Feasibility Study on Anaerobic Digestion in South Kerry

Final Report

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AD: Anaerobic Digestion

CBM: compressed biomethane

CH_4: methane (Biomethane)

CNG: compressed natural gas

CO_2: Carbon dioxide

CO_2 eq.: carbon dioxide equivalent

DM: dry matter

ED: electoral district

EMP: Energy Master Plan

GWh: gigawatt-hour or a million kWh

GW: gigawatt capacity

kWh: kilowatt-hour or a thousand Wh of energy

kW: kilowatt capacity

kWe: kilowatt electrical capacity

IRR: Internal Rate of Return

LCOE: Levelised Cost of Energy

MSS: Multi Species Swards

MWh: megawatt-hour or a thousand kWh

MWe: megawatt electrical capacity (1,000 kWe)

Nm^3: normalised cubic meter

NPV: Net Present Value

PRG: Perennial Rye Grass

RE: Renewable energy

RES-e: electricity produced from renewable energy sources

RES-heat: Heat produced from renewable energy sources

tCO_2: tonne of CO_2

t_{DM}: tonne of dry matter

t_{VS}: tonne of volatile solid

tWM: tonne of wet matter

tFM: tonne of fresh matter

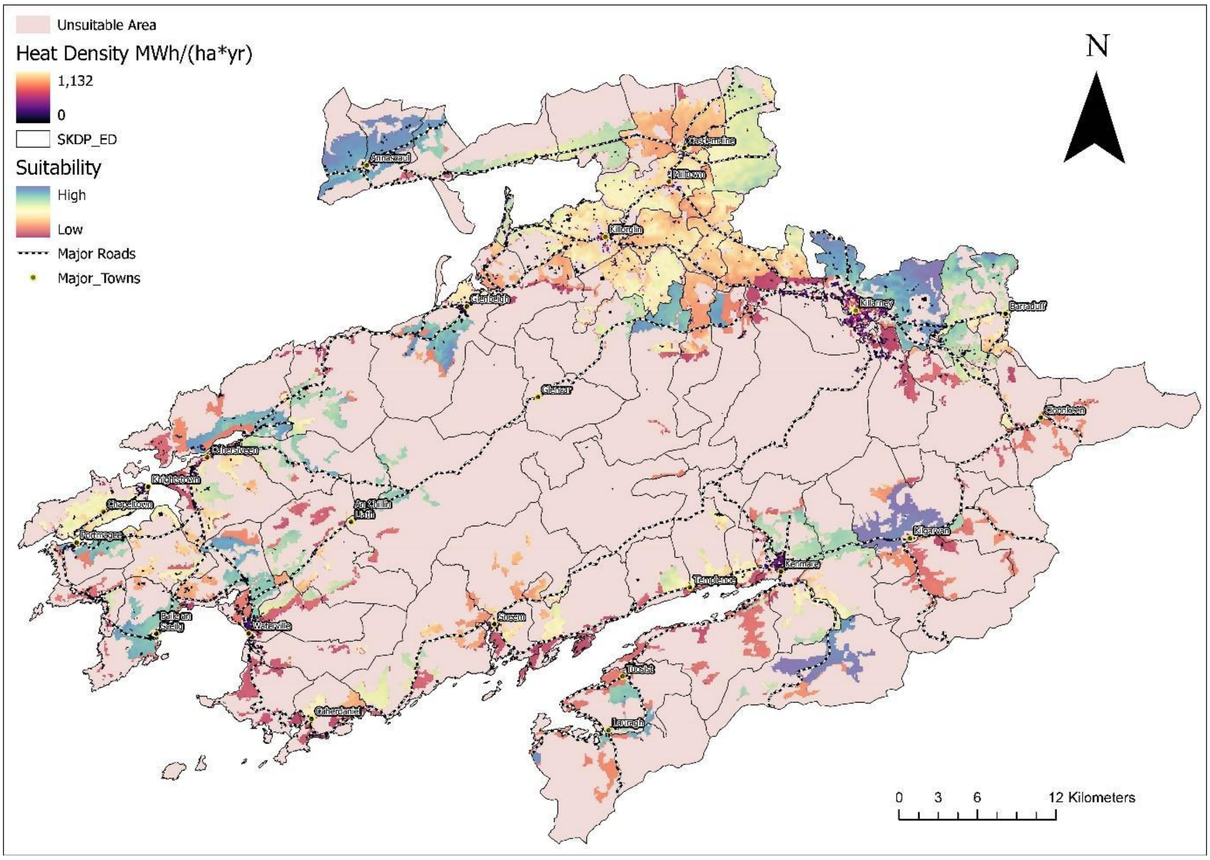
TWh: Terawatt-hour, or a billion kWh

Summary

The overall objective of this study commissioned by the South Kerry Development Partnership is to assess the feasibility of developing anaerobic digestion (AD) in the region and its ability to meet the energy needs of the region in a sustainable manner while providing economic opportunities for farmers. The specific objectives of the feasibility study included a comprehensive assessment of the biomass resource available in the region, a multi-criteria spatial analysis aiming to identify areas suitable for the development of AD projects in the region, a review of the key considerations for the sustainable development of AD projects. In addition, the greenhouse gas emissions (GHG) impact of farm-based AD projects along was assessed along their value chain together with the potential additional income for farmers arising from practices leading to GHG reductions. Finally, the study also reviewed potential models for AD feedstock supply agreements and explored elements of an agri-environmental pilot scheme to support the development of AD in the region.

A detailed assessment of AD feedstocks from agricultural, municipal and industrial origins was conducted in order to determine the technical potential of biomethane in the South Kerry region. Overall, the above analysis has identified a range of AD feedstocks for which the estimated quantity available is up to 83 thousand tonnes in dry matter. The total biomethane potential has been estimated at 23 million Nm3, with an energy content close to 230 GWh/yr. This would be sufficient to meet the needs of up to 11 medium-sized AD plants (20 GWh/yr biogas production) installed in a farm setting, or up to 6 larger (40 GWh/yr), centralised plant more likely to be in an industrial setting. Generally, it is clear from the above analysis that agricultural feedstocks will play an important role in the production of biogas in the study area, with grass silage representing at circa 85% of the total potential and slurry/manures another 15%. While with a much smaller potential (1% of total potential), municipal and industrial feedstocks in the region would also play a part, as they typically attract a gate fee and contribute positively to the viability of an AD project.

The next step in the feasibility study was to conduct a spatial analysis aiming to identify areas most suitable for the development of AD projects, considering multiple criteria including factors such as feedstock availability, energy demand density, proximity to roads and refuelling stations, etc. as well as constraints such as certain land covers, areas liable to flooding, slopes over 15 degrees, settlements, protected and designated lands.

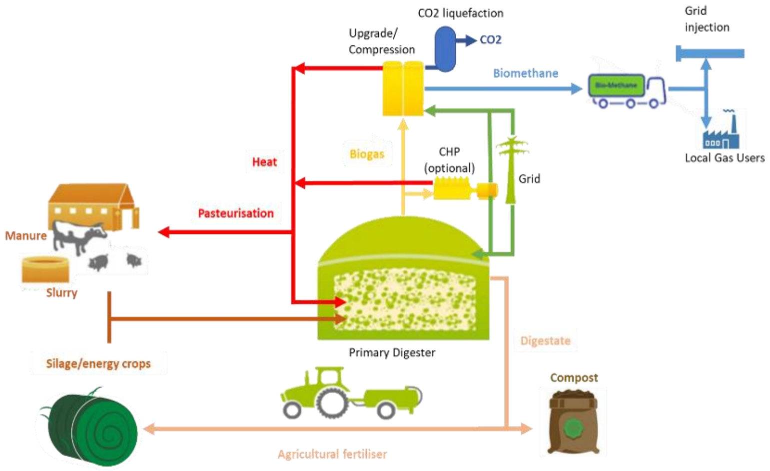


All lands outside of 'constrained areas' were scored for their suitability to develop an AD project and the results of the spatial multicriteria analysis show a number of hotspots for AD development, as per the map above, including: areas to the North/North-East/East of Killarney; areas to the East and South of Kenmare; the Western side of the region, the surroundings of Annascaul; areas around Killorglin, Milltown and Castlemaine. Generally, these areas combine feedstock availability, low population density, access to a suitable road network, at a reasonable distance from areas with a higher density of energy usage, and limited planning and environmental constraints. In addition, planning considerations were reviewed for AD projects that are farm-based and primarily using agricultural feedstocks, or projects that are larger-scale and utilise a combination of industrial, municipal and agricultural feedstocks (typically co-located with industrial sites or on brownfield sites in rural areas). This confirms the approach taken with the spatial analysis where the assessment of an AD project proposal would consider proximity to the point of demand (for the AD outputs) and source materials (feedstocks), ability to accommodate increased traffic flow on the road network (for the import of feedstocks and export of AD products), impact on residential or visual amenities alongside other material planning considerations.

