products cannot be converted to methanogenic substrates such as volatile fatty acids and alcohols. Acetogenic bacteria have the function of oxidising these large compounds to obtain acetic acid, carbon dioxide, and hydrogen. At this stage, both acetogenic and methanogenic bacteria are active in the anaerobic digestion process.

Methanogenesis

Methanogenesis is the main methane formation stage of anaerobic digestion and the slower biochemical reaction. This stage oversees methanogenic bacteria which converts the acetic acid into methane and carbon dioxide, and the hydrogen and carbon dioxide into methane and water. Approximately 70% of the methane produced comes from acetates and the rest 30% originates from the conversion of carbon dioxide and hydrogen. This process is critically influenced by the digestion conditions.

4.2 Parameters

Different microorganisms are involved in the process of anaerobic digestion, and they require certain conditions to grow. The main parameters in the AD process and their importance are:

1. **Temperature** - The bio methanation process can occur at different temperature ranges: between 25-42°C known as the mesophilic range, between 43-55 °C thermophilic range, and at temperatures below 20°C psychrophilic range. At mesophilic temperatures, the anaerobic digestion process is more stable than at thermophilic and psychrophilic conditions due to this temperature range the anaerobic bacteria are more tolerant to changes in the environment. Furthermore, the temperature directly influences the efficiency of the AD process and therefore it should be kept constant to have an efficient process. A rapid variation in the temperature may cause up to 30% of gas yield loss or discontinue the process.

2. **pH** - This parameter influences the growth of methanogenic bacteria and thus methane production. The optimum pH value for the anaerobic digestion process is in the range of 6.5-7.5. The pH is a determining parameter for AD because at low pH values the methane formation is inhibited.

3. **Pressure** – the pressure is the mixing power that influences the gas recirculation, especially for technologies lacking mixing systems. An increment in pressure during the AD process leads to high carbon dioxide concentrations in the liquid phase. an increase in pressure can result in a high concentration of CO_2 in the substrate stimulating methane production. Additionally, an increase in the partial CO_2 pressure decreases the pH value lowering the non-ionized ammonia concentration. On the other hand, a

decrease in the partial CO_2 partial pressure increases the pH level lowering the non-ionized hydrogen sulphide concentration.

4. **Toxic compounds** - formation of toxic compounds is dependent on the pH and composition of the substrate. Ammonia, sulphides, and volatile fatty acids are present in substrates containing significant amounts of carbohydrates and lipids. The effects of these compounds can cause inhibition in bacteria growth and methane production. Ammonia is toxic for the AD bacteria at pH higher than 7 and hydrogen sulphide and volatile fatty acids are toxic at pH below 7.

Additionally, there are two operational and design parameters to be considered for anaerobic digestion: hydraulic retention time (HRT) and organic loading rate (OLR):

1. **Hydraulic Residence Time (HRT)** - is the average time interval at which the substrate is kept in the reactor. This parameter is relevant for determining the dimensions of the digester since it relates the digester volume with the flow rate of feedstock fed per time unit. The HRT value decreases when the organic load is increased. The HRT should be long enough to guarantee the availability of microorganisms in the substrate. This means that the number of microorganisms removed in the digestate does not have to be bigger than the number of reproduced organisms. A stable fermentation at long retention times results in higher methane yield and a volatile solids reduction. In cold regions, such as in Ireland, where the anaerobic digestion process is conducted at psychrophilic range, a long HRT is needed.

2. **Organic Loading Rate (OLR)** - indicates the amount of organic dry matter (DM) that can be fed into the digester per volume and time unit. Several factors influence the determination of the OLR such as the type of digester, the substrate, and the temperature. The microorganisms must adapt to the rate load; thus, it is important to determine the optimum frequency of loading the digester.

4.3 Feedstock

The most suitable feedstock for anaerobic digestion is:

1. **Animal manure and slurries** - are a common type of feedstock for anaerobic digestion in rural areas and farms. The feedstock contains anaerobic bacteria and has high water content that helps to dilute the substrates, improving the mixing and flowing of the biomass. Slurries contain between 4-8 % of dry matter and they are suitable for wet fermentation. In contrast, other animal manure contains around 35% of dry matter being suitable for dry digestion. These substrates are considered good for anaerobic digestion due to their nitrogen and phosphorus content and high content of volatile solids.
2. **Food waste** - anaerobic digestion is suitable for treating both mixed municipal waste and organic fractions of municipal solid waste. Municipal solid waste is composed of

household waste, food waste, garden waste, etc. The waste fractions and characteristics vary depending on the country's conditions.

3. **Sewage sludge** - originated from wastewater treatment plants. The biogas produced from digesting sewage sludge has a moisture content of approximately 60 -70%. The digestate can be used as a soil conditioner, incinerated, or disposed of to landfill. The final use of the digestate depends on its toxicity level in heavy metals and other compounds. The benefits obtained from treating sewage sludge with anaerobic digestion are reduction of volume and disposal.

Aside from these, there are ongoing research studies into the potential of biogas production of fish waste and marine algae - or seaweed.

In some cases, co-digestion (digestion of two or more different feedstock) results in a higher amount of methane production and resource savings in comparison to the digestion of only one type of feedstock, e.g., combination of pig slurries with manure reduces the amount of water needed for the dilution of solids.

4.4 Products

The main products of the process are the biogas and the digestate.

Biogas is a renewable source of energy produced from raw materials like manure, food waste, sewage, and plant material. Through an anaerobic digestion process in which bacteria break down the organic matter into its components until all that is left are gases and a residue called digestate.

The chemical composition of biogas is:

- Methane (CH_4, 50-70%)
- Carbon dioxide (CO_2, 25-50%)
- Other gases: nitrogen (N_2, less than 5%), hydrogen (H_2, less than 1%), and oxygen (O_2)
- Traces of hydrogen sulphide (H_2S, less than 3%), water vapour (H_2O, less than 10%), and ammonia (NH_3, less than 1%)

The biogas energy content is chemically related to the methane content. It can be used directly to generate heat and power or used as cooking fuel and used as vehicle fuel after passing through the upgrading process.

The chemical composition of biogas varies with a series of factors, from the quality feedstock characteristics, digestion technologies, hydraulic retention time (HRT), temperature, organic loading rate (OLR), etc. [3].

The digestate is the residue from the anaerobic digestion process. Depending on the properties of the substrate, the digestate obtained can be rich in nutrients such as nitrogen, phosphorus, potassium, and other micronutrients. The common range values of nutrient content in the digestate per ton are 2.3-4.2 kg of nitrogen, 0.2 -1.5 kg of phosphorus, and 1.3 - 5.2 kg of potassium [4].

The digestate can be utilised for different purposes. Depending on its characteristics, it can be used for energy generation by incineration, disposed of in a landfill, or used as fertiliser. The advantage of using digestate as fertiliser instead of raw animal manure is the reduction of odours, since anaerobic digestion stabilises, disinfects, and deodorises the waste, and the higher ratio of carbon/hydrogen.

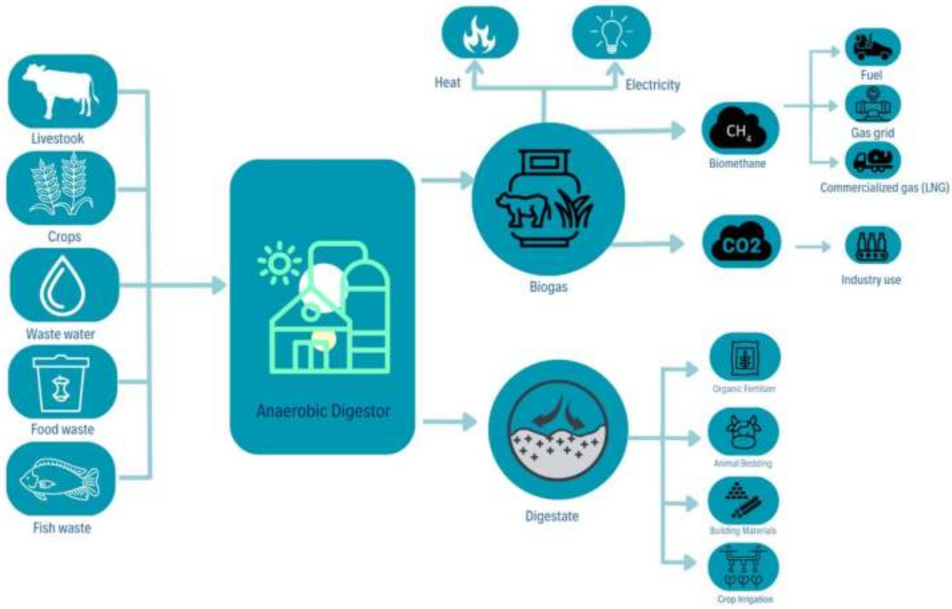


Figure 4 - Anaerobic digestion potential feedstocks and products

5 ANALYSIS OF THE ANAEROBIC DIGESTION FEEDSTOCK

5.1 Objective

The objective of the feedstock analysis is to understand the potential production of biogas, based on an assessment of the organic materials available within the study area (Inishowen Peninsula).

The analysis relied on the following sources of data:

1. Central Statistical Office (CSO)'s Population Census (2016).
2. Central Statistical Office (CSO)'s Agriculture Census (2020).
3. Teagasc National Farm Survey (2021).
4. Other published sources of data and information.

Note: additional data was requested from farmers of the region but it was not received in time to feed into this study. This data is important for a full analysis and is recommended as an early action item for the Inishowen SEC to contribute to the next stage to advance the project.

The study also took into consideration the non-feedstocks available in the Inishowen Peninsula, such as food waste and fish waste.

5.2 Agricultural Feedstock Analysis

The agricultural feedstocks that have been considered in terms of potential for biogas in this study are:

Table 5-1 - Categories of agricultural feedstock considered

Category	Description	Considered
Grass silage	Grass silage is the forage biomass harvested and ensiled for use as winter fodder for cattle and sheep. It is primarily produced to feed animals, being also an excellent feedstock for anaerobic digestion.	Yes
Slurry from cattle	Captured when the cattle are housed and generally stored under the cattle shed, or in adjacent above or below-ground tanks in some cases. There is a marginal amount of slurry captured from the milking parlour.	Yes
Manure from sheep	Manure from sheep is not considered as practical feedstock for Anaerobic Digestion.	No
Slurry from pigs	Pigs' systems are represented though pig slurry production is not taken into consideration because we don't have information about specific quantities of	Yes
Manure from poultries	Poultries are not represented because of the small number of farms in these systems.	No

5.3 The agricultural context of the Inishowen Peninsula

The agriculture sector in Inishowen faces, along with the rest of the sector in Ireland, a major challenge: the requirement to reduce green gas emissions by 25 percent by 2030, as part of the country's Climate Action Plan, which pledges to halve overall carbon emissions by 2030 and reach net zero by 2050 [2].

Agriculture is the single largest contributor to Ireland's overall climate impact. Cattle outnumber people, and agriculture accounts for over 37 percent of carbon dioxide (CO_2) emissions. Although Ireland has committed to reducing its CO_2 emissions by 4.8% per annum from 2021- 2025 under the first carbon budget, energy-related emissions were conversely up 5.4% in 2021. The average dairy farm emits three and a half times more emissions than the average beef farm and four times more than the average tillage farm.

Ireland also has the highest methane (NH_4) emissions per capita of all EU member states, with much of this due to beef production. Further growth in the dairy sector is envisaged by Teagasc, a goal that is incompatible with climate policy. The current Government emissions reduction roadmap for the sector (AcClimatise) is not consistent with the 2020 Programme for Government commitment to reduce emissions by on average 7% per annum or 51% by 2030, as it assumes a stabilisation as opposed to an absolute reduction of methane emissions by 2030. Total emissions of greenhouse gases and nitrate/ammonia impacts must be reduced.

To meet Climate Action Plan targets, Inishowen's agricultural sector is being forced to scale back, bringing with it considerable financial hardship. On top of this, many farmers currently carry significant financial commitments, and many will struggle to meet these targets without cutting the herd.