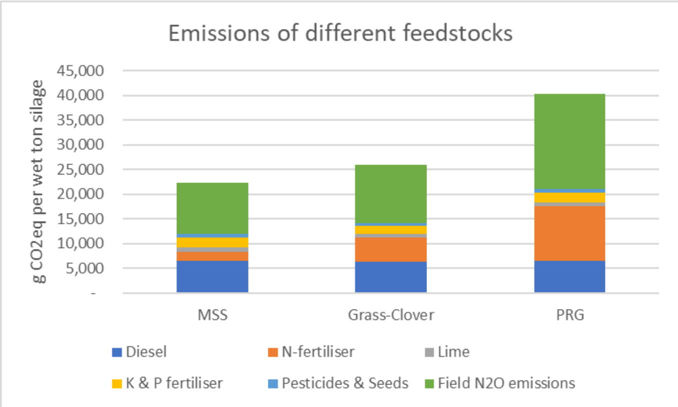
Key considerations for the sustainable development of farm-based AD in South Kerry pertain to three issues principally: the procurement of feedstocks (silage and slurry), nutrient management and greenhouse gas emissions. One scenario explored in the potential analysis for silage as an AD feedstock was based on increasing yields from existing grassland by an average of 4 tDM/ha/year above current cattle requirements, by building soil fertility to optimum levels and then use digestate as a biofertilizer to maintain yields. Substituting perennial ryegrass with multi-species swards (MSS) or a grass-clover mix increases significantly the sustainability of the silage production system by reducing the demand in synthetic fertiliser and pesticides, as well as improving soil health and biodiversity. The other scenario explored focused on the anticipated reduction in cattle herd size associated with the Carbon Budget adopted by the Irish government for agriculture, with less emphasis on productivity and more focus on implementing environmental measures for soil health, carbon sequestration, water protection, etc.

While slurry is a low energy density feedstock, it's treatment in an AD plant has many positive environmental impacts, compared to spreading raw slurry, including reduced pathogen load to the environment, less odour emissions, significant reduction in methane emissions from slurry, and highly plant-available nitrogen in the digestate. The recast Renewable Energy Directive's Sustainability Criteria will require a 80% greenhouse gras reduction from biomethane by 2026, effectively mandates the use of a significant proportion of slurry (40-55%) together grass silage. The Animal By-Products (ABP) regulations will apply in most cases as slurry will be imported from several farms, and imposes strict technical (pasteurisation, storage, etc.) and management requirements which impact the capital and operational costs of an AD plant.

As fossil-based fertilisers become more expensive, good management of the nutrient content of digestates will become important as a cost-saving measure for farms. Digestate is also packed with trace elements and potential animal and plant pathogens are significantly reduced, and in most cases are eradicated, due to the requirement to pasteurise the feedstock as required by the ABP regulations. Managing the digestate is an important aspect of an AD project development and establishing a nutrient management plan in conjunction with farmers in the vicinity of the plant is an essential part of planning the project. Industry best-practice application techniques that minimise the risk of nutrient run-off and water contamination, as well as reduce ammonia/nitrogen oxide emissions, should be followed.

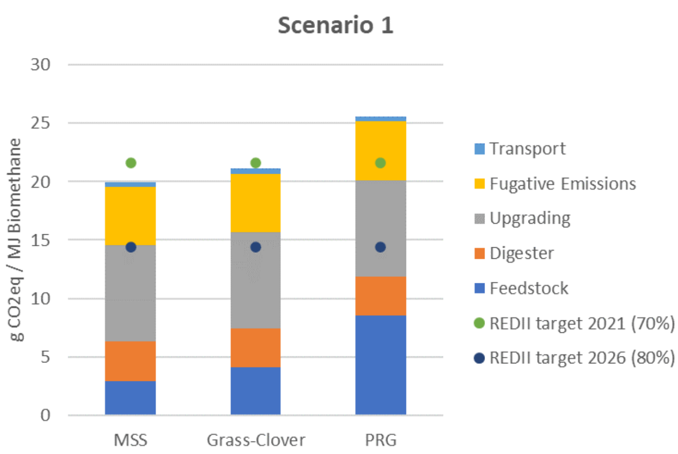


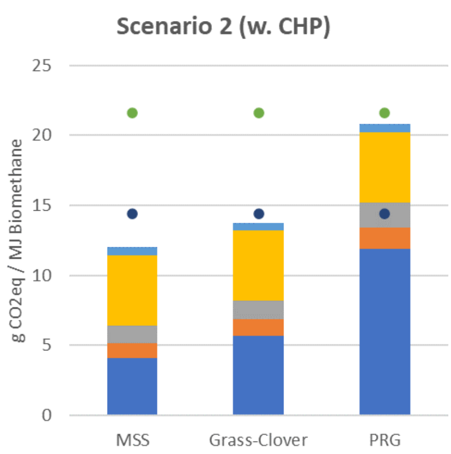
A detailed assessment of greenhouse gas (GHG) emissions along the value chain of a standard farm-based AD project (as illustrated herewith) was conducted, considering the net emissions associated with producing and supplying the feedstock mix (grass silage and slurry) to the plant, the potential for carbon sequestration in the grassland soil, the GHG emissions avoided by substituting fossil fuels with the biomethane produced. The latter includes the energy inputs to the AD system and final use of the biomethane. The modelling approach applied is consistent with the REDII directive and the IPCC's methodology.



Three types of grass silage feedstocks were evaluated: a) perennial ryegrass (PRG) as representative of the typical existing farm system used in Ireland; b) a grass-clover (GC) mix and c) a multispecies sward (MSS), considering varying levels of nitrogen input and yields. The lower nitrogen requirement of GC and MSS results in significant reductions (35% and 45% respectively) in GHG emissions associated with the manufacture of synthetic nitrogen and with N_2O emissions. Emissions could be further reduced if tractors were switched from diesel to biomethane. Soil carbon sequestration can be built up over time in well-managed grassland where AD digestate is applied and, together with the introduction of hedgerows, will have a significant impact in terms of GHG reductions, soil health, water conservation and biodiversity on farms.

In this case study project, the AD plant uses a 45%-55% slurry-grass feedstock mix to produce a net biomethane output of 20 GWh/year. The graph below compares the balance of GHG emissions in CO_2 equivalent per MJ of biomethane produced with the three grass silage types, benchmarked against the requirements of the REDII directive for 2021 and 2026 (70% and 80% reduction on fossil fuel comparator respectively), for an AD system with combined heat & power unit (scenario 2) and without (scenario 1). This analysis shows the importance of using low-synthetic nitrogen input grass silage mixes and reducing the emissions associated with the electricity use of the biogas upgrade plant by adding a CHP unit, to achieve the stringent REDII requirements for 2026. It is worth noting that if the if the CO_2 separated from the biogas when it is upgraded to biomethane is captured and used to replace the fossil fuel based CO_2 used in industrial food and beverage applications, there is the potential to significantly improve the GHG balance of the proposed AD system and possibly move them in negative emission territory.





In an AD plant using silage from grass-clover and MSS swards (requiring significantly less nitrogen), there could be an excess of circa 200kg of nitrogen per ha in the digestate which could be spread on other farmland where it would substitute mineral nitrogen. In addition to providing a revenue stream from the sale of digestate, this could result in additional GHG reductions of one tonne of CO_2 eq. per ha. If the development of AD is conducted in the context of farms reducing the size of their herds, there is the added impact of the concomitant reduction in enteric fermentation emissions, equivalent to -3.4 tCO_2/year per dairy cow, -2.1 tCO_2/year per suckler cow, or -2.4 tCO2/year per male cattle 1-2 years old.

All in all, there are a number of environmental services that could be attributed to farmers adopting best practices in the production and supply of agricultural feedstocks to an AD project, including switching from perennial rye grass to a grass-clover mix or MSS, substituting synthetic nitrogen with digestate as a biofertilizer, increased carbon sequestration under grassland, and the planting of hedgerows. For an average beef farm of 31 ha of productive grassland dedicating 50% to growing MSS and planting 0.75 ha of hedgerows, this could result in over 100 tCO_2 of carbon credits per year, which could result in an additional income of €5000/year for the farmer. In a scenario whereby there is a concomitant 50% cattle herd reduction, an additional 47 tCO_2 emissions would be avoided on the farm. With European carbon market average price forecasted to grow to €100[1] per tonne of CO_2 next year, the potential revenue could be more than double. Concomitant environmental benefits associated with the above practices such as reduced pollution, increase biodiversity and water conversation could attract further incentives.

Securing a reliable feedstock supply is fundamental to the viability of an AD project and obtaining a long-term supply contract from feedstock producers on acceptable terms is critical. The AD plant operator has certainty of feedstock supply, at an agreed price and defined quality standards, over an appropriate period of time. The farmer supplying slurry and/or silage to the AD plant, has a degree of certainty on his/her future income from his land and can better plan and manage his/her farming enterprise. Feedstock supply contracts should include the following key elements: agreement on the quantity and timing of feedstock delivery; the logistics of harvest and storage of the feedstocks; the quality of the feedstocks and testing regime; and of course a fair price received for the supply of these feedstocks. Gas Network Ireland and the Renewable Gas Ireland forum promote the adoption of a 'Biomethane Charter' by which would co-exist with feedstock supply agreements, whereby participating farmers would commit to complying with key requirements around sustainability governance (REDII, NAP, SMR, GAEC) and practices (reduced nitrogen use, soil health, biodiversity, soil carbon sequestration, etc.).

Agriculture as with other industries have been given targets to reduce emissions by 2030 and have a target of being climate neutral by 2050. The biggest emissions are related to enteric fermentation, N_2O and synthetic nitrogen usage. While some agriculture practices cause emissions, farms and farmers can reduce these emissions and also are in a relatively unique position of also being able to sequester and store carbon in soils. Supplying quality grass silage as a feedstock for AD plants in the region presents an opportunity for alternative income, building on their existing farming infrastructure while adopting new environmental practices. In addition to the sale of silage, payments and funding from the new CAP will compensate farmers by rewarding them for reducing their GHG emissions, carbon sequestration, improving water quality and biodiversity.

An agri-environmental pilot scheme to support the deployment of AD in the region would pay landowners to produce silage for an anaerobic digester sustainably, at a fixed price for a period (subject to quality and quantity). Such a scheme would ensure a long term supply of feedstock for an AD plant without the need to increase grass production in the region. This would ensure that land continues to be maintained and properly managed in the long term as payments to farmers would be directly linked to this. The potential benefits of such as scheme include:

- Reduced methane output from animals in the region, leading the transition to low-carbon agriculture nationally.
- A secure business model for the development of AD plants given input costs would be fixed for a period and supply of feedstock would be secure.
- Demonstrate how biomethane can support the decarbonisation of the energy system in the region and the country.
- Better land management leading to a greater level of biodiversity and more carbon storage.
- Reduced mineral fertilizer demand by using AD digestate as the primary source of organic fertiliser in the region, bringing environmental benefits as well as reducing production costs.
- Potential to keep rural populations in place by encouraging farmers to remain on the land – secure, sustainable long term income.
- Potential to encourage farmers to look at other renewable energy options to further help reduce GHG emissions.

A model such as this could be trialled in the region, using the recommendations of this report, paving the way for its deployment across the country. based on the outcomes of the AD report.

One of the challenges for agriculture to monetise the emission reduction it delivers, is the cost of measuring, verifying and trading carbon credits. A co-operative approach under one or several farm-based AD projects[2] is a good candidate to establish a local carbon credit management system (including measurement & verification and trading), working on behalf of the AD project developers & operators, and the farmers involved. This may provide an opportunity to access the carbon

[1] https://capital.com/carbon-price-forecast-an-esg-commodity-to-watch

[2] A 20 GWh/yr biomethane capacity AD project will require a land base of between 1300 and 1800 ha to produce the grass silage required, assuming an incremental yield of 4 tDM/ha/yr to service the needs of the plant above current cattle forage requirements.

credit market at premium rates, which previously would be unobtainable to the typical individual farmer. A regional agri-environmental scheme supporting the develop of sustainable farm-based AD projects in South Kerry should also encompass outreach, training and advisory services for farmers.

There is a broader rationale for adopting a co-operative approach to developing AD in the South Kerry region, organised around core principles such as voluntary and open membership, democratic member control, autonomy and independence, concern for the community, member economic participation, education, training and information. Research has shown that a majority of farmers want a co-operative approach to develop AD project, which in turn will increase the commitment to a secure supply of feedstocks to the plants.

1. Introducing the Feasibility Study

South Kerry is a rural region in the southwest of Ireland, with a population of 55 thousand according to the Central Statistical Office (CSO)'s 2016 Census. The region's main urban centres are Killarney, Kenmare, Sneem, Killorglin, Caherdaniel, Valentia, Waterville, Beaufort. The region is renowned nationally and internationally for its scenery and natural heritage. Tourism is a key driver for the local economy – it is estimated that the region hosts 3.6 million night stays on a good year – but agriculture and food production are also important for the local economy.

Figure 1: Map of the South Kerry Development Partnership's region.

Climate change, with increased risks of flooding, droughts and storms, is a critical threat to the region's ecosystem and by extension its agriculture. Conversely, climate action represents real opportunities for the South Kerry agri-food sector, including:

- Leveraging land as its primary asset to produce renewable energy.
- Adopting circular economy practices, using organic wastes as a valuable resource which can ultimately generate a high-quality fuel.
- Pioneering innovative, sustainable solutions to meet our national and global commitments to decarbonisation.

SKDP aims to be at the forefront of this transformation together with farmers in South Kerry and has commissioned XD Sustainable Energy Consulting Ltd. to undertake a feasibility study on anaerobic digestion[3] (AD) in the region. The overall objective of the study is to investigate the potential for biogas production to contribute to the region's energy needs in an affordable, secure and sustainable manner.

The specific objectives of the feasibility study are:

- To conduct a comprehensive assessment of the biomass resource available in the study area to determine their practical potential for biogas, their spatial distribution and cost.
- To undertake a multi-criteria spatial analysis aiming to identify areas suitable for the development of AD projects in the region.
- To assess the key considerations for the sustainable development of AD projects in the region.
- To investigate the greenhouse gas emissions (GHG) impact of farm-based AD projects along their value chain, and review potential additional income for farmers arising from practices leading to GHG reductions.
- To review potential models for AD feedstock supply agreements and benefits for the stakeholders involved.
- To explore elements of an agri-environmental pilot scheme to support the development of AD in the region.

[3] Anaerobic Digestion (AD) is the process of breaking down organic materials to produce biogas (methane (CH_4) + carbon dioxide (CO_2)).

The study, funded by the ECCO project under the North West Europe Interreg programme, is undertaken by XD Sustainable Energy Consulting Ltd., with a team of experts in biogas system design and engineering, advanced renewable energy systems and spatial planning.

2. Anaerobic Digestion Feedstocks Analysis

A. Introduction

The objective of the feedstock analysis is to understand the potential of biogas production in the study area, based on a detailed assessment of the organic materials available, in terms of suitability for anaerobic digestion, quantities that can be practically mobilised and cost. The analysis relies on the Central Statistical Office (CSO)'s Population Census (2016) and Agriculture Census 2010 updated with data available for the Census 2020, EPA licensing data for industrial sites and waste management facilities, as well as other published sources of data and information.

The following feedstocks have been assessed:

- Agricultural feedstocks: grass silage, cattle slurry and pig slurry.
- Food waste from municipal sources.

There was no readily available data on other potential sources of organic material suitable for anaerobic digestion at the time of the study such as food processing waste, in particular from larger facilities that would be licensed with the EPA and report on their waste outputs.

B. Agricultural Feedstocks

The following agricultural feedstocks have been considered in terms of potential for biogas:

a) **Grass silage:** forage biomass harvested and ensiled for use as winter fodder for cattle and sheep. Although silage is primarily produced as a feed, it is also an excellent feedstock for anaerobic digestion. Grass silage has a number of advantages: grass is widely available in the area, grass silage has a relatively high density and methane content, it can be transported over reasonable distances and can be stored seasonally. The disadvantages are that it is an expensive feedstock for AD, that is a key component of the existing agricultural system.
b) **Cattle slurry:** captured when the cattle are housed during the winter (typically 100 days) and generally stored under the cattle shed, or in adjacent above or below ground tanks in some cases. Cattle slurry is normally spread on land as an organic fertiliser. Its water content is high (above 90%).
c) **Pig slurry:** collected year-round on pig farms, stored in tanks or pits, and normally spread on land from February till October. Pig slurry has a high water content (typically over 95%).

Manure from sheep is not considered as practical feedstock for AD.

1. Grass Silage

a) Grass silage potential for AD in South Kerry

The potential of grass silage as an AD feedstock was determined on the basis of the CSO Agricultural Census 2010 data, which provides detailed figures for crops and livestock down to the electoral division (ED) level. The 2010 data has been extrapolated to 2020 based on the Agricultural Census 2020 data available for County Kerry (no ED resolution available yet).

A total of 143 thousand hectares of grassland were farmed in the study area (projected to 2020 from 2010 census data). Four classes of grassland are inventoried under the census: silage (21,200 ha), pasture (58,300 ha), hay (2,500) and rough grazing (61,200 ha). The other factor affecting the potential of grass silage is grass yields.

Recognising that grass yields will vary in the region to reflect local conditions (soil, drainage, etc.) and grass management practices, three levels of average grass yields were assumed based on the stocking rates (heads of cattle per ha of grassland) in each electoral district:

- 12 tDM/ha/year where stocking rates are above 2.5 heads of cattle/ha, typically in EDs where dairy farming is the prominent farming enterprise.

- 8 tDM/ha/year where stocking rates are between 1.7 and 2.5 heads of cattle/ha, typically in EDs where beef farming is prominent.
- 6 tDM/ha/year where stocking rates are below 1.7, typically in EDs with low intensity farming and significant areas of rough grazing.

The potential availability of grass silage was calculated by multiplying the total area of grassland classified as 'silage' and 'pasture' in each ED, by the relevant yield figure above according the ED's stocking density. This results in a **theoretical grass availability of 554 thousand tonnes DM**, with a biomethane potential of 202 million Nm3 of biomethane (364 Nm^3 CH_4/t_{DM}) in the study area. This amount of biomethane has an energy content of 2 TWh/year, equivalent to the fuel used for heating close to 135 thousand homes.

In practice, all this grass is already accounted for feeding the cattle and sheep in the area, as fresh grass or silage. While silage is seen as a key feedstock for the deployment of AD in Ireland, it is relatively costly as a feedstock. Its availability will be strongly conditioned by its existing demand as a cattle feed in the winter, future changes in local agricultural systems linked to diversification in farming enterprises and/or improved grass land management, and very importantly the price farmers would receive for its supply to an AD project.

The latest Farm Survey Results 2019 for the South-West region indicates that approximately 40% of dry cattle farms, 40% of sheep farms and 12% of dairy farms are vulnerable economically and could be incentivised to diversify towards the production of silage for biogas. In this context, it is assumed that most of the grass silage potentially available for anaerobic digestion would be derived from grassland where beef farming is prominent. Considering our analysis of stocking rates within the study area above, we estimate there are circa 2090 farms in the study area that are primarily specialised in beef production, farming a total of 12,340 ha for silage and 42,800 ha as permanent pasture.

Two scenarios were used to explore the technical potential of grass silage as a feedstock for AD in the region. The first one is a 'productivist' scenario whereby it is assumed that a cohort of farmers increase their grass yields by an additional 4 tDM/ha/year on top of their current grass production, by applying improved grassland management and increased soil fertility (see Chapter 1.A.1). On the assumption that 20% of beef farmers in the region would adopt these practices, this could deliver an additional 44,100 tDM/year of silage technically available for AD. This represents a **technical potential of 16 million Nm3 CH4/year** with an energy content of 160 GWh/yr, equivalent to the heating fuel requirement of 10,700 homes.