Another fact about the Inishowen agriculture sector is that many farmers have off-farm income and lack succession, as many farmers are now encouraging their children to look elsewhere to provide a living for themselves due to the long hours, over-regulation, and non-existent returns. Most of the farms in the Inishowen Peninsula and indeed through Ireland are no longer capable of generating a sufficient income.

For these many reasons, creative solutions that support farms to thrive sustainably, and which balance economic, social, and ecological issues, are crucial.

With that in mind, the *Inishowen Uplands project*[7], a European Innovation Partnership (EIP) funded by the Department of Agriculture, Food, and the Marine (DAFM) under the Rural Development Programme 2014-2020 was created. The aim of this project is to ensure that the farming activity that is carried out balances economic, social, and environmental sustainability.

This project is focused on the development of best practices in managing both commonly and privately owned uplands in Inishowen and how together with innovative practices, including agroforestry, and climate-smart innovation can improve the low land to reduce costs and maximise returns.

One of these solutions is how the conservation and proper management of this blanket bog (a rare ecosystem in an international context) coupled with climate mitigation measures on improved low land would yield several important environmental benefits such as good quality water, carbon sequestration, high-quality biodiversity, and flood mitigation.

Note: information about the *Inishowen Uplands project* and its results were not yet available at the time of publication of this feasibility study. We recommend that ISEC seek out further information about this project as it could be important for the biogas project execution, and to a larger extent, a feed for potential future ISEC projects.

5.4 The structure of agriculture and spatial distribution of manure

The population of livestock in 2010 (based on the most recent Census of Agriculture) in Ireland is illustrated in Figure 5.

Even though the data is more than a decade old, it is still representative as it is not expected to have significantly changed in terms of proportion of livestock distribution. The greatest concentration of cattle is in the south of Ireland. Donegal is a county where cattle are less represented. Instead, Donegal is one of the counties where the sheep population is mostly

[7] https://www.inishoweneip.com/

concentrated. The population of pigs in Ireland is primarily in Cavan and Cork, while poultry in Ireland is predominantly farmed in Monaghan, Limerick, and Waterford.

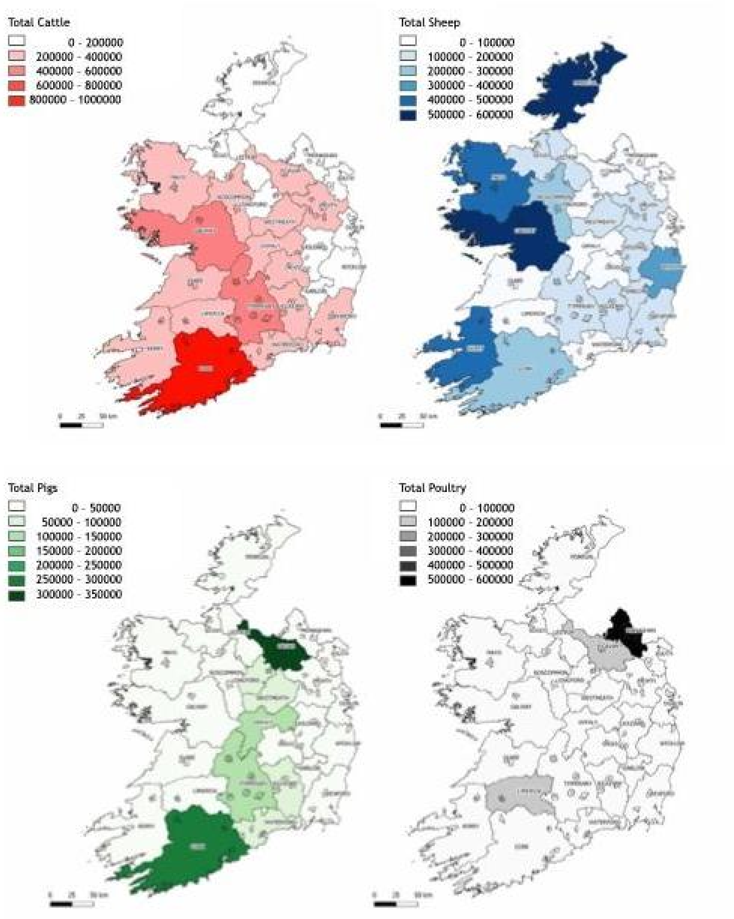


Figure 5 – Livestock population by county in Ireland 2010 (Source: CSO Census of Agriculture 2010)

In this spatial distribution of livestock, it is particularly evident that in the Inishowen peninsula the number of sheep farms and beef production farms is much higher than the dairy farms, with each one representing approximately 37% of the total number of farms on the Inishowen peninsula.

Table 5-2 - The agricultural context in Inishowen Peninsula

Category	Quantity	Unit	Source
Farms	1961	un.	Energy Master Plan
Average farms size	27	ha	Energy Master Plan
Number of farmers	2688	un.	Inishowen Uplands website
Sheep production	36,72%	%	CSO Census of Agriculture 2010
Beef production	37,46%	%	CSO Census of Agriculture 2010
Dairy production	1,94%	%	CSO Census of Agriculture 2010
Tillage production	1,52%	%	CSO Census of Agriculture 2010
Mix grazing	12,6%	%	CSO Census of Agriculture 2010

Category	Quantity	Unit	Source
Mix Crop & Livestock	1,50%	%	CSO Census of Agriculture 2010
Mix field crop	7,61%	%	CSO Census of Agriculture 2010
Other	0,60%		CSO Census of Agriculture 2010
Nº of farms of sheep production	720	un.	Calculated
Nº of farms of beef production	735	un.	Calculated
Nº of farms of dairy production	38	un.	Calculated
Nº of farms of tillage production	30	un.	Calculated
Nº of farms of grazing	247	un.	Calculated
Nº of farms with crop & livestock	29	un.	Calculated
Nº of farms with field crop	149	Un.	Calculated
Nº of farms with others	12	Un.	Calculated
Heads of dairy cows	Only available for Co. Donegal	un.	CSO Agriculture Census 2020 [3]
Heads of sheep	Only available for Co. Donegal	un.	CSO Agriculture Census 2020

5.5 Characteristics of husbandry

Cattle

On the Inishowen peninsula, cattle are farmed on pasture land for most of the year to maximise the use of grass. During the winter months cattle are housed indoors, the volume of manure storage over the winter period must cover housing for a period of 16 to 22 weeks. Data for 2018 [14] indicates that cattle spend 58%–98% of their time grazing on open pasture. When cattle are housed indoors 81% of manure is sent to a pit storage system in the form of slurry. Only the manure which is collected during the winter months as slurry when cattle are housed indoors can be used in biogas plants.

Sheep

Approximately 89% of lowland ewes and other sheep older than 1 year are housed for 28–85 days during the winter [14]. Most remaining sheep are not housed indoors during the winter. Only manure collected when sheep are housed could be used in Biogas power plants.

Pigs

Most pigs in Ireland are housed indoors year-round and manure produced by pigs is managed as slurry using pit storage [14]. The intensive farming of pigs in Ireland at a relatively small number of farms, coupled with the year-round collection of pig slurry could make pig slurry a viable resource for biogas production.

Poultry

Poultry are also farmed in an intensive manner by a small number of specialised farmers. Most poultry are housed indoors year-round [14]. Manure storage systems used for poultry manure consist of litter-based systems along with pit storage systems. Intensive farming of poultry and year-round manure collection could make poultry manure a viable resource for biogas production.

5.6 Size distribution of farms and spatial distribution within county

Most farms in Inishowen Peninsula have an area size of between 10 to 20 ha, while only 2.35% of the farms have more than 100 ha. The number of farms with an area size between 30-50 ha is 378.

Table 5-3 - Distribution of farm size in Inishowen Peninsula

Category	Percentage	Quantity	Source
Farms > 100 ha	2,35%	46	CSO Census of Agriculture 2010
50 ha < Farm < 100 ha	10,45%	205	CSO Census of Agriculture 2010
30 ha < Farm < 50 ha	19,26%	378	CSO Census of Agriculture 2010
20 ha < Farm < 30 ha	15,81%	310	CSO Census of Agriculture 2010
10 ha < Farm < 20 ha	25,68%	504	CSO Census of Agriculture 2010
2 ha <Farm < 20 ha	24,78%	486	CSO Census of Agriculture 2010
Farm < 2 ha	1,66%	33	CSO Census of Agriculture 2010

In terms of spatial distribution, the majority of herds is concentrated in Gleneely and Carndonagh, followed by Straid. Gleneely has the majority of cattle (beef production and dairy), followed by Kilderry and Culdaff. It is also in Gleneely where the average number of dairy cattle per herd is higher.

Table 5-4 - Spatial distribution of the number of herds, within Inishowen's electoral division

Inishowen Electoral Division	Total Number of Herds	Average Number of Total Cattle per Herd	Average Number of Beef Cattle per Herd	Average Number of Dairy Cattle per Herd
ARDMALIN	92	1721,75	1546,25	175,5
BALLYLIFFIN	83	1045	968,25	76,75
BIRDSTOWN	70	1629	1347,75	281,25
BUNCRANA	103	1435,25	1378,25	57
CARNDONAGH	116	1415,5	1322,5	93
CARTHAGE	66	662,5	629,5	33
CULDAFF	83	2403,75	1876,25	527,5
DESERTEGNY	85	904,25	904	0,25
DUNAFF	66	541,5	541,5	0
FAHAN	57	1950	919,25	1030,75

GLENEELY	152	3668,5	2170	1498,5
GLENEELY (CULDAFF)	83	2225,75	2033,25	192,5
GLENNAGANNON	37	1149	838,5	310,5
GLENTOGHER	52	424	420,5	3,5
GREENCASTLE	50	878,25	410	468,25
ILLIES	104	1103,25	1091,75	11,5
KILDERRY	57	2837,75	1586,75	1251
MALIN	81	1582,25	1338	244,25
MINTIAGHS	79	630,75	585,5	45,25
MOVILLE	58	1418,5	1178,25	240,25
REDCASTLE	60	845,25	690	155,25
STRAID	112	980,75	976	4,75
THREE TREES	29	586	428,75	157,25
TURMONE	61	924,5	893,5	31
WHITECASTLE	74	1319,25	881,25	438

Adapted from: Pobal Maps, 2023

5.7 Socio-economic factors that affect the farming community

To assess the potential of agricultural feedstock for biogas it is also important to consider the socio-economic factors that affect the farming community in the Inishowen Peninsula, where most farming activity results in low financial returns. As shown on the Table 5-5 most farms have a reduced business volume (below €4000).

Table 5-5 - Number of farms classified by economic size

Category	Percentage	Quantity	Source
Farms > €100 000	1,96%	38	CSO Census of Agriculture 2010
€50 000 ha < Farm < €100 000	2,26%	44	CSO Census of Agriculture 2010
€25000 < Farm < €500000 ha	5,90%	116	CSO Census of Agriculture 2010
€2500 < Farm < €5000 ha	5,90%	116	CSO Census of Agriculture 2010
€15000 ha < Farm < €25000	9,31%	183	CSO Census of Agriculture 2010
€8000 <Farm < €15000	17,50%	343	CSO Census of Agriculture 2010
€4000 <Farm < €15000	24,77%	486	CSO Census of Agriculture 2010
Farm < €4000	38,22%	749	CSO Census of Agriculture 2010

6 BIOGAS POTENTIAL PRODUCTION ANALYSIS

After the feedstock analysis, it is possible to determine the biogas produced during the anaerobic digestion of agricultural feedstocks (mainly, cattle manure, cattle slurry, and grass silage). Also, it is possible to determine the biogas potential production from food waste and fish waste. It was not possible to determine the biogas potential production of sewage sludge.

6.1 The Potential of Biogas Production from Agricultural Feedstocks

The table below outlines the potential for biogas resources from livestock herds in Ireland.