However, a different scenario tending towards more 'extensive agriculture', is emerging since the introduction of a Sectoral Carbon Budget by the Irish Government in July 2022, which targets a 25% reduction in GHG from agriculture by 2030. In addition, Ireland's CAP Strategic Plan 2023-2027 (Sept. 2022) puts a strong emphasis on the achievement of a higher level of climate and environment ambition, and introduces strengthened sustainability compliance requirements and rewards actions beneficial to the climate, environment, water quality and biodiversity. Both policies for agriculture point towards a significant reduction in herd numbers, and farmers being incentivised to adopt alternative farming enterprises such as anaerobic digestion, solar power generation, forestry, etc. In line with the Climate Advisory Council's Carbon Budget Technical Report (Oct 2021), it is assumed that the 25% GHG emission reduction target will require a reduction of 15% of bovine herd numbers in the study area i.e. minus 13,300 heads or 9,450 livestock unit. This would 'free up' 55,400 tDM/year of grass currently produced to be used for anaerobic digestion, representing a **technical potential of 20.2 million Nm3 of biomethane per year**, with an energy content of 202 GWH/yr, equivalent to the heating fuel requirement of 13,450 homes.

2. Slurry and manure

a) Cattle slurry

The theoretical potential of cattle slurry for biogas was calculated based on the numbers of cattle per type taken from the census 2010 data, extrapolated to 2020 following changes in cattle numbers at County Kerry level based on the CSO livestock surveys[4]. The results have been combined with indicators of slurry production (in tonnes of fresh weight) by cattle type during the housing period (16 weeks), taken from a study by Teagasc [13], see Table 1.

[4] See CSO database here: https://data.cso.ie/table/AAA10

It is also assumed that 10% of the cattle is outwintered (some dry stock and dairy replacements). The DM content of slurry was taken to be 8% and its biomethane potential as 107 Nm^3 CH_4/t_{DM}. The practical biogas potential from slurry considers that slurry loses (10%) of gases during storage. The length of time of storage of waste in tanks negatively impacts gas yields, so cattle slurry's availability will vary seasonally.

Our modelling suggests there is close to 91 thousand head of cattle in the study area that produce 31 thousand tonnes in dry weight of slurry when housed. This slurry can be harvested for anaerobic digestion purposes and potentially produce … 3 million Nm3 of biomethane per year, with 29.5 GWh/year in energy content, equivalent to the fuel use for heating of 1,970 homes.

Table 1: Slurry Production by cattle type.

Cattle Type	Head of cattle 2020 (,000)	Slurry that can be captured (tonnes/year/head)	Slurry Available for AD (,000 tDM/year)
Dairy Cows	15.6	5.84	6.6
Bulls	1	5.84	0.4
Other Cow	20.9	5.20	7.8
Other Cattle	53.5	4.10	15.8
Total	**91**		**30.6**

Please note that under the scenario whereby the Carbon Budget for Agriculture leads to a herd reduction of 15%, the availability of cattle slurry will be **reduced by an equivalent 4,700 tDM/year.**

b) **Pig slurry**

The agricultural census doesn't provide a head count of pigs reared in the study area, but the 2020 census indicates there are 35,000 heads at county level. The EPA licensed facilities database includes one pig farm near Kilgarvan, rearing circa 8,900 animals in average, producing 15,800 m3 of slurry per year, with a biomethane potential of 120 thousand Nm3/yr, equivalent to 1.2 GWh/yr. This is enough biomethane to generate most of the electrical requirement of the pig farm as reported in their Annual Environmental Report 2020.

Please note that pig slurry has a very high water content and poor biomethane potential. Considering the volume it would occupy in a digester and the amount of heat required to maintain suitable digestion temperatures, the net energy contribution of pig slurry is very reduced. Where available locally, it can be considered as a co-substrate to digest other feedstocks such as grass silage and to compensate for the seasonality of cattle slurry.

c) **Chicken manure**

The agricultural census doesn't provide a head count of poultry reared in the study area. Chicken manure is a suitable feedstock for co-digestion however it has a high nitrogen content so can be an issue in high quantities. ……..

C. Non-Agricultural Feedstocks

The collection and local treatment of municipal & industrial organic waste with anaerobic digestion has key benefits:

- It contributes to the circular management of organic waste, at a local level.
- It can generate revenue from the collection of gate fees for the waste management service.
- It reduces the amount of waste going to landfill and helps the region meets the legislative requirements in this regard.
- It avoids the environmental burden of traditional organic waste disposal approaches, in terms of GHG emissions, water and air emissions.

The following sections provide a preliminary inventory of municipal and industrial organic waste in the study area, based on published data.

1. Municipal Waste

a) Sewage Sludge

Please note that the practical use of WWTP sludge is extremely limited due to environmental regulations and Bord Bia's guidelines regarding use of digestates containing this waste on food-producing land - even after pasteurisation. This restricts recycling of digestate containing sewage sludge to few outlets such as forestry and energy crops.

b) Food waste

The treatment of food waste in anaerobic digestion is an efficient way to recover energy and nutrients from this resource and reduce CO_2 emissions associated with its decomposition. There are two main sources of food waste in the study area: a) from households, b) from commercial/public streams. The total household food waste resource available was estimated using a figure of 85 kg of fresh food waste/person/yr factor (Cre, 2010) and a collection rate of 50% average between rural and urban areas (Southern Waste Region, 2017). This gives a total potential resource of 920 tonnes of household food waste per year (280 tDM/yr).

The average non-household source segregated organic waste collected in the South-West region during the 2011-2012 period was equivalent to 15 kg/inhabitant/yr, which gives a total potential in the study area of 326 tonnes of fresh organic waste per year (100 tDM/yr). In addition, the tourism sector generates significant amounts of food waste from catering to the millions of visitors to the region every year. It is estimated that the 3.6 million night stays in the region generate 834 tFW/yr of food waste (255 tDM/yr).

Overall, the residential and non-residential food waste available in the area was estimated at 636 tDM/yr, with a biomethane potential of 0.154 million Nm3 per year, with an energy content of 1.5 GWh/yr, enough to heat 103 homes.

2. Industrial waste

There is no statistical data available on potential industrial organic waste available in the study area. While a small amount of fish waste, meat processing waste or milk processing waste might be available in the study area, their potential to contribute to AD in the region will be negligible.

3. Marine Algae

Marine algae, or seaweed, could potentially be a suitable feedstock for AD plants. Ireland also has significant seaweed resources on its coast, and the temperate oceanic climate is well suited to cultivating seaweed both naturally and through farms. The majority of seaweed harvesting in the country happens in counties Galway and Donegal, where it is used primarily for food. Seaweed is particularly suitable in combination with fish farming to recycle nutrients and increase plant growth. Some seaweed species also co-digest well with slurry, with a 2:1 ratio of seaweed to slurry being the optimum. Seaweed can be considered a third-generation biofuel source, with no land or freshwater requirements. Being third-generation, seaweed would fulfil the EU's criteria for advanced biofuels, which is required to supply 3.5% of our transport energy supply by 2030.

Despite the benefits and advantages of seaweed cultivation for AD, there are many challenges and disadvantages associated with it. It is difficult to estimate costs of wild seaweed harvesting for AD in Ireland - it is reported to cost around €50/tWM [26] and also €330/t_{DM} [27]. Cultivation on fish farms would most likely be more economical, which would result in costs of around €20/tWM. However, these cost figures are optimistic and do not take initial investment costs into consideration. There is also no simple methodology to estimate the practical and economic potential for seaweed along the South Kerry coastline. Wild seaweed quality varies according to season and local conditions and would require a careful harvesting plan. Salt levels in the seaweed would have to be monitored over time, as too much salt inhibits bacterial processes in AD plants. If wild seaweed were to be harvested, the impact on biodiversity would be a big issue and would have to be considered carefully. Due to the difficulties in assessing the practical potential of seaweed in South Kerry, as well as the unlikelihood of it being financially viable, seaweed was not quantified as a feedstock for AD in this study.

D. Summary of AD feedstock analysis

Table 2 summarises the AD feedstock analysis in terms of quantities potentially available, the associated biomethane potential, energy content and equivalent home heating energy use. The variation in silage and cattle slurry potential reflects the alternative scenarios discussed above, scenario 1 reflecting increase in grass yields (+4 tDM/ha/yr) and scenario 2 a reduction in cattle herd number by 15% in the study area.

Table 2: Summary of biogas feedstock analysis.

	Feedstock Technical Potential (,000 tDM/year)	Biomethane potential (MioNm^3 CH_4/year)	Energy potential (GWh/yr)	Equivalent home heating energy (# homes)
Silage	44.1 – 55.4	16.0 – 20.2	160.4 – 201.7	10,700 – 13,450
Cattle slurry	25.9 - 30.6	2.5 - 3.0	25 - 29.5	1,670 - 1,970
Pig slurry	0.6	0.1	1.2	80
Food Waste	0.6	0.2	1.5	103
Total – scenario 1	**75.9**	**19.3**	**192.7**	**12,848**
Total – Scenario 2	**82.5**	**22.9**	**229.4**	**15293**

Overall, the above analysis has identified a range of AD feedstocks for which the estimated quantity available is 76 to 83 thousand tonnes in dry matter. The total biomethane potential has been estimated at 19.3 to 22.9 million Nm3, with an energy content close to 193-230 GWh/yr. This would be sufficient to meet the needs of 9-11 medium-sized AD plants (20 GWh/yr biogas production) installed in a farm setting, or about 5-6 larger (40 GWh/yr), centralised plant more likely to be in an industrial setting. Generally, it is clear from the above analysis that agricultural feedstocks will play an important role in the production of biogas in the study area, with grass silage representing above 83-88% of the total potential and slurry/manures another 12 to 16%.

While with a much smaller potential (1% of total potential), municipal and industrial feedstocks in the region would also play a part, as they typically attract a gate fee of between €20 and €50 per wet tonne. Further research into the potential of municipal and industrial waste from outside of the study area would be justified in terms of generating gate fee revenues for an AD plant based in South Kerry.

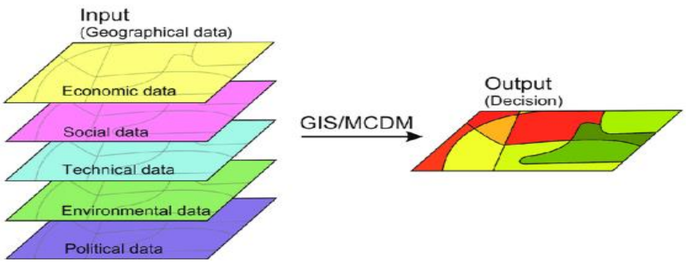
The seasonality of feedstocks must also be taken into consideration. Food waste production in the study area would have a seasonality linked with the large influx of tourists as well as ramping up of some food processing during the summer months. Equally, the seasonality of slurry and silage harvesting, and storage will impact the potential material flows into AD plant(s) in the study area and this should be considered carefully in the planning of the feedstock supply logistics.

While there are no specific references on energy use in the study area, a simple calculation based on the national total energy use[5] per capita ratio of 35.3 megawatt-hour (MWh/yr) gives an estimated 1,942 GWh/yr energy use in South Kerry across the whole economy (including for heat, electricity and transport). At a high level, this is promising in that the above analysis indicates that anaerobic digestion could potentially meet over 10% of the region's energy requirements, using local feedstocks to contribute to the local economy in a sustainable, circular manner. Chapter 3 will present the results of a spatial analysis of the potential for AD development in South Kerry undertaken as part of the study to determine the distribution of AD feedstocks and suitable locations for AD plants. Sustainability issues pertaining to the integration of AD in the agricultural sector in terms of providing the feedstocks required will be reviewed in 4.

[5] This is the 'primary energy use' and it includes the fuels used in the production of electricity.

3. Spatial Multi-Criteria Analysis

A. Introduction



The overall objective of this section of the study was to identify areas with a high degree of suitability for the location of potential AD projects, using a spatial multi-criteria analysis approach (MCA). The key steps for the spatial MCA included:

- Identify key criteria to be considered and acquisition of relevant GIS datasets.
- Define scoring matrix for individual criteria in terms of suitability for AD development.
- Apply an overall suitability scoring system for all the parcels of land in the study area, compiling the individual criteria scoring.
- Produce a map with the overall scoring results with visual aids to help identify areas that are most suitable areas for AD development.

The spatial MCA will then enable conduct more detailed investigations on potential locations that have been shortlisted. The spatial MCA will also provide a basis to engage with the local community and key stakeholders at the early stages of potential project development. An analytical hierarchy process (AHP) is employed to assign appropriate weights to the criteria according to their relative importance. The spatial MCA has taken cognisance of Kerry County Council's locational criteria for Bio-Energy facilities as set out in the policy section of this report.

E. Criteria Considered

In a spatial MCA, *criteria* are defined as the set of guidelines or requirements used as basis for a decision. There are two types of criteria: *factors* and *constraints*. A *factor* is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. *Constraints* serve to limit the alternatives under considerations. These are areas that are categorically unsuitable for development, and therefore are eliminated from the analysis. Various geographic layers containing information about the spatial distribution of factors and constraints relevant to siting an AD development have been sourced and form the key inputs into the analysis. These are summarised as follows:

Table 3 Geographical layers included in the analysis.

Layer	Spatial Resolution	Source
Total Heat Density (2015)	100m x 100m	Hotmaps Project (2016)
Silage Potential	ED Level	Agriculture Survey 2010
Slurry & Manure Potential	ED Level	Agriculture Survey 2010
Municipal & Industrial Waste Potential	Point data	Environmental Protection Agency licensed sites (2020)
Land cover	100m x 100m	CORINE Land Cover 2018
Special areas of conservation (SACs) or special protected areas (SPAs)	Vector Data	National Park and Wildlife Services (2019)
Natural Heritage Areas, Prime Special Amenity and Visually sensitive areas	n/a	Kerry County Council (2015)
Slope	90m x 90m	National Aeronautics & Space Administration (2012)
Fuelling Stations	n/a	OpenStreetMap contributors (2022)
Roads	n/a	OpenStreetMap contributors (2022)
Zoned land, Flooding data	n/a	Kerry County Council (2015)
Settlements	n/a	Kerry County Council (2015)

F. Factors

1. Heat Density

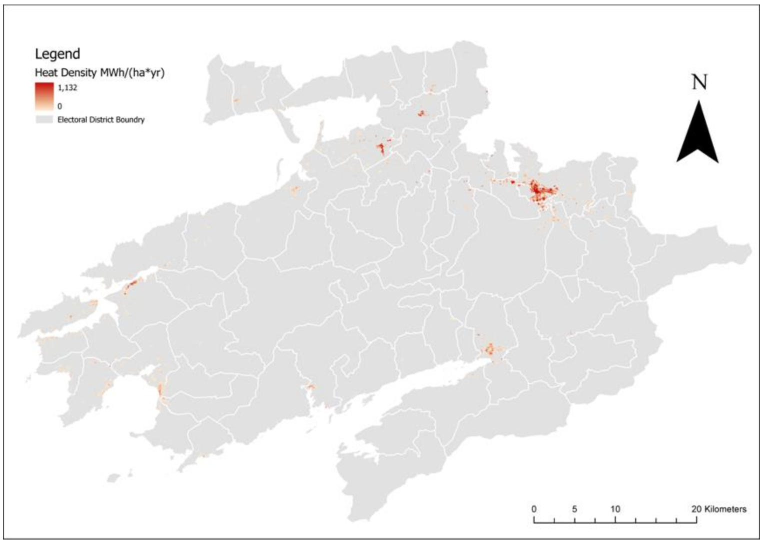


Figure 2: Heat Density Map

Heat density data was taken as a proxy to identify areas of high energy demand, where AD plants could contribute to the local energy supply. This is particularly relevant for district heating applications whereby the heat produced by an AD plant can be distributed to users in a concentrated area via a pipe network circulating hot water. An alternative would be to distribute the biomethane produced by an AD plant via an existing or newly installed gas distribution network.

Heat demand (or heat density) has been calculated for buildings in the EU28 + Switzerland, Norway and Iceland as part of the Hotmaps project[6] . The data were extracted and clipped to the bounds of the study area (Figure 2). The heat density layer was normalised to range from 0-255 (0 = least suitable for AD development, 255 = most suitable for AD development). All mapped factors were normalised to this scale for the purpose of comparison.

As expected, areas of high heat demand are clustered around settlements. Killarney features particularly strongly on the map and has sufficient heat density for networked energy solution development such as district heating or a gas network, which could be fuelled by an AD plant. Large energy users with a strong base load such as hotels, swimming pools, factories, … could be leverage a anchor tenants for a renewable energy system of this type. Other towns such as Kenmare, and Killorglin could present interesting opportunities in this regard.

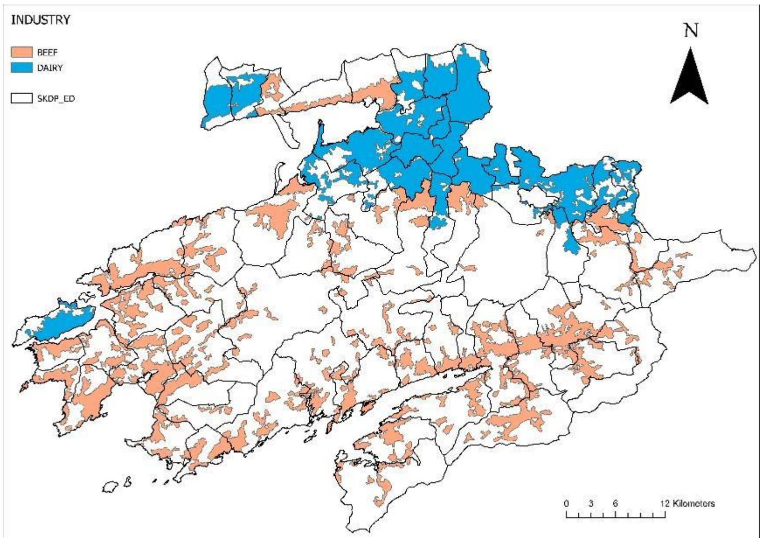


Figure 3: Farming enterprise distribution. Source: XDC

2. Silage Potential

As discussed in the above analysis, it is anticipated that beef farmers are more likely to respond to an additional demand for silage created by the development of AD. In this context, further analysis of the CSO Agricultural Census data (2010 extrapolated to 2020) was conducted to attempt determining the spatial distribution of farm enterprises in the study area, distinguishing electoral districts (EDs) where farming is primarily concentrated on beef farming or dairy farming (Figure 3: Spatial distribution of beef/dairy farming enterprises.). The key factors used in the statistical analysis to determine the primary specialisation of an ED was the ratio between the number of dairy

[6] EU H2020 Project: Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables). WP1 Report. 2016.

cows and the number of other cows + bulls, as well as the ratio between the silage area and the total grassland area in each ED. This is then represented in Figure 3: Spatial distribution of beef/dairy farming enterprises. by reallocating the ED level data to the polygons identified as grassland in the CORINE Land Cover layer.