Table 6-1 – Potential biogas resource from the livestock herds In Ireland

Category	Herd Flock Size (nº heads)	Indoor period (days)	Weekly manure (m^3)	Annual manure (m^3)	VS (%FM)	BMP (LCH_4kgVS^{-1})	Gross biogas output * (kW)	Gross electrical output** (kWeq)
Average Herd / Flock sizes (*)								
Beef	44	141	0,29	257,02	6,76	310	6,11	2,14
Dairy	63	117	0,33	347,49	6,9	239	6,51	2,28
Sheep	185	85	0,03	67,39	22,6	171	2,96	1,03
Pigs	3 099	365	0,04	630 204	2,6	292	54,31	19,01
Poultry	15 406	356	0,81x10-3	650,68	51,46	228	86,67	30,33
Largest Average Herd / Lock Sizes								
Beef	110	141	0,29	642,56	6,76	310	15,29	5,35
Dairy	143	117	0,33	788,75	6,9	239	14,77	5,17
Sheep	253	85	0,03	92,16	22,6	171	4,04	1,42
Pigs	50 000	365	0,04	101 678,57	2,6	292	876,32	306,71
Poultry	50 000	356	0,81x10-3	2 111,79	51,46	228	281,27	98,45

Source: IEA Bioenergy, June 2021

6.2 The Potential of Biogas Production from Food Waste

The table below presents the data and statistics related to food waste production in the Inishowen region.

Table 6-2 – Data and statistics related to food waste production in Inishowen

Category	Unit	Quantity	Source
Annual municipal waste production per person 2020	kg/person	645,0	EPA's National Waste Statistics 2020
Annual household waste production per person 2020	kg/person	379,0	EPA's National Waste Statistics 2020
Total Annual food waste production per person 2020	kg/person	150,4	EPA's National Waste Statistics 2020
Households' annual food waste production per person 2020	kg/person	46,6	EPA's National Waste Statistics 2020
Manufacturing and processing annual food waste production per person 2020	kg/person	43,6	EPA's National Waste Statistics 2020
Restaurants and Food service annual food waste production per person 2020	kg/person	34,6	EPA's National Waste Statistics 2020
Primary production annual food waste production per person 2020	kg/person	13,5	EPA's National Waste Statistics 2020
Retail and distribution annual food waste production per person 2020	kg/person	12,0	EPA's National Waste Statistics 2020

The biogas potential from collectible food waste in the Inishowen Peninsula is calculated with the following assumptions:

a) The population data from the Population Census (2016) and an annual food waste production factor of 150,4 kg/person [8];

b) The quantity of food waste available from businesses (restaurants, hotels, shops, etc.) and non-permanent residents (holiday homes) is estimated according to the number of domestic and overseas visitors to the study area using data from the Inishowen Peninsula Destination and Experience Development Plan [9]. The same food waste production per person factor as above is used. A dry matter content of 30,6%, and a biomethane potential of 242 Nm^3/tDM.

6.3 Determination of the Potential of Biogas Production from Fish Waste

The table below presents the data and statistics related to fish waste production in the Inishowen region.

Table 6-3 - Data and statistics related to fish waste production at Inishowen region.

Category	Unit	Quantity	Source
Total fish landed at Killybegs Port (being the largest port in Ireland)	ton.	152 294	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2015
Total fish landed at Greencastle Port	ton.	2 673	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2015
Total fish landed at Rathmullen Port	ton.	1 356	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2016
Total of fish that was processed	ton.	22 310	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2017
Percentage of the total weight of fish that is waste	%	35	Disposal and Re-utilisation of fish waste (including Aquaculture Waste), Nick Pfeiffer Nautilus Consultants Ireland Ltd
Total fish waste	ton.	8 508	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2017
Estimated total fish waste from wild fisheries and aquaculture (Donegal)	ton./year	11 500	An Appraisal of Fish Waste in County Donegal – ReNEW - April 2018

A. The total weight of live fish landings into Inishowen harbours was 156,323 tonnes in 2021.
B. Assuming the amount of fish waste produced is 35% of the total weight of fish caught, according to the EPA report - Food Loss and Waste from Farming, Fishing and Aquaculture in Ireland (2019) [11].
C. The fact that all fish brought to Irishwomen’s harbours are processed there.
D. A dry matter content of 32%.
E. Biomethane potential of 216 Nm^3/tDM, according to the article Anaerobic batch co-digestion of sisal pulp and fish waste, Bioresource Technology (2004) [12].

6.4 Determination of the Potential of Biogas Production from Marine Algae

Marine algae, or seaweed, could potentially be a suitable non-agricultural feedstock for biogas production in anaerobic digestion plants. Ireland's northwest region has significant seaweed resources on its coast and the temperate oceanic climate is well suited to cultivating seaweed both naturally and through farms. The Donegal region, including Inishowen, has a big tradition of seaweed harvesting, where it is used primarily for food.

Seaweed is also considered a third-generation biofuel source, with no land or freshwater requirements. Despite the benefits and advantages of seaweed cultivation for the anaerobic digestion process, there are many challenges and disadvantages associated with it. At this stage, it is difficult to estimate the costs of wild seaweed harvesting for anaerobic digestion in Ireland. Cultivation on seaweed farms would most likely be more economical, however do not take initial investment costs into consideration. Another major issue to be considered is the impact on biodiversity, which would have to be considered carefully.

Due to the difficulties with assessing the practical potential of seaweed on the Inishowen Peninsula, as well as the unlikelihood of it being financially viable, seaweed was not considered as a feedstock for an anaerobic digestion plant in the Inishowen Peninsula, at least for now.

Nevertheless, it is important to better understand the work that is being developed by the *Inishowen Algae*[8] project, which is a pilot scheme to demonstrate innovative and carbon-neutral options for revenue generation on small-scale farms.

7 MAIN CHALLENGES

Financing difficulties are seen as the major barrier to the development of biogas projects in Inishowen, and Ireland in general. This is due to:

1. Lack of knowledge around renewable energy systems in general, and biogas systems. This applies to consumers generally, but also to those involved in the value chain for biogas from concept through to operation.

2. Low levels of capital funding instruments available for the development of biogas projects. The current budget for 2023, announced by the Department of Agriculture, attributes only €3 million per year of funding over four years for biogas projects.

3. Low feed-in-tariff for biomethane producers that want to sell the produced electricity or the renewable gas to the grid (i.e., feed-in-tariff with cogeneration is 0,18 €/kWh and without cogeneration is 0,13 €/kWh).

[8] https://www.inishowenalgae.com/

4. The lack of incentives to use natural gas to power vehicles, for example, to fuel public transportation.

5. Lack of a district heating (DH) system in Co. Donegal. According to a study promoted by IrBEA[9], the nearest potential DH system to Carndonagh is the one located at an early-stage research project in Letterkenny, Co. Donegal (60 km distance). This system is proposed by Letterkenny Institute of Technology, contemplating a campus-wide district heating scheme, and is participating in the SEAI exemplar program to progress the project. Unfortunately, the project is currently on hold pending details [15]. As an action item it is recommended that the Inishowen SEC seek updates on this project and potential for collaboration.

6. General lack of a supportive gas pipeline network, especially in Donegal County where there is no gas pipeline. According to Gas Network Ireland, they are currently examining connection options, however installing a new connection is something that will take a significant period to be operational. In the shorter term, the transportation of biomethane in gas cylinders is possible, which is expensive. Kildare is the nearest gas connection node, where the transported gas can be injected. That solution is not feasible due to transport costs. Transporting biogas using trucks is also not environmentally sustainable. In the overall value chain of this, it might result in more CO_2 emissions than the ones that are avoided by the biogas project.

7. The local electrical grid infrastructure requires upgrades or expansions, which could represent the need for investors of the biogas power plant to bear the costs of this to facilitate their required connection.

8. There is the possibility of connecting to the electricity network, however it is expensive and difficult to implement.

9. The availability of feedstock, mainly manure, is also a challenge since the majority of Inishowen's cattle herds are of a smaller scale and there is only a short period of time during which manure can be collected throughout the year. This means that a biogas power plant that is supplied at the individual farm level is unlikely to be viable.

10. There are significant administrative overheads in the development of a biogas project due to the multitude of parties who need to be engaged with, planning, waste licensing, agricultural regulations, government support schemes and grid connection processes.

11. General public opposition to biogas power plants due to concerns regarding associated risks of biogas power plant operation i.e., odour, impact on water quality, potential impacts on human health, potential impacts on the health of livestock, increased traffic volumes associated with biogas facilities, and "Not in My BackYard" (NIMBY)

[9] IrBEA - Irish Bioenergy Association

syndrome. As an example, the *Gort Biogas Concern Group* was set up to oppose plans to construct a biogas plant on a 10,1-hectare site in the townlands of Ballynamantan, Kinincha and Glenbrack, Gort in Galway.

12. The need for investment in the supplementary skills and training required for such a project. This is even more critical due to the exodus of skilled young people from the Inishowen peninsula, as a result of the historical lack of job opportunities.

8 MAIN DRIVING FORCES

Regardless of the challenges faced to develop a biogas project, truth is that Ireland is taking significant steps towards the expansion of biogas production to replace natural gas in Ireland's energy mix and enhance Ireland's security and diversity of supply, due to the need to accomplish the targets established in the Climate Action Plan and the need to find alternatives to Russia's gas. Consequently, there are several steps that are being taken that serve as driving forces to the development, namely:

1. Ireland's targets regarding renewable energy, such as:
   - 80% of electricity is from renewable sources.
   - development of at least 500 MW of renewables through local community-based projects.
   - deployment of zero-carbon heating in 50000 commercial buildings.
   - raise the blend of biofuels to B20 in diesel and E10 in petrol.
   - 5,7 TWh of biomethane in the grid by 2030, which would represent 10% of Ireland's current natural gas demand and abate roughly 2,1MtCO2eq, requiring 150-200 medium-to-large biogas plants.

2. Biogas power plants have the potential to:
   - Provide 28% of Ireland's overall gas needs by 2050
   - Cut carbon emissions by 200 million tonnes annually
   - Sustain rural businesses, and
   - Lead to the creation of 3000 new permanent jobs in the industry

3. The number of biogas plants in Ireland is currently very small compared to the overall potential of the 900 plants identified by the Government. By 2030, the Government is targeting approximately 150-200 operational biogas power plants.

4. The number of supports available for energy efficiency, heat pump, biomass boilers, and Anaerobic Digestion plants under the Support Scheme for Renewable Heat (SSRH), which incentivises renewable heat sources as a more cost-effective option.

5. The fact that natural gas prices have risen exponentially. From December 2021 to December 2022, the price of natural gas rose by 86.5%, liquid fuels (home heating oil) were up 39.9%, and solid fuels were up 46.9% in that year. Wholesale gas prices hit

their peak in August 2022 rising to €346 per megawatt hour – a more than 450% increase on prices before the Russia invasion.

6. Heat demand density is a key criterion for commercial viability of district heating systems powered by biogas where sufficient load is required to justify the network costs and heat losses over long pipe runs. The type of dwellings and the layout of new housing estates will dictate the heat demand density and will affect the feasibility of district heating.
7. The increasing Irish government support for high-impact energy efficiency projects and renewable energy projects to a maximum of €3 million.

8. The European Investment Bank (EIB) has approved €700 millions of financing for agriculture and the bioeconomy. The initiative aims to unlock around €1.6 billion of investment in these sectors by supporting private companies operating throughout the value chains of production and processing of food, bio-based materials, and bioenergy.

9. The range of economic funding options that have been presented to the government in the *KPMG Integrated Business Case for Biomethane in Ireland*, take into consideration the social metrics alongside production costs as the most acceptable and preferred solution. These include a gas public service obligation levy, a biomethane obligation scheme, and capital grants.

10. The establishment of a national *Renewable Gas Registry,* which serves as a Guarantee of Origin certificate for renewable gases in line with the requirements of the European Union Renewable Energy Directive (RED) II.

11. Ongoing development of renewable-gas business processes and new connections policies by Gas Networks Ireland.

12. The ongoing efforts to optimise production methods in order to raise yields and reduce costs through schemes such as Teagasc's *Grass 10* program, which may also lead to reducing the requirement for fertiliser in the growing of grass crops.

13. The EU has imposed a target that a max of 10% of waste produced can end up in landfill. Any solution that results in waste being used as by-products must be considered.

14. Increase interest of large energy users to procure renewable gas due to their obligations to reduce their carbon footprint.