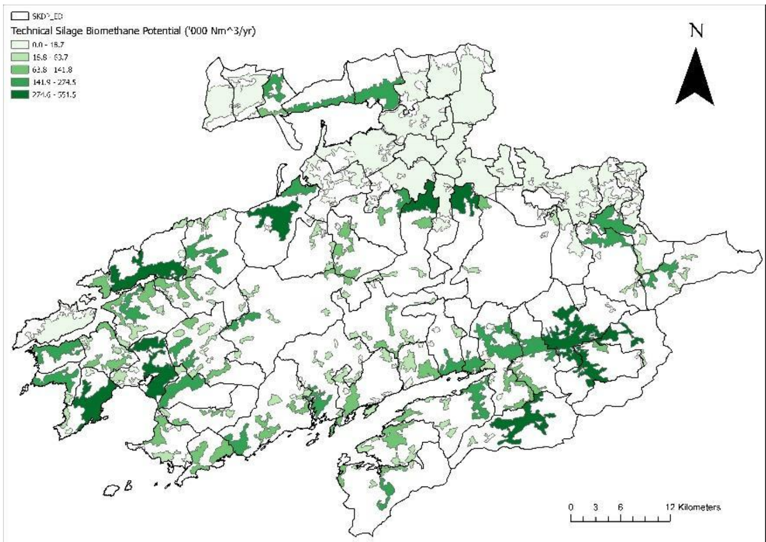


Figure 4: Technical silage potential distribution. Source: XDC

The same approach was taken to represent the spatial distribution of the practical silage potential derived in the feedstock analysis undertaken in B.1.a), see Figure 4. The map indicate that the practical silage potential is highest in the lowlands adjacent to the Roughty river from Kilgarvan to Kenmare, as well as the river Sheen, in the South-East of the study area. On the Western side of the Iveragh peninsula, there are pockets of silage potentially available. There are pockets with a good potential in the Northern side of the study area, but generally it is less promising in terms of silage potential given the primary dairy farming orientation.

The practical silage potential layer was normalised to a scale of 0-255 for the purposes of the MCA. The vector polygons were then converted to a raster grid with a resolution of 100m x 100m for the MCA analysis.

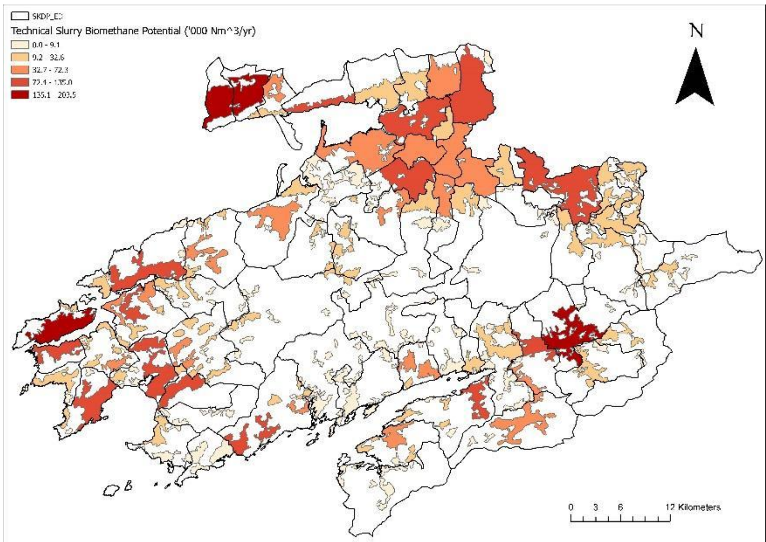


Figure 5: Slurry potential distribution. Source: XDC

3. Slurry Potential

The practical slurry potential has been mapped at the ED level as part the feedstock analysis, and then reallocated to the relevant polygons designated as grass cover in the study area. The practical slurry potential layer was normalised to a scale of 0-255 for the purposes of the MCA. The ED boundary vector polygons were then converted to a raster grid with a resolution of 100m x 100m for the MCA analysis.

Areas with high slurry potential areas naturally coincide with those with a higher density of cattle, notably in the western side but also in the northern side of the study area with a primary dairy orientation (with some additional slurry collected year round in dairy parlours. comes stronger. It is also worth noting the high concentration of slurry near Kilgarvan due to the availability of pig slurry nearby (see B.2.b) for details).

4. Municipal Organic Waste Potential

The practical municipal waste potential, taken as the residential and non-residential food waste available in the study area, was assessed at the ED level as part of the feedstock analysis. The associated biomethane potential layer was normalised to a scale of 0-255 for the purposes of the MCA. The vector polygon was then converted to a raster grid with a resolution of 100m x 100m for the MCA analysis.

The main food waste potential is as expected concentrated in Killarney and other secondary urban centres such as Kenmare, Killorglin, Cahersiveen and Caherdaniel, with tourism making a significant contribution to this resource.

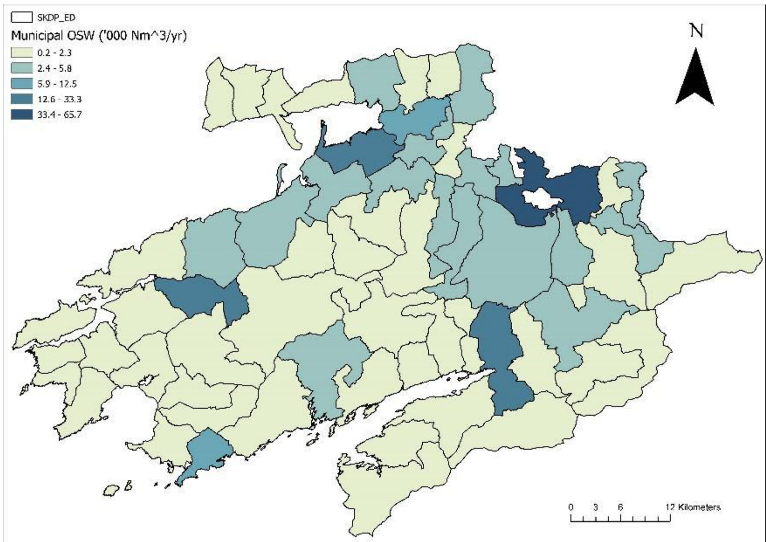


Figure 6: MOSW distribution. Source: XDC

5. Land cover

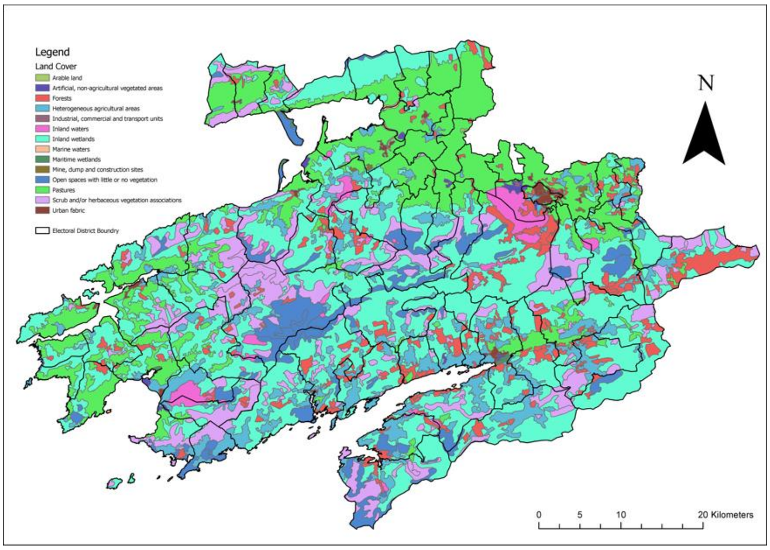


Figure 7: Landcover distribution. Source: XDC.

The land cover layer was sourced from the European CORINE Land Cover dataset for 2018. Nineteen land cover types were present within the study area. These were assigned scores (ranging from 0-255) based on their desirability as land cover types for AD development. Since these were categorical data, the scores assigned reflect the relative desirability of the different land cover types. The scores assigned to the land cover types were:

- Pastures = 255 (most desirable)
- Industrial, commercial and transport units = 255 (most desirable)
- Land principally occupied by agriculture with significant areas of natural vegetation, and natural grasslands = 255 – 25%(255) = 161
- Natural grasslands = 255 – 50%(255) = 128
- All other land cover types = not scored (neither desirable nor undesirable)

6. Protected or Zoned Land

Protected sites including special areas of conservation (SACs), special protected areas (SPAs) and designated and proposed Natural Heritage Areas were mapped from data obtained from the NPWS for 2019, (Figure 8: Protected sites. Data source: NPWS (2019)). Bioenergy development are to be prohibited in these areas in the upcoming Kerry County Development Plan. As such, only areas outside of these ecologically sensitive areas were considered appropriate for development. A data layer was produced representing the areas outside of designated sites. When performing MCA, only areas outside of the designated sites were analysed. This was converted to a 100m x 100m raster and given a score of 255.

The zoned land data layer was mapped as per the Kerry County Development Plan 2015-2021 (Figure 9). This layer included prime and secondary special amenity areas. Prime Special Amenity Areas are those landscapes which are very sensitive and have little or no capacity to accommodate development. Development in these areas is mostly prohibited, except under exceptional circumstances. As such, this was considered a constraint. Secondary Special Amenity areas are areas that are sensitive to development. Accordingly, development in these areas must be designed so as to minimise the effect on the landscape. Since development *can* occur in these areas, this was not considered a constraint. However, it would be desirable to locate a development *outside* of these areas. As such, a new data layer covering the land *outside* of secondary amenity areas was created. This was converted to a 100m x 100m raster and given a score of 255. Settlements were considered a constraint, and there is only potential on industrially zoned land within settlements as discussed later in this report.

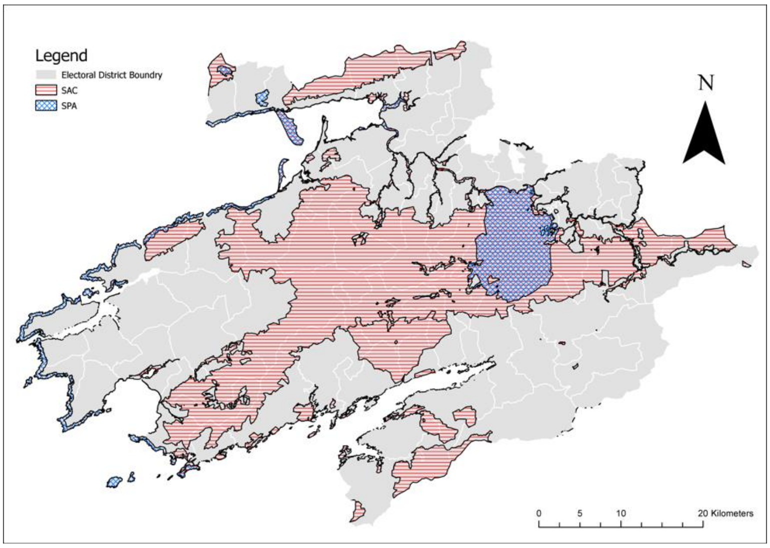


Figure 8: Protected or zoned land. Source: XDC.

As can be seen from these maps, significant areas of land in the study area are designated for a level protection. However, the areas identified as offering a strong potential in terms of AD feedstocks offer plenty of scope for developing AD projects.

7. Proximity to roads and fuelling stations

Proximity to roads and fuelling stations (Figure 10.a) was also considered in the analysis. A raster cost path layer was produced using the fuelling stations and elevation data as inputs (Figure 10.b). This represents the proximity of the fuelling stations, considering topography, to all locations in the study area. The values for this layer were normalised to a scale of 0 – 255 for the MCA analysis. The same procedure was applied to the roads layer (Figure 10.c). The road infrastructure is important for the location of a potential AD project, as the supply of feedstocks to the plant has considerable logistical requirements. A medium-size AD plant (20 GWh/yr) would typically require 85 tonnes of silage (typically supplied from within a 10 km perimeter) and 70 tonnes of slurry every day (from a 5 km radius).

Equally, the biomethane produced in farm-based plants will typically be shipped to a point of use (e.g. large energy users, a transport refuelling station, etc.) or to a natural gas grid injection site (the nearest potential injection points would be Macroom and Listowel, at a 50 km distance or more from the study area). A medium-size plant would see a standard compressed biomethane trailer coming in and out of the site each day in average. Existing refuelling stations for fleets of heavy goods vehicles or tractors which have been converted to biomethane can also play an important role in the development of a biomethane infrastructure in the area.

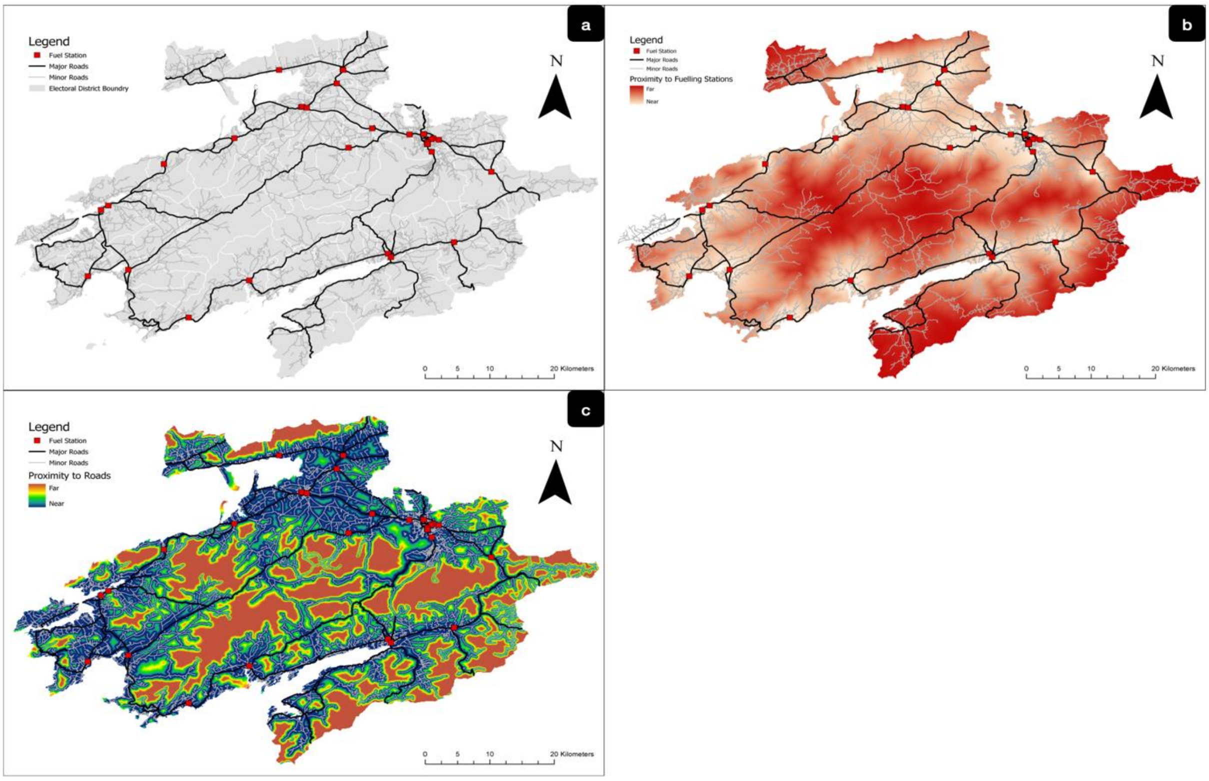


Figure 10: a) Roads and fuelling stations; b) Raster Cost Path Layer illustrating proximity to fuelling stations, considering topography; c) Raster cost path layer illustrating proximity to roads, considering topography.

G. Constraints

A constraints layer was produced to eliminate categorically unsuitable areas from the spatial MCA. Area inside the buffer of 250m around the settlements (derived from CORINE land cover) but excluding industrial land, areas which are designated Prime Special Amenity in the Kerry County Development Plan, areas liable to flooding (derived from the OPW flood maps), or with a slope of >15 degrees was used as constraint areas in combination with SAC and SPA designated sites. Additionally, all areas not meeting the criterion of suitable landcover was also used as constraint. This layer included the features shown in Table 4. A map of the overall constraint areas is shown in Figure 11.

Table 4 Constraints – features that were considered categorically unsuitable areas for AD development.

Feature	Layer from which these were extracted
Coniferous forest	Land cover
Mixed forest	Land cover
Beaches, dunes, sands	Land cover
Intertidal flats	Land cover
Sea and ocean	Land cover
Estuaries	Land cover
Water bodies	Land cover
Salt marshes	Land cover
Burnt areas	Land cover
Sport and leisure facilities	Land cover
Inland marshes	Land cover
Transitional woodland-shrub	Land cover
Prime special amenity areas	Zoned land
Settlements + 250m buffer (after Thompson *et al.*, 2013)	Settlements

Land with slope >14 degrees (after Thompson *et al.*, 2013)	Slope

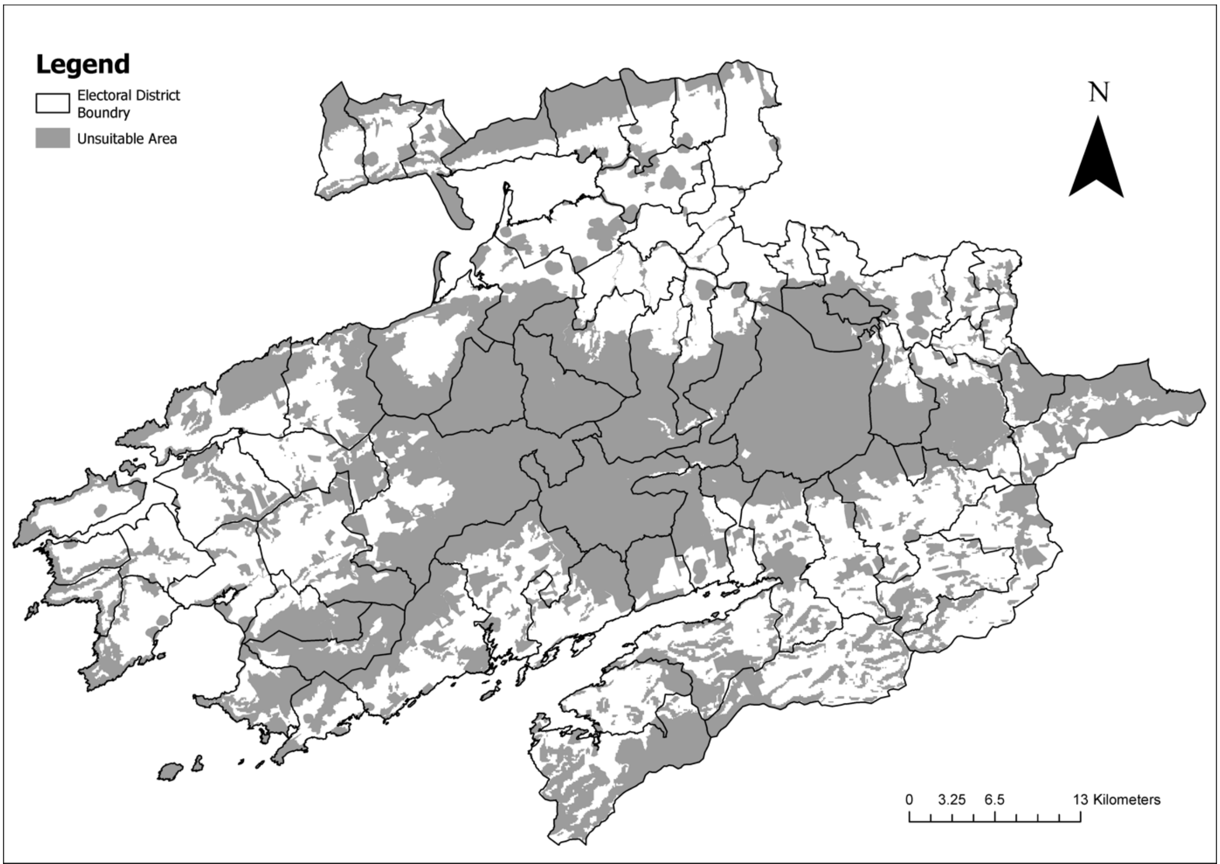


Figure 11: Constraint areas (areas excluded from spatial MCA).