15. The development of power-to-gas (P2G) technologies like gasification offers exciting potential to multiply the benefits of a renewable gas and electricity grid as they can help to balance a highly renewable grid and increase the renewable gas output from anaerobic digestion technologies. Both gasification and P2G technologies have the potential to increase the production of renewable gas substantially.

16. Collaborative research between SEAI and the International Energy Agency on bioenergy on the development of power-to-gas (P2G) technologies that have the potential to multiply the benefits of a renewable gas and electricity grid.

17. Difficulties faced by the farming sector, in general, and Inishowen region with declining income, notably beef production and dairy farming. The increasing age profile of farmers, where the majority are at or close to retirement age with limited succession prospects for a younger generation, triggers the necessity of adopting “new solutions” by this sector.

18. The lack of progression and employment opportunities for young people is generally a feature of Inishowen and rural depopulation continues to be a problem.

19. The Inishowen region is very dependent on fossil fuels for heating, transport, and farming/fishing (91% of the total energy consumption for heating is from non-renewable energies (63% from oil and 18% from coal), which represents a huge necessity for change to meet national climate action targets.

9 POTENTIAL AD PLANT LOCATION

To select the most feasible site for the biogas power plant implementation the following factors were considered:

- **Biogas demand** – an economically justifiable use of the biogas produced at a scale large enough to equal the output.

- **Feedstock availability** -- the proximity of the feedstock supply will reduce additional logistics costs. In most situations the feedstock is a major consideration when deciding where to build a biogas plant, and proximity to a source of feedstock is especially crucial for biomass with high moisture content, such as cow slurry.

- **Proximity to raw materials and infrastructure** -- it is challenging to feed the plant daily if it is located far from the supply of feed material. The cost of the pipeline will rise the further it is from the gas consumption point. In addition, the site’s water supply is a vital element to consider. It is always preferable to choose a location on the side of the animal enclosure that is closer to the source of feed material.

- **Land terrain** -- the terrain should also be considered because of the nature of materials being transported (i.e. slurry and gas).

- **Size of the plant** -- the chosen site for the biogas plant will be determined by its size. If the biogas plant is large, it will need a bigger one with the necessary land available to accommodate this.

- **Proximity to nearby water sources** -- it is not advisable to have a biogas plant within 10 metres from any source of water due to pollution risk.

- **Interaction with the environment** -- Site safety should also be considered when choosing a location for the plant, i.e. avoiding any nearby schools or children's play areas.
- **Construction costs** – the site should be accessible for construction works and associated raw materials to avoid cost increases. .

- **The temperature of the area** -- Warmer temperatures promote more microbial activity in the dome ensuring more gas production (ideally the temperature would be between 20-35ºC). Does not mean that a biogas power plant can't be in colder regions, with average temperatures in winter lower than 0ºC).[10]

- **Digestate demand** -- digestate demand refers to the ability to supply the produced digestate (biofertilizer) to customers in a cost-effective manner. Digestate has a high moisture content (about 95% water) making handling and shipment a relatively expensive issue. Therefore, the site must be strategically positioned to handle and transport the slurry from digestion.

At this stage it is only possible to have a macro-level analysis of the biogas plant location. So, we can only point to the area where the biogas power plant would be most favourable and not the specific location. Thus, the main factors that we had in consideration at this stage were:

1. biogas demand,
2. feedstock availability, and
3. proximity to infrastructures.

Based on an analysis of biogas demand, feedstock availability, and proximity to infrastructure, two suggested potential locations for the biogas plant in Inishowen are Carndonagh and Gleneely. Table 9.1 below sets out a comparison of these locations.

A major consideration of the overall feasibility of the project is the gas pipeline in the area. Further analysis and considerations are required in the next stage of the project. At present, the nearest injection gas node to the potential biogas power plant is in Co Kildare (approximately 370 km away). Gas Networks Ireland is currently developing a second injection facility in Mitchelstown, County Cork, while a third is under consideration for the north. The

[10] The country in Europe with more biogas power plants is Germany, followed by France and the United Kingdom, whose climate is very cold and rainy in winter. As it can be seen in the second edition of the 'European Biomethane Map'.

most advantageous for Inishowen, however, is the possible extension of the gas network across the border to the gas pipeline node in Derry and Strabane.

Any gas output from an anaerobic digester located in Inishowen would have to be transported by road to Co. Kildare, resulting in higher costs and associated carbon emissions. Moreover, since there isn't fed to local gas-using premises, or a natural gas service station, to feed gas fuelled transports.

Combined Heat and Power (CHP) technology to convert biogas to heat and electricity would be ideal for the peninsula as this could be utilised by any one of a number of existing facilities (e.g., hospitals, hotels, and oyster hatchery premises). However, there is currently no district heating system in operation in Co. Donegal. The nearest potential district heating (DH) system is the one proposed by Letterkenny Institute of Technology DH system, which, as of publication of this study, is currently on hold. Despite these restrictions this opens the opportunity for new social innovations and industries to emerge to respond to these challenges. Support from the Inishowen SEC will be fundamental to realising this potential with training plans outlined in their strategic roadmap.

It is important the existence of a district heating system in Co. Donegal. The use of the heat produced in the biogas power plant can be one of the main sources of heat of a district heating system in Co. Donegal. District heating systems use one of the by-products of the biogas power plant (heat), while the production of heat by a biogas power plant greatly increases the economic viability of DH systems. This is even more significant with the approval of the Support Scheme for Renewable Heat (SSRH), which promotes renewable heat incentives that makes renewable heat sources a more cost-effective option.

As Buncrana is the most populated town at Co. Donegal, with approximately 7,000 residents, this would be an ideal location for a district heating system which requires to be analysed in a specific feasibility study.

Despite its relatively new housing stock, Buncrana has a heavy reliance on fossil fuels. Over 70% of homes are heated using oil. The proportion of homes that are heated by coal (19%) is almost five times that across Ireland. With a relatively strong tourism industry (which is expected to increase), it has ten medium to large sized hotels. Many of these hotels have swimming pools and spas with large, heated floor areas and therefore high hot water demands, making it ideal for a DH system that is powered by a biogas power plant. Buncrana has also a public swimming pool, at the Buncrana Leisure Centre, that could be connected to the DH system.

Table 9-1 – Comparison between the main two potential locations of the biogas power plant

Category	Carndonagh	Gleneely
Biogas demand	Higher biogas demand due to the high number of buildings with a high demand for alternative sources of heating. It is around 20 km away from Buncrana which is one of the major places at Inishowen with residents and business owners, and that also has a hot water swimming pool that requires more affordable sources of heating.	Lower biogas demand due to the lower number of buildings with a high demand for alternative sources of heating. It is around 30 km away from Buncrana which is one of the major places at Inishowen with residents and business owners, and that also has a hot water swimming pool that requires more affordable sources of heating.
Feedstock availability	A high number of herds. Distance to Greencastle port (main potential fish waste source): approximately 15 km	Highest number of herds. Main average number of total cattle (beef production and dairy). Highest average number of dairy cattle per herd. Distance to Greencastle port (main potential fish waste source): approximately 25 km
Nearness to raw materials and infrastructures	Distance to Carndonagh electrical substation: less than 5 km Distance to Moville electrical substation: approximately 20 km Distance to Buncrana electrical substations: approximately 20 km Distance to Buncrana (potential location for a district heating system): approximately 20 km Distance to Kildare gas grid node 4h (via A5); 4h15 (Via M1); 4h22 (via N55 and A5) Distance to Strabane and Derry gas grid node – 65 Km (60-70 minutes by road transport)	Distance to Carndonagh electrical substation: approximately 10 km Distance to Moville electrical substation: approximately 10 km Distance to Buncrana electrical substations: approximately 30 km Distance to Buncrana (potential location for a district heating system): approximately 30 km Distance to Kildare gas grid node 4h02 (via A5); 4h13 (Via M1); 4h23 (via N55 and A5) Distance to Strabane and Derry gas grid node – 65 Km (60-70 minutes by road transport)

Both Carndonagh and Gleneely present very similar conditions in support of the location of a biogas power plant. Even though Gleneely has the highest feedstock availability it is further away from other infrastructure. Thus, the location of a biogas power plant at Carndonagh can better serve the purpose of ISEC's vision to become a centre of excellence and a reference as a sustainable energy community.

Regarding the specific site location, the biogas power plant should preferably be situated on land owned by local authorities or community partners to reduce the overall cost of the project. An alternative option would be the farmland of someone that shares the same values and community interests of the Inishowen SEC and in the business and governance model of this document. These farmers could also be one of the feedstock suppliers of the project.

Important to note that for the biogas power plant location, it is required approximately 4 hectares of land are for a 500-kW biogas power plant and approximately 6 hectares for a 1,000-kW biogas power plant. This area only includes the feedstock area, the bio digestor area, the CHP engines area, as well as the storage area and processing area of the digestive. The most precise area can only be addressed in the phase of design and conception of the biogas power plant supplier.

10 FEASIBLE TECHNOLOGY ANALYSIS

10.1 Determining the Anaerobic Digestion Technology

There are many different digester types and the most common are summarised in the figure below:

Figure 6 – Different digester types

The method used for comparing the technologies of anaerobic digestion (AD) is called Multi-criteria Analysis (MCA). Multi-criteria Analysis is useful for decision-making, and it is based on the evaluation of several options according to certain criteria. The MCA involves 8 steps:

1. Establish the decision context including the aim of the MCA, the decision makers, and other players.
2. Identify the options.
3. Identify the criteria.
4. Define the performance of the option for each criterion by giving each a score.
5. Assign a weighting to each criterion according to their relative importance with regard to the final decision.
6. Combine the scoring and weighting values for each option and determine the overall value.
7. Examine the results.
8. Perform the sensitivity analysis of variations in scores and weights.

The MCA consists of a performance matrix where the rows represent the options and the columns the performance of the criteria for each option.

The criteria for the analysis were selected following desk research of the general characteristics of anaerobic digestion plants which achieve the best biogas performance in conditions similar to those being considered for Inishowen.

The local characteristics of the Inishowen Peninsula were taken into account when evaluating the criteria and similarly, the selected technology needs to be optimum for working in Irish climate conditions.

In selecting the technology, one must also take into consideration the lack of technical and specialised skills that are needed for biogas power plant operation and maintenance.

Five criteria are chosen to analyse AD technology:

1. **Technology lifespan** - how long before the technology becomes obsolete. This criterion is important due to the reliance on electricity generation. A long lifespan is preferable to avoid long-time disruptions in the electricity supply and production of organic fertiliser. The average lifespan for biogas plants is between 10-12 years and it is expected that the technology selected will last at least this period.
2. **Technical knowledge and skills** - this criterion is important because technical knowledge and skills directly affect the efficiency of biogas production.
3. **Physical structure** - the design of the structure has important effects on biogas performance. The structure of the anaerobic digestion plant should provide for optimal anaerobic conditions and the development of the microorganisms inside the AD plant.
4. **Investment costs** - the digester, pipes and other structures needed to produce the biogas are included in the investment costs. Variables such as the capacity of the digester, material, and training of the personnel will differ for each specific case.

10.2 Description of the Biogas Power Plant Solution

Considering the five criteria mentioned above, the preferred AD technology is *complete mix digesters*, commonly referred to as Continuously Stirred Tank Reactors (CSTR), as they are the most compatible with combinations of livestock manure and work well with most co-digestion feedstocks. These communal digesters could co-digest additional feedstocks with a high biomethane yield such as source segregated food waste, by-products from food processing, or grass silage with the manure.

CSTR are engineered tanks above or below ground that treat feedstocks with total solids (TS) concentrations from 3 to 12 percent. These systems require less land than lagoons and are heated. Contents are mixed mechanically, hydraulically, or both. The tank is topped with an impermeable gas-collecting cover. Complete mix digesters work best when the manure is diluted, usually with wastewater used for sanitary purposes at the milking centre.

Overall, as represented in Figure 7, this project includes the establishment of two complex mix digesters (CSTR) located at Carndonagh, as a centralised digester system that is fed by several feedstock sources. That can include cow slurry, pig slurry, food waste, fish waste and even marine algae. This feedstock is transported by truck to these centralised complex mix digesters

(CSTR). This produced biogas is burnt by one Combined Heat Power (CHP) engine, which is part of the all-biogas plant, located at Carndonagh. The biogas in the CHP will be used for producing electricity and heat. The produced electricity could be possibly injected into the electrical grid in the Carndonagh 38kV electrical substation, situated nearby to Carndonagh Cross and the peak Crocknakilladerry. The produced heat energy is injected into a district heating system that we proposed to be implemented at Buncrana. As an alternative, the heat could be sold to business owners of hotels, spas, and heated swimming pools. The biomethane produced could be transported to be injected in the most feasible gas grid node (potentially Derry & Strabane if this becomes operational) or sold as compressed gas to some specific industries that required compressed gas in their industrial process. The compressed gas could also be potentially injected into fuel-gas stations. The biofertilizer (solid organic fertilizer) that is produced in the complex mix digesters is transported to be commercialized. The resulting slurry can be used to irrigate the solid organic fertilizer and be stored in a specific lagoon/tank, or even treated by an osmose process, for controlled discharges.

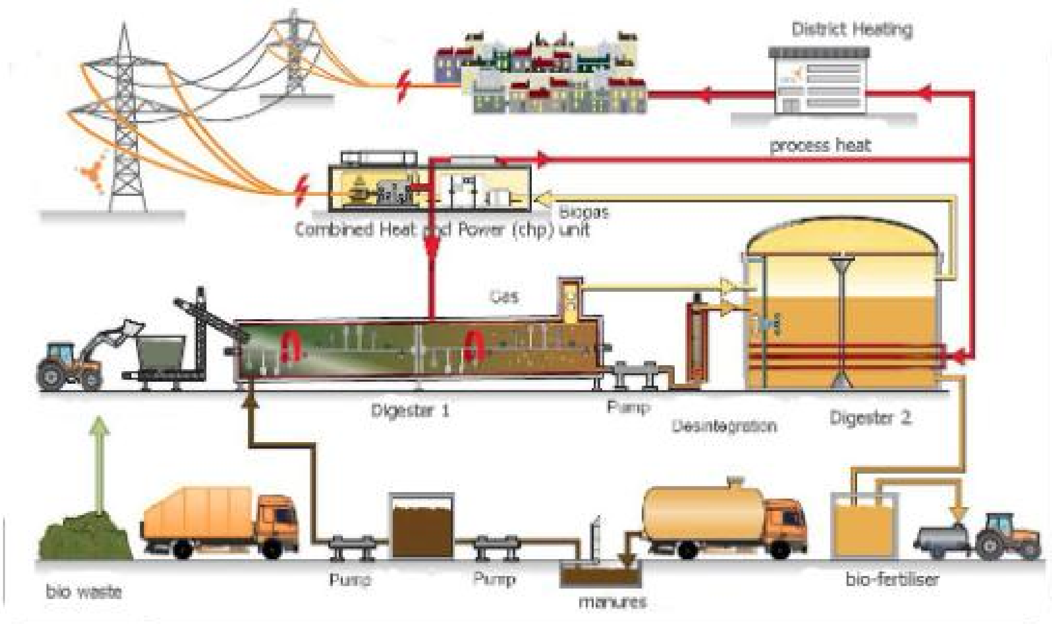


Figure 7 – Representation of the proposed biogas power plant solution

There are several commercial versions of this technology solution, however some of the most interesting biogas power plant suppliers to explore are Bioenergy International (Xergi)[11], BD Agro[12], Weltec[13], AgriKomp[14] BTA International[15], WTT[16], and HOST[17]. It is important to note that the *Engineering, Procurement, and Construction (EPC) contract* should be written by a specialised and experienced EPC contractor, under the coordination of ISEC, with the support of a consultancy team.

[11] https://bioenergyinternational.com/

[12] https://www.ad-agro.de/

[13] https://www.weltec-biopower.com/

[14] https://agrikomp.com/

[15] https://bta-international.de/en/

[16] https://wtt.nl/

[17] https://www.host.nl/en/

11 TECHNICAL, ECONOMIC, ENVIRONMENTAL, AND SOCIAL IMPACT ANALYSIS

A technical-economic model has been prepared for the biogas power plant project. In this model, we have not considered:

- Land costs associated with the project. Given the early stages of this study and the recommendations to work with Donegal County Council or a local farmer, it is not possible to calculate the exact land cost at this stage. The Inishowen SEC, with the advanced data they have from this feasibility study and network they have created, present a commercially attractive partner for any joint ventures and this will need to be fully considered in the next stages of the project.
- The full costs associated with feedstock acquisition.
- The costs associated with the development of external grid connections.
- The costs associated with the transportation of compressed gas by road.
- The costs associated with the possible extension of the network from the potential production site to Derry and Strabane.
- The use of pig slurry, food waste, and fish waste as feedstock for the biogas plant, the revenue from sales of gas to the grid, bio fertiliser sales, sales of gas as fuel for transportation, and sales of CO_2 to beverages industries.
- The adoption of a capital grant or any other type of public funding.

The following assumptions were made in the financial modelling:

- The lifetime of the system is 10-15 years, which is the average for AD plants.
- The cost of the technology including the reactor, storage tanks, and connection pipes for diffusion, mixing, and distribution to be taken into consideration, as well as the turbine to produce energy.
- The maintenance costs of the biogas plant are assumed to be 10% of the investment costs. This includes the costs for repairs and general maintenance of the equipment.
- The operational and administrative labour costs assumed are the median salary for an operational / administrative role in Ireland Only the biogas potential of cow manure is considered as it is difficult to quantify the availability of other sources, such as fish waste and food waste.
- an interest rate of 4%.
- a price index of 2%.

Since the size of the biogas power plant makes a difference due to economies of scale (a larger plant produces more electricity/gas at a lower cost), we have studied two different scenarios:

- Scenario 1 - a small-scale biogas power plant constituted by a CHP engine of 500 kW;
- Scenario 2 - a medium-large-scale biogas power plant constituted by a CHP engine of 1,000 kW.

The study of two different scales of biogas power plants allows comparison with other European examples:

- in Germany the preferred approach was the development of a higher number of small-scale biogas plants or
- in Denmark the chosen avenue was the development of a lower number of medium-larger scale.

Either way, this study acknowledges both approaches by considering the feasibility of small-scale and medium-large-scale biogas power plants.

11.1 Technical results

The technical parameters of the biogas power plant in this study are presented in Table 11-1. These parameters provide an overview of the plant's operation in terms of feedstock used (we have only considered cow manure and silage and not pig slurry or another animal slurry, food waste or fish waste quantities), plant specifications, resulting methane yield, and application of energy.

By operating over a combined 7884 hours, 2,824,427.80 kWh of electricity will be produced during a year (in Scenario 1) and 10,282,985.41 kWh (in Scenario 2), which covers the biogas power plant's own demand and for demonstration, is equivalent to approximately 673 houses and 2,204 houses, respectively. During the operation of the CHP engine, 1,631,043.20 kWh per year (in Scenario 1) and 5,141,492.73 kWh per year (in Scenario 2) would be produced, which has the potential to fuel the heating needs of residential and commercial buildings in Buncrana.

Table 11-1 – Technical characteristics of scenarios under study

	Scenario 1 (500kW)	Scenario 2 (1000 kW)
Herd characteristics		
Herd size (adult cows)	1 500,00	5 350,00
Cow manure yield (ton FW/year)	23 542,50	83 968,25
Specific cow manure (ton/cow)	15,70	15,70
Manure production/head (kg/day)	43,00	43,00
Availability (hours/year)	7 884,00	7 884,00
Methane content (%)	55%	55%
LHV (kWh/nm3)	5,50	5,50
Total biogas production from cow manure (m3/year)	1 005 264,80	3 585 444,28
Crop characteristics		

	Scenario 1 (500kW)	Scenario 2 (1000 kW)
Land available for energy crops	120	240
Grass silage yield (ton FW/year)	2 880,00	5 760,00
ton/ha (*)	24	24
Total biogas production from cow manure (m3/year)	544 320,00	1 088 640,00
(*) (can be between 18 and 28 ton/ha, depending on site)		
CHP specifications		
CHP Efficiency (Electrical)	40%	40%
CHP Efficiency (Thermal) (**)	0,20	20%
Thermal power available biogas (kWe)	1 081,01	3 260,71
CHP engine power (kWe)	432,40	1 304,29
(**) maximum 44% with flue gas at 120ºC		
Methane yield		
Methane yield (m3/year)	852 271,61	2 570 746,35
CO2 yield (m3/year)	697 313,14	2 103 337,92
Biogas (55%) (m3/year)	1 549 584,80	4 674 084,28
Biogas (55%) (m3/h)	196,55	592,86
Energy consumption of the Biogas Power Plant		
% Electrical self-consumption	10%	10%
Electricity consumption (kWh/year)	340 908,65	1 028 298,54
Heat consumption (kWh/year)	73 500,00	0,00
Farm Energy Demand		
Electricity demand (kWh/year) (***)	0,00	0,00
Heat demand (kWh/year) (***)	0,00	0,00
(***) Since the electrical and heat production are in a centralised AD plant, does not serve for any farm self-consumption		
Final Use of Excess Energy		
Final use of excess electrical energy (kWh/year)	2 824 427,80	10 282 985,41
Equivalent electricity consumption households (number houses)	672,48	2 203,50
Exported heat to district heating system (kWh/year)	1 631 043,20	5 141 492,73
Equivalent heat consumption households (****)	13,50	13,50
Total energy production (kWh/year)	3 409 086,50	10 282 985,41
Hours of production	7 884,00	7 884,00
% Self consumption	10%	10%
(****) Assuming 4200 kWh/year per household)		

11.2 Economic results

A comprehensive economic analysis was carried out to investigate the revenues, expenditures, and financial indicators of each of the scenarios over a 15-year life span, as illustrated in Table 11-2.

Table 11-2 – Economical characteristics of scenarios under study

	Scenario 1 (500kW)	Scenario 2 (1000 kW)
Project Revenues		
Electricity consumption price (€/kWh)	0,23	0,23
Feed in tariff (€/kWh) with cogeneration (*)	0,18	0,18
Feed in tariff (€/kWh) without cogeneration (*)	0,13	0,13
Feed in tariff district heating (€/kWh) (**)	0,08	0,08
Sale of exported electricity (€)	552 272,00	1 682 502,07
Sale of exported heat to district heating (€)	136 363,46	415 432,61
Farm electricity savings	0,00	0,00
Farm heat savings	0,00	0,00
Total revenues (€) (***)		**2 097 934,68**
(*) Source REFIT		
(**) assumed		
(***) Does not include revenues from biofertiliser sales, sales of gas to grid, sales of gas as fuel for transportation, sales of CO2 to beverages industries		
Project Expenditures		
CAPEX (€)	2 810 636,97	8 477 854,53
CHP plant cost (€/kWe)	6 500,00	6 500,00
Grass silage cost (€/ton)	35,00	35,00
OPEX (%CAPEX)	10%	10%
Price heating oil (€/kWh) (*)	0,1184	0,1184
Feed in tariff district heating (€/kWh) (**)	0,08	0,08
CAPEX (€)	2 810 636,97	8 477 854,53
OPEX	381 863,70	1 049 385,45
O&M	281 063,70	847 785,45
Grass silage cost	100 800,00	201 600,00
(*) (SEAI - Fuels comparison January 2023)		
Financial Indicators		
EBITDA (€)	306 771,76	1 027 777,60
Price index	2%	2%
Interest rate	4%	4%
NPV at 4% (€)	2 318 531,80	6 993 494,88
IRR (%)	13,56%	13,56%
Payback period (Years)	7,45	7,30

The result of this analysis showed that both scenarios are feasible and profitable for a biogas power plant with a CPH engine of 500 kW and for its upgrade to 1,000 kW, representing feedstock from 1,500 cows and 5,350 cows respectively.

If we assume that the average number of dairy cattle per herd in Carndonagh is 93, as illustrated in Table 5-4:

- 16-17 dairy cow herds would be required to feed a 500-kW centralised CHP engine, located in Carndonagh.
- 58 dairy cow herds would be required to feed a 1000 kW centralised CHP engine, located in Carndonagh.

There are 116 cattle herds in and around Carndonagh, which is more than double required to feed a 1,000 kW centralised CHP engine. So, even though there is potentially more cow manure available than required to feed a 1,000 kW CHP engine, we cannot rely on that it would be feasible to count on 58 farmers to feed the centralised system. That is why we also suggest the use of fish waste and food waste to feed the centralised system, even though we did not consider the quantity of these wastes produced annually in our calculations.

Therefore, we consider it particularly relevant that a feedstock assessment is developed, so that all the potential sources of waste are correctly quantified as well as knowing exactly (and not only theoretically) their biogas potential.

Addressing the most accurate quantity of the different sources of feedstock could have a significant impact on this financial model, by making it even more profitable. More even in the case of feeding a 1,000 kW centralised CHP system, due to economies of scale.

Required capital investment

Even though both scenarios have the same Internal Rate of Return (IRR) the capital investment requirement differs greatly between the two. To implement the full project it would require an investment of more than €8M.

Because of the high capital investment requirement under both scenarios, it is recommended that either scenario would be implemented in two phases;

- **Phase 1** - initial design, implementation of a biogas power plant with CHP engine of 500 kW (€3M).

- **Phase 2** - later upgrade to a CHP engine of 1,000 kW (representing an incremental investment of €5M).

It is very hard to have to have risk capital for projects like this, which reinforces the need for a more accurate financial model that addresses the sources of revenue and costs that are in place.

Ireland's public funds could be a potential source for risk capital, but unfortunately Irish funding mechanisms are not very supportive of biogas projects, at least at the present moment.

Even though the Irish government has allocated a budget of €3M per year for biomethane production projects, this is far from what is needed to reach the national target of 150-200 operational anaerobic digestion plants by 2030.

Although Ireland's National Recovery and Resilience Plan (NRRP) includes some support for renewable energy, biomethane is not included.
The Renewable Heat Obligation (RHO) requires fuel suppliers in the heat sector to ensure a percentage of the fuel they supply comes from renewable sources. The heat produced in the CHP engine using the biomethane produced in the biogas power plant could be applied to meet this obligation for natural gas customers. This seems to be too far of a market-led incentivisation scheme since there is no State support. Even if capital grants of 50% were introduced, the heat cost for customers would still be very high for customers, and that needed a state support of around €50/MWh.

Irish government funding supporting schemes are not, at least for now, something that this project should rely on. There is an important role for ISEC to play here, along with other interested public institutions, private companies, and NGOs, in putting pressure on the government to provide support of around €50/MWh.

EU public funding like HORIZON Europe 2021-27 could be another potential source of funding to support any capital investment needed, in case of a project that could be considered as innovative.

As innovation is highly ranked in these funding schemes, the focus in any application should be on the use of fish waste as feedstock, mixed with livestock feedstock and food waste. Any application should be led by a research institution with expertise in this area such as the Technology Centre for BioRefining and BioEnergy (TCBB)[18] based at NUI Galway.

Even though ISEC has no experience in applying to Horizon Europe applications, we believe that applying to call under the Horizon Europe specific programme – Food, Bioeconomy, Natural Resources, Agriculture, and Environment, could be an excellent way to promote cross-country partnerships with other European Union countries, collaborative design-thinking, and develop a step-further project description that could be very important for the project overall concept, even if the investment is not secured.

In addition to national and EU funding mechanisms, is it worth exploring other types of financing that could support capital investment.

[18] tcbb RESOURCE

Bank loans from ethical banks are one avenue and Triodos Bank is one such bank. Triodos Bank has more than 30 years' experience in the renewable energy sector, with more than 70 deals in their portfolio. Their financial instruments are tailored to longer-term investment cycles and business models (such as this project). They range from equity and mezzanine finance to (senior) debt, with funds such as *Triodos Energy Transition Europe Fund*, *Triodos Impact Mixed Fund*, and other mechanisms that could serve as a source for the required capital investment.

Other ethical banks of note are Alternative Bank Schweiz, APS Bank, Banca Etica, Cultura Bank, Ekobanken, GLS Bank and Merkur.

Of course, other main source of risk capital is private investment through equity. There can be several business owners, mostly the ones that are potential feedstock suppliers, such as farmers, supermarket owners, hotel owners, fishermans, etc. that are interested in investing in the initial capital of investment required in an equity model.

11.3 Environmental impact

A CO_2 balance that fully assesses the CO_2 inputs and outputs of the scenarios under investigation is presented in Table 11-2. The methodology undertaken was a "cradle-to-grave" approach to provide an accurate representation of the net CO_2- savings for each of the biogas power plant scenarios per year.

The two scenarios investigated exhibited a net CO_2 reduction. Significant net CO_2 savings were shown for each of the scenarios under investigation.

Table 11-2. Annual CO2 balance for scenarios under study.

	Scenario 1 (500kW)	Scenario 2 (1000 kW)
CO2 Produced (kg CO2-eq./year)		
Crop production		
Soil ploughing and crumbling	588,00	912,00
Sowing and maintenance	669,00	1 038,00
Sowing	199,00	295,00
Weed control (fuel)	33,00	43,00
Weed control (mineral production)	81,00	131,00
Fertiliser spreading (fuel)	856,00	1 386,00
Fertiliser (mineral production)	11 195,00	18 065,00
Feedstock Collection and Transport		
Harvest	5 950,00	9 600,00
Harvest transport	3 212,00	5 379,00
Silo compaction	1 105,00	1 708,00
Digester feeding (Crops)	2 970,00	4 972,00
Collection and digester feeding (Manure)	922,00	1 014,00

Biogas Production Process		
CO2 Content	826,93	1 289,70
Digestate Disposal		
Transport and spreading of digestate	11 649,00	23 012,00
Total CO2 produced	40 255,93	68 844,70
CO2 reduction (kg CO2-eq./year)		
Do nothing scenario		
Manure storage	513,23	975,14
Manure land application	205,29	390,05
Final Use of Excess Energy		
Electricity exported	2 824 427,80	10 282 985,41
Heat exported to district heating	1 631 043,20	5 141 492,73
Total CO2 reduction	1 252,00	2 106,00
Net CO2 savings (kg CO2-eq./year)	39 003,93	66 738,70

11.4 Social impact

The social positive impact is directly connected with the creation of new local jobs and new local businesses, potentially contributing to the Inishowen region being more attractive for young people, reducing their need to look for job opportunities outside of the region.

The operation and maintenance of the plant would require 12 newly skilled FTEs[19] direct jobs, and we have identified potentially two spin-off businesses;

- a biofertilizer company: a biofertilizer company whose purpose is to deliver the biofertilizer to farmers, municipalities, domestic farmers, and other potential consumers of organic fertiliser.
- a feedstock management company: to manage the supply of feedstock food waste, and fish waste from various sources.

At this stage it is not possible to determine the feasibility of both businesses, however both have the potential to become financially viable and scalable.

12 BUSINESS & GOVERNANCE MODEL

As has been acknowledged before, feeding a biogas power plant only by manure and grass silage at an individual farm scale is not viable.

A biogas power plant has a high capital investment, so ideally, to reduce the investment effort that must be made initially, it is suggested a model where several parties could invest and have

19 Full-time equivalent

the return of their investment. Thus, it is recommended that the biogas power plant can be run as a multi-stakeholder cooperative model.

Multi-stakeholder cooperatives are co-ops that are owned and controlled by more than one type of membership class such as consumers, producers, workers, volunteers, or community supporters. Stakeholders can be individuals, NGOs, businesses, governmental agencies, or even other cooperatives. In the case of this project in particular, the multi-stakeholder cooperative could be owned and controlled by feedstock suppliers (such as farmers, supermarket owners, hotel owners, fishermen), ISEC (including the community champions), and Donegal County Council.

In this case, the ones that own and control the multistakeholder biogas cooperative are the ones that invest in the biogas power plant construction, as well as the operation and maintenance, having shares of the cooperative according to their investment. The stakeholders that contribute with feedstock for biogas production see their feedstock selling fee translated as shares (in a model of redistribution that must be defined).

The same model is applied to ISEC and the community champions, whose coordination, facilitation, and engagement services are translated into shares of the multi-stakeholder cooperative. The potential streams of revenue that result from the produced electricity, heat, biomethane (renewable source of gas), and digestate, return into the multi-stakeholder cooperative, as represented in the Figure 8.

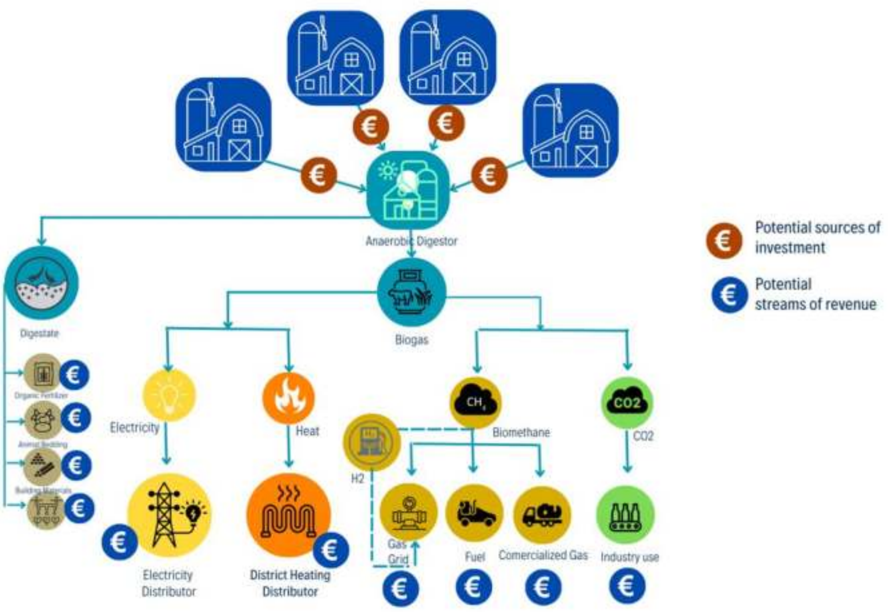


Figure 8 – Representation of potential sources of investment and revenue

Since this multi-stakeholder cooperative is built around a renewable energy project, it can be legally constituted as a Renewable Energy Community (REC). According to the *Terms and*

Conditions for the Second Competition under the Renewable Electricity Support Scheme - RESS 2 (October 2021)[20], a REC means a legal entity:

- which, in accordance with applicable law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located (in the case of SMEs or local authorities) or resident (in the case of natural persons) in the proximity of the RESS 2 project that is owned and developed (or proposed to be owned and developed) by that legal entity;
- the shareholders or members of which are natural persons, SMEs, local authorities (including municipalities), not-for-profit organisations or local community organisations;
- for any shareholder or member (with the exception of "Sustainable Energy Communities" as registered with SEAI), that shareholder or member's participation does not constitute their primary commercial or professional activity;
- the primary purpose of which is to provide environmental, economic, societal or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits;
- in respect of which, each shareholder or member is entitled to one vote, regardless of shareholding or membership interest; and which is, or which has at least one shareholder or member that is, registered as a "Sustainable Energy Community" with SEAI, and all of the above criteria must be evidenced to the satisfaction of the Minister.

Moreover, since the size of this project is lower than 5MW, it can be considered as a community-led renewable energy under the scope of *Renewable Electricity Support Scheme* (RESS)[21]. The advantage of being recognised as a community-led project is being able to get a connection offer on a preferred basis, thereby reducing implementation barriers.

To be deemed as a community-led REC project, under the scope of RESS, this suggested multi-stakeholder cooperative must:

- be part of a "Sustainable Energy Community", like Inishowen SEC. The Declaration of community-led project must identify the SEC to which the project is correlated and the relationship between the applicant and the SEC.
- the majority ownership (51%) must be a Renewable Energy Community having as primary purpose community benefits (environmental, economic, or social) rather than financial profit.
- at least 51% of all profits, dividends, and surpluses are returned to the REC.

Governance-wise, the establishment of a Steering Committee for the development of a multi-stakeholder cooperative, is critical. This could be made up of elected members of the

[20] https://www.gov.ie/en/publication/7f0bb-renewable-electricity-support-scheme-2-ress-2/

[21] https://energycommunitieshub.com/country/ireland/

cooperative shareholders (approx. 8), which could include members of ISEC, the community champions, and the major investor(s).

Many multi-stakeholder cooperatives fail due to a “costly” decision-making structure. However, if the Terms of Reference are robust from the outset, it is possible to govern successfully in the pursuit of shared goals.

In addition to the Steering Committee, we also recommend the establishment of a Principles Committee, a Technical Committee, and a Stakeholder Advisory Group.

The Principles Committee is responsible for decision-making with regard to principles and standards-setting, as well as the provision of views, advice, and recommendations on the operation of biogas cooperative to the Board, other cooperative committees, and the cooperative secretariat. The Principles Committee must be represented equally by civil society and commercial interests.

The role of the Technical Committee is, amongst other things, to provide advice to the Steering Committee on technical and scientific functions, including but not limited to biogas cooperative accreditation criteria and methodologies. The Committee roles must be filled by specialist expertise across the disciplines.

Finally, the Stakeholder Advisory Group provides a platform for stakeholder input and advice to support the work of the Principles Committee in the development, implementation, and maintenance of the cooperative principles and related documents. This Committee is the main platform for stakeholder engagement as these stakeholders don’t have cooperative shares. The output for the stakeholders on this Committee is to be able to engage with the operation of the project and share views and perspectives around it.

Even though a multi-stakeholder cooperative could potentially be the most appropriate model to leverage a renewable energy project led by the community, the fact is that engaging several different stakeholders to invest in a biogas power plant is not an easy task, and can take a long time to be developed.

For this reason, we acknowledge the importance of addressing other potential business models that can be more easily executed and are not attached to the engagement of several stakeholders at the same time.

Thus, the following strategy regarding the potential business model can be followed:

1. **Option 1** - The biogas power plant is owned by a small group of shareholders: the main capital investor (which could be feedstock supply business owners, as for example: farmers, supermarket business owners, and hotel business owners, or fishermen), along with ISEC. In this model, ISEC shares are addressed as part of the payment for their coordination/facilitation services provided to the project. In this model the feedstock supply:

a) is ensured by a *Feedstock Suppliers Co-Op*, whose shareholders are feedstock suppliers (such as farmers, restaurant owners, supermarket owners, hotel owners). In this case the variations in the feedstock quality could be evaluated and a standardised price per tonne is established to be paid to the Co-Op.

b) is directly provided by each feedstock supplier, having the disadvantage of no existing standardised price.

2. **Option 2** - The biogas project is owned by an impact venture capital associated with an EPC contractor (biogas power plant technology supplier), owning shares according to their agreement. In this model, ISEC also owns shares as part of the payment for their coordination/facilitation services provided to the project. In this model the feedstock supply:

   a) is ensured by a *Feedstock Suppliers Co-Op*, whose shareholders are feedstock suppliers (such as farmers, restaurant owners, supermarket owners, hotel owners). In this case the variations in the feedstock quality could be evaluated and a standardised price per tonne is established to be paid to the Co-Op.

   b) is directly provided by each feedstock supplier, having the disadvantage of not existing a standardised price.

3. **Option 3** - Or the project be majorly owned by an already existing REC, such as CommunityPower.ie, which capital invested is translated as shares (owning at least 51% of shares), along with ISEC. Also, in this model, ISEC shares are addressed as part of the payment for their coordination/facilitation services provided to the project. In this model, the project can be considered as a community-led REC. In this model the feedstock supply:

   a) is ensured by a *Feedstock Suppliers Co-Op*, whose shareholders are feedstock suppliers (such as farmers, restaurant owners, supermarket owners, hotel owners). In this case the variations in the feedstock quality could be evaluated and a standardised price per tonne is established to be paid to the Co-Op.

   b) is directly provided by each feedstock supplier, having the disadvantage of not existing a standardised price.

13 KEY-SUCCESS FACTORS

The most critical aspect for the successful implementation of the community-led biogas project is community awareness and engagement. A community-led biogas project has the potential to trigger the disruption of a centralised energy system and lead the transition to a low-carbon future for the Inishowen peninsula. A community-led biogas project also can lead to many societal positives including increased acceptance of renewable energy developments, improved awareness of renewable energy technologies and issues, as well as more conscious behaviours.

There can be mixed public reaction to the implementation of biogas power plants, such as the plant at Ballyfeard, located in Cork, which was subject to strong community opposition. In contrast, Lissarda biogas power plant had virtually no opposition.

To reduce the risk of public misunderstanding, it is recommended that a strategic communication and engagement plan is executed during the pre-planning stage, well in advance of any development works. Personalised engagement with the local community to better understand any potential concerns in a transparent and integrative way is key to gaining buy-in and stimulating enthusiasm amongst the community.

Tailored initiatives delivered to influential stakeholder groups in the region, such as the farming community, would be important. The objective of these targeted campaigns is to create awareness of the biogas power plant but more so to inspire these interested parties in becoming members of the multi-stakeholder cooperative, gathering momentum at each stage of the process.

13.1. Community Champions

Engaging community champions is key to community acceptance. Community champions, when centrally coordinated, by for example the ISEC, can play a positive role in creating awareness and facilitating knowledge-sharing thereby dissolving misconceptions and removing barriers to change.

Community champions play even a more important role with farmers, since farmers, are more resistant to engaging on “new” solutions, since they have been suffering a major pressure to maintain their businesses financially sustainable, this is due to two main factors:

- the targets established in Ireland’s Climate Action Plan; and
- the increased costs of production, being very resistant towards these innovative solutions and models.

It is very useful to upskill community champions on project and financial management, as well as community engagement skills. Moreover, it is useful that community champions can involve community members in the multi-stakeholder cooperative steering group, requiring the ability to address the benefits of being part of a cooperative, as well as the need for resilience as planning and implementing a project of this scale can take time.

13.2. Partnerships

Another critical aspect for the success of this project is the establishment of mutually beneficial partnerships. In this case, ISEC would play a facilitation role, coordinating engagement with regional and national public institutions, industry associations, companies, academia, and civil society organisations.

Therefore, we recommend the active collaboration, and the establishment of partnership agreements, specifically for this project implementation, with public and civic institutions with direct role on the definition of policies, funding schemes, infrastructures strategies, such as Inishowen Co-Op, SEAI, Gas Network Ireland, EirGrid, Derry City & Strabane District Council, Donegal County Council, North-West Regional Energy Agency, North West Gateway (Derry-Letterkenny), Western Development Commission, Teagasc, DAFF Climate Change and Bioenergy Policy Division, IrBEA - Irish Bioenergy Association, and also Renewable Gas Forum Ireland.

Also, important would be the establishment of a partnership protocol with some of the main research institutions that are developing research studies on biogas, such as Technology Centre for Biorefining and BioEnergy (TCBB), and Dairy Processing Technology Centre of Limerick University.

Creating opportunities for knowledge-sharing and peer-to-peer learning between other energy communities across Ireland, such as Dingle Peninsula Hub, Community Power (CRES), Energy Community Tipperary Cooperative, Aran Islands Energy Cooperative, Tait House Community Enterprise, Claremorris, and Western District Energy Cooperative, is also key. We also suggest the ISEC actively seek out collaboration opportunities with potential EU partners (mainly for EU funding purposes), such as: Stichting Duurzame Projecten Loenen (DPL (Netherlands), EnerGent (Belgium), Gemeente Apeldoorn (Netherlands), Kamp C (Belgium), RESCoop.eu (Germany).

14 PHASES OF DEVELOPMENT

As discussed earlier in this document, we recommend a phased approach to this project implementation:

- Phase 1 – operationalization of a 500-kW biogas power plant
- Phase 2 - operationalization of a 1000-kW (1MW) biogas power plant

We additionally consider a transition phase, between the 1st and 2nd phase, since we must move progressively from a 500-kW biogas power plant and a 1000-kW biogas power plant.

In the table below, there is a resume of the most important issues in each of these phases.

Table 14-1 – Resume of the most important issues on each phase of development of the biogas project

Category	Phase 1	Transition Phase	Phase 2
Biogas plant power capacity	500 kW	500 kW→1000 kW	1000 kW (1MW)
Sources of feedstock	Cow slurry, pig slurry, grass silage, food waste from restaurants, hotels, tanneries industries, food waste from waste management operators.	Cow slurry, pig slurry, grass silage, food waste from restaurants, hotels, tanneries industries, food waste from waste management operators.	Cow slurry, pig slurry, grass silage, food waste from restaurants, hotels, tanneries industries, food waste from waste management operators, fish waste, waste water, marine algae.
Business & Governance Model	1.Feedstock supplier Private owned company; 2.Impact investor/EPC contractor investor; 3. REC (51% shares) and the rest from other community residents. Plus, a Feedstock suppliers Co-Op for feedstock supply or feedstock suppliers sell feedstock directly to the biogas power plant.	1.Feedstock supplier Private owned company; 2.Impact investor/EPC contractor investor; 3. REC (51% shares) and the rest from other community residents. Plus, a Feedstock suppliers Co-Op for feedstock supply or feedstock suppliers sell feedstock directly to the biogas power plant.	1.Feedstock supplier Private owned company; 2.Impact investor/EPC contractor investor; 3. REC (51% shares) and the rest from other community residents. Plus, a Feedstock suppliers Co-Op for feedstock supply or feedstock suppliers sell feedstock directly to the biogas power plant.
Sources of investment	Equity/bank loans ISEC (shares are constituted as part of the payment for their coordination/facilitation services provided to the cooperative Existing REC (for example CommunityPower.ie) Grant/Fund.	No need for investment at this stage	Equity/bank loans ISEC (shares are constituted as part of the payment for their coordination/facilitation services provided to the cooperative Existing REC (for example CommunityPower.ie) Grant/Fund (probably HORIZON 2030) Profits, dividends, and surpluses, derived from the project.
Sources of revenue: Sale of electricity to the public electricity company	Yes	Yes	Yes
Sources of revenue: Sale of heat	Yes directly to building owners (mainly hotels, spas, and swimming pools) and through PPA[22] agreements	Yes directly to a district heating distributor located in Buncrana	Yes directly to a district heating distributor located in Buncrana
Sources of revenue: Sale of gas	Yes (if it is there is a high intensive industrial consumers of gas through PPA agreements	Maybe If the costs of transporting gas by road from Co Donegal to Co Kildare are not very high and the risk/reward balance is there. Or, if the gas grid pipeline connecting Donegal to Strabane-Derry is operational. Plus, if there is an increase/improvement feed-in-tariff related to selling gas to the public gas grid. This will require a re-evaluation of the feasibility study.	Maybe If the gas grid pipeline connecting Donegal to Strabane-Derry is operational. Plus, if there is an increase/improvement feed-in-tariff related to selling gas to the public gas grid. This will require a re-evaluation of the feasibility study
Sources of revenue: Sale of digestate (biofertilizer)	Yes (Low revenue)	Yes (Medium revenue)	Yes (Long revenue)
Sources of revenue: Sale of CO2 to industries	No	Maybe	Yes
Sources of revenue: Revenues from disposal of digestion substrates	Yes	Yes	Yes
Sources of revenue: Reduction of costs for disposal of agricultural residues	Yes	Yes	Yes

22 PPA - Power Purchase Agreement

Category	Phase 1	Transition Phase	Phase 2
Sources of revenues: credits of carbon emission reduction	No	Maybe	Yes
Timeline for full operation	1,5-3 years	3-5 years	5-7 years

15 ROADMAP & ACTIONS TOWARDS CATALYST PROJECT IMPLEMENTATION

To implement this biogas project, several key-activities must be taken. The main key activities are outlined in the following table.

Table 15-1 – Biogas project development action plan

Actions description	Responsibles	Timeline
Identify a community champion for the Biogas project implementation	ISEC	Until June 2023
Conduct community awareness sessions around biogas	ISEC; Community Champion	Until September 2023
Determine the most precise quality & quantity of feedstock availability to be secured by the potential farmers and other alternative feedstock suppliers, such as food waste suppliers and fish waste suppliers (including a surveying of farming and fishing communities).	Community Champion; ISEC	Until October 2023
Determine the legal impact of the feedstock being used. Identifying the types of feedstock to be supplied will determine this.	Community Champion; ISEC; Inishowen Co-Op	Until October 2023
Support the due diligence process to analyse all the potential revenue streams on products produced by CHP, direct biogas sales, and other revenue options (carbon dioxide, waste management, digestive, and indirect benefits (carbon credits).	ISEC (with the support of a consultancy partner); Community Champion	Until November 2023
Engage potential farmers to develop the project in a cooperative model (feedstock supply cooperative)	ISEC; Community Champion (facilitation)	Until November 2023
Establish a multi-stakeholder cooperative model pre-agreement – Feedstock Suppliers Cooperative (if that is the case).	ISEC; Community Champion; Feedstock Suppliers Cooperative	Until March 2024
Create feedstock supply agreements.	Biogas power plant investors; Feedstock suppliers	Until January 2024
Engage potential investors to develop the project in a private owned model or multi-stakeholder cooperative model	ISEC; Community Champion	Until February 2024
Support the due diligence process to select the most appropriate site for the project. Confirming locations of feedstock to be supplied and ascertaining transport requirements is important as well as availability of grid connection and potential uses for heat in CHP models and also identifying any potential planning restrictions etc.	ISEC; Community Champion; Biogas power plant investors; Inishowen Co-Op;	Until January 2024
Support the due diligence process with Northwest Energy Agency, Northwest Region Cross Border Group, Co. Donegal Council, IrBEA, SEAI, and ATU Donegal Letterkenny to address the issue concerning the existence of a district heating system in the Donegal region, including the analysis of the feasibility of a district heating system located at Buncrana. And address the need for more supportive schemes to fund biogas production to inject renewable gas in the grid and heat, also.	ISEC; Community Champion; Biogas power plant investors;	Until June 2023
Establish formal partnerships with potential Irish partners: IrBEA - Irish Bioenergy Association, Technology Center for Biorefining and BioEnergy (TCBB), Dairy Processing Technology Centre of the Limerick University, Community Power (CRES), Energy Community Tipperary Cooperative, Aran Islands Energy Cooperative, Tait House Community Enterprise, Claremorris and Western District Energy	ISEC; Community Champion; Biogas power plant investors	Until June 2023

Actions description	Responsibles	Timeline
Cooperative.		
Establish formal partnership with potential EU Partners (mainly for EU Funding projects): Stichting Duurzame Projecten Loenen (DPL (Netherlands), EnerGent (Belgium), Gemeente Apeldoorn (Netherlands), Kamp C (Belgium), RESCoop.eu (Germany).	ISEC; Community Champion; Biogas power plant investors;	Until June 2023
Support the due diligence process with Northwest Gateway (Derry-Letterkenny) and Gas Networks Ireland to address the issue of the gas pipeline connection, securing the existence of a gas grid node connection at Strabane-Derry.	ISEC; Community Champion	Until November 2023
Support the due diligence process with the public Electricity Supply Board / Electric Ireland to address the issue of electricity connection and awarded feed-in-tariff. Alternatively, establish PPA agreements with private business owners.	ISEC; Community Champion	Until November 2023
Support the procurement and selection of the most suitable biogas plant technology and supplier (suitable for feedstock type and quantity, locally available and certified, where good engineering practices are followed), preferably an EPC contractor.	ISEC (with the support of a consultancy partner); Community Champion	Until January 2024
Undertake an updated version of the feasibility study that takes into consideration all the specifics of the project, including a breakdown of all the costs/investment required and all potential revenue streams.	ISEC (with the support of a consultancy partner)	Until April 2024
Risk assessment analysis (including Environmental Impact Assessment if required).	ISEC (with the support of a consultancy partner) and the EPC Contractor.	Until April 2024
Support the completion of all the required licences and permits.	ISEC (with the support of a consultancy partner) and the EPC Contractor.	Until January 2024
Secure project funding/investment.	ISEC (with the support of a consultancy partner)	Until March 2024
Secure landowner agreement	Biogas power plant investors; Site owner; ISEC	Until January 2024
Complete feedstocks supply final agreement, off-take agreements, EPC Contract, O&M contract)	Biogas power plant investors; EPC contractor	Until April 2024
Rollout of the necessary skills related to biogas plant operation	ISEC (with the support of a consultancy partner); EPC contractor	Until May 2024
Construction of the biogas plant.	EPC contractor	Until November 2025
Commission the biogas plant.	EPC Contractor; Biogas power plant investors;	December 2025
Operations and maintenance of the biogas plant.	EPC contractor; Biogas power plant investors;	Until 2038
Upgrade the biogas plant - Phase 2.	EPC contractor; Biogas power plant investors;	Until April 2026
Create a learning living lab around the biogas plant that serves the community on topics related to energy systems decentralisation by farmers, sustainable agriculture practices.	ISEC (with the support of a consultancy partner)	Until March 2027
Continuous evaluation of the project development evolution	ISEC (with the support of a consultancy partner)	Until 2038

16 EVALUATION AND DISSEMINATION OF RESULTS

ISEC, in their coordination, facilitation and "project management" roles must continuously monitor and evaluate the impact of the biogas project as it develops at the local and regional levels, through specific metrics.

We recommend issuing an annual report detailing policy decisions, best practices, insights, and lessons learned, as well as practical guidance. This report should be promoted among all Inishowen community members, serving as a way to disseminate and expand the biogas project concept and facilitate the uptake of other biogas projects.

As a key dissemination vector for this project's outcomes, it is suggested the organisation of an annual event to present the annual report.

17 CONCLUSIONS & RECOMMENDATIONS

Throughout this document we have outlined the importance of pursuing the implementation of a community-led biogas power plant, regardless of the existing challenges.

More than just a decarbonisation project, a community-led biogas project has the most potential to foster relationships between the Inishowen Sustainable Energy Community and the local community, where both collaborate to influence and shape the ISEC's vision for Inishowen.

Even if it is challenging to build a multi-stakeholder cooperative model to govern the biogas power plant, this biogas project is an ideal project to launch a REC and develop a multi-stakeholder cooperative model, having the advantage of being a waste-base project that requires the waste supplier from different stakeholders.

If based on a multi-stakeholder cooperative model, the economic benefits related to the transition to biogas, produced and used locally, reinforcing the Inishowen community's ability to secure its own energy and reduce its carbon footprint, while contributing to Inishowen rural development in Inishowen.

Compared with all the other renewable energy catalyst projects mentioned in the strategic plan, the biogas project is the one that is most viable in the medium-long term for the Inishowen region (subject to several requirements listed along with this feasibility study).

Financially, this type of project can provide a return for the community investors whilst also providing employment opportunities in the form of asset management positions and operations and maintenance positions, as well spin-off small-scale businesses, such as the biofertiliser business and feedstock management-related enterprises are also possible.

Developing a biogas power plant project in two phases: one first phase where the CHP engine has 500 kW and a 2nd phase where the CHP engine has 1,000 kW, it is a strategy that allows for showcasing the technology without having to make the full investment upfront and serves as a reference for other Sustainable Energy Communities.

Both scenarios are feasible, even though some initial capital investments were not considered, as well as most of the streams of revenue due to the by-products generated in the digester of the biogas power plant. Aside from this, this biogas project should be promoted as part of a drive for sustainable tourism on the Inishowen Peninsula and an integral part of Inishowen Sustainable Energy Community’s development. As it is already established as a Sustainable Energy Community (SEC) and is an active role in terms of SEAI grants, Inishowen community-led biogas project is well positioned to qualify as a Renewable Energy Community (REC).

We do not underestimate how challenging it will be to bring this project to life - its viability is dependent on several technical and financial requirements that are not an easy fix, such as the lack of a gas pipeline network and the lack of a district heating system.

This lack of proper infrastructure, along with the lack of proper policy framework, financial support, and regulatory framework to govern and fund the development of bio-methane, will be a challenge. ISEC could have an active role in overcoming these challenges by collaborating with other public and private organisations to address the main issues that may constrain the development of this project and other community-led biogas projects. This active role could include contributing to:

- the development of a district heating system, through planning policy, stakeholder engagement, and involving other public buildings as anchor loads.
- the process related to the gas pipeline connection between the biogas production utility and the existent gas grid node connection at Strabane-Derry.
- the reduction of commercial rates, applied to a biogas community-led project, at a Council level.
- a more favourable feed-in-tariff for electricity and gas applied to biogas projects in Ireland.
- more funding mechanisms available to fund small-scale and medium-large-scale biogas projects.
- reducing the number of shareholders needed for a project to be deemed as a community-led project, mostly in rural areas.

Aside from this, ISEC's major role is related to facilitating and coordinating all the actions required to explore the potential for erecting a biogas power plant in the Inishowen area, mainly all the actions concerning creating community awareness and engagement around the community-led biogas project.

The biogas project could most surely serve as the main catalytic project to:

- Enhance the community population's access to alternative income-generation activities and support services, that promote rural employment and market-access.
- Enhance more reliable decentralised energy production systems.
- Unlock the potential in people to overcome their challenges, moving them towards a position of empowerment, while thriving together.

For these reasons we recommend that ISEC puts its best effort towards this project development.

REFERENCES

[1] CSO (2016), *Population Census Report, 2016*
Available: https://www.cso.ie/en/census/census2016reports/

[2] Government of Ireland (2021), *Climate Action Plan 2021*.
Available: https://www.gov.ie/en/publication/6223e-climate-action-plan-2021/

[3] Persson, Per Olof, et al. *Cleaner Production-Strategies & Technology for Environmental Protection*. Stockholm: KTH-Royal Institute of Technology, Industrial Ecology, 2011.

[4] NNFCC The Bioeconomy Consultants. *What is digestate? Anaerobic Digestion.* [Online] Available: http://www.biogas-info.co.uk/what-is-digestate.html.

[5] CSO (2016), *Agriculture Census Report*, 2020
Available: https://www.cso.ie/en/releasesandpublications/ep/p-coa/censusofagriculture2020detailedresults/

[6] C. Buckley *et al.*, Teagasc (2021), Teagasc National Farm Survey 2021
Available: https://www.teagasc.ie/media/website/publications/2021/Teagasc-National-Farm-Survey-2020.pdf
[7] C. Buckley *et al.*, "Teagasc National Farm Survey 2021 Sustainability Report," 2022. Available: https://www.teagasc.ie/media/website/publications/2022/2021-Sustainability-Report.pdf
[8] Teagasc (2020), *Bovine Manure Management, Application, and Storage Practices in Ireland, 2021.* Available: https://www.teagasc.ie/media/website/publications/2020/Manure-Management-Practices-Report.pdf

[9] EPA (2022), Food Waste Statistics, EPA, 2022.
Available: https://www.epa.ie/our-services/monitoring--assessment/waste/national-waste-statistics/food/

[10] Failte Ireland (2022), Inishowen Peninsula Destination and Experience Development Plan, 2022. Available:
https://www.failteireland.ie/FailteIreland/media/WebsiteStructure/Documents/Wild%20Atlantic%20Way/inishowen-dedp-(dl)_1.pdf

[11] Kelessidis, A. and Stasinakis, A. *Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries*, PubMed, 2012.
Available: https://pubmed.ncbi.nlm.nih.gov/22336390/

[12] EPA (2019*), Food Loss and Waste from Farming, Fishing and Aquaculture in Ireland Report*, 2019.
Available: https://www.epa.ie/publications/research/waste/Research_Report_410.pdf

[13] A. Mshandete, *et al.* (2004) Anaerobic batch co-digestion of sisal pulp and fish waste, *Bioresource Technology*, Vol. 95, Issue 1, October 2004, Pages 19-24.
Available: https://www.sciencedirect.com/science/article/abs/pii/S0960852404000331

[14] Duffy, P., Black, K., Fahey, D., Hyde, B., Kehoe, A., Murphy, J., Quirke, B., Ryan, A.M., Ponzi, J., 2020. Ireland's National Inventory Report 2020. Greenhouse Gas Emissions 1990-2018. Johnstown Castle Estate, Wexford.

[15] Codema & BioXL (2016), A Guide to District Heating in Ireland.