H. Weighting the Criteria

An analytical hierarchy process (AHP) was undertaken to weight the factors described above. This is a decision-making procedure developed by Saaty (1977) and commonly implemented in spatial MCA analyses. The way it works is, first, each criterion is compared with the others relative to its importance on a qualitative scale (Table 5).

Table 5 Scale used in AHP analysis.

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over the other	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured, and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed

A matrix is then constructed, and priority vectors (weights) are calculated. AHP weights are expressed in numerical weights that sum up to 1. For this analysis, a spreadsheet template was used to calculate the weights of the factors considered above (Richard O'Shea 2019, personal communication, 19 September). The weights for each factor are shown in Table 6. Weights were multiplied by the scaled values of each of the factor layers described previously in this report.

Table 6 Weights calculated from AHP analysis.

Factor	Weight
Heat Demand	0.2295
Proximity to Roads	0.2295
Proximity to Fuelling Stations	0.2295
Land that is outside of a secondary special amenity area	0.1199
Non-designated land (not an SPA or SAC)	0.1171
Practical Silage Potential	0.0746
Practical Municipal Waste Potential	0.0500
Practical Slurry Potential	0.0330
Land cover	0.0214

I. MCA results, interpretation & planning considerations

1. Conducting the MCA

Using the raster calculator, the factor layers were aggregated using a weighted linear combination, described mathematically as follows:

$S = \Sigma w_i x_i x \Pi c_j$ where:

S = is the composite suitability score

w_i = weights assigned to each factor (from AHP)

x_i = factor scores (0-255)

Π = product of constraints (1-suitable, 0-unsuitable)

c_j = constraints

Σ = sum of weighted factors

The composite suitability score is unitless, with the highest values representing highest levels of desirability. Figure 12 shows the output of the analysis and highlights areas that are most suitable for the development of AD considering the criteria and constraints above.

2. Interpretation

The following general areas indicate a good to high degree of suitability for AD project development:

- Areas to the North/North-East/East of Killarney, with the proximity of the town and its large energy demand in facilities such as hotels being an advantage, in addition to the potential availability of grass silage, slurry and food waste within a short distance, offer significant potential for one or several AD projects.
- Areas to the East and South of Kenmare indicate high suitability for one or several farm-based AD projects, largely due to the availability of agricultural feedstocks and possibly food waste, as well as the proximity to the town and its dense energy use. These areas are outside of the Prime and Secondary Special Amenity Areas and are reasonably close to a National or Regional Road which means there is likely to be opportunities to assimilate an AD project into the landscape and highways network. There are a number of walking routes in the area to the

south which may make this area more sensitive to change. The areas contain agricultural buildings and have a low population density; there should be opportunities for an AD project that will not impact residential amenity.

- Equally, areas in the Western side of the region indicate a good degree of suitability, again due to the availability of agricultural feedstocks and possibly food waste, and the proximity to a number of towns and villages with their energy demand. Here, the ambitions of Valentia Island Sustainable Energy Community (SEC) for renewable energy and hydrogen development might offer interesting opportunities for the development of AD. These areas are outside of the area of the Prime and Secondary Special Amenity Areas and are reasonably close to a National or Regional Road which means there are likely to be opportunities to assimilate an AD project into the landscape and highways network. The areas contain agricultural buildings and have a low population density; there should be opportunities for an AD project that will not impact residential amenity.
- The coastal area between Castlemaine et Annascaul, and the surroundings of Annascaul also have the potential to sustain a farm-based AD project development again due to the potential availability of agricultural feedstocks. Here, the 60 km distance to a potential gas grid injection point in Listowel is an advantage. It is also worth pointing out that the Dingle SEC and the West Kerry Dairy Farmers SEC ambitions to develop AD projects could offer interesting opportunities. The area is outside of the Prime and Secondary Special Amenity Areas and are reasonably close to a National (N86) which means there is likely to be opportunities to assimilate an AD project into the landscape and highways network. The area contains agricultural buildings and has a low population density; there should be opportunities for an AD project that will not impact residential amenity. The area is surrounded by ecologically sensitive areas and AD projects will need to carefully assess any potential impacts on the environment.
- Areas around the Killorglin, Milltown and Castlemaine axis appear to have a lower degree of suitability for AD development due to their dairy farming orientation, restricting the potential availability of grass silage. However, this is mitigated by the strong availability of cattle slurry, the density in energy demand in these urban centres, and the absence of ecological or landscape planning policy protections. Additionally, the network of major roads in the area are likely to have capacity for the additional traffic associated with an AD project. The low population density and presence of agricultural and industrial buildings means an AD project could be accommodated which does not harm residential amenity.

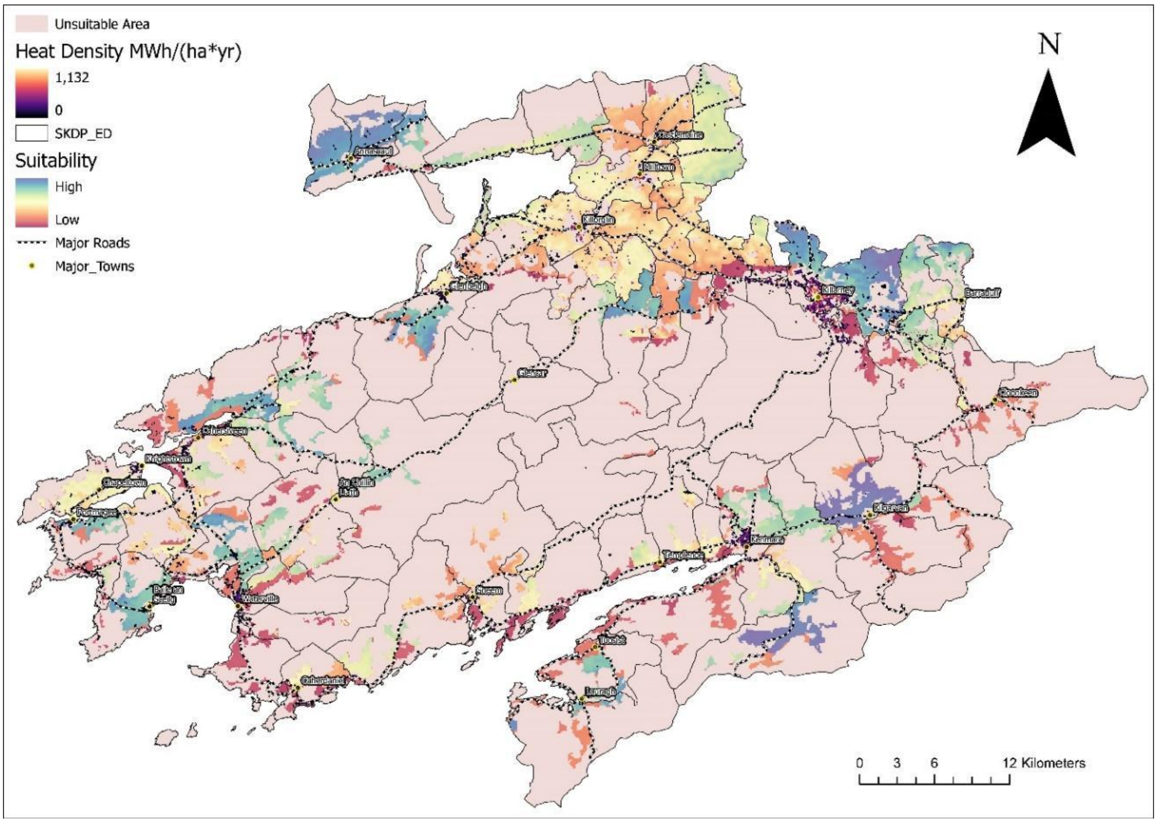


Figure 12: Site suitability map for AD development in the study area.

3. Planning Considerations

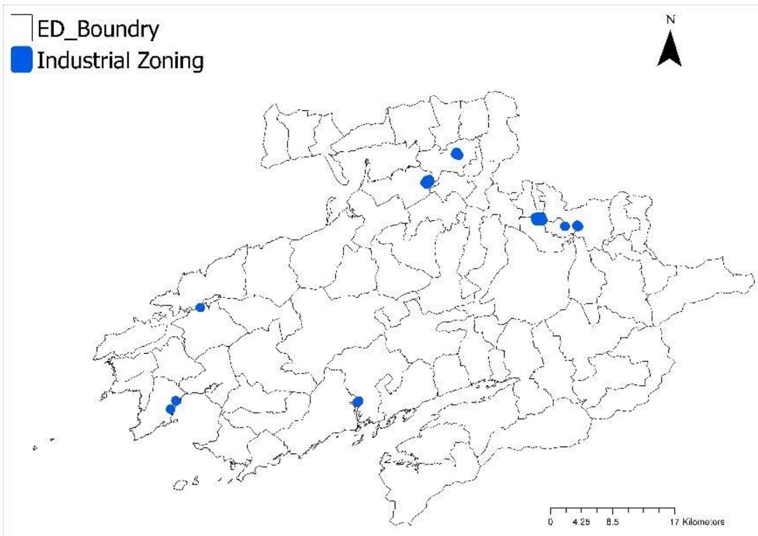
This section provides a commentary on the planning policy approach for AD projects at different scales within the study area. The types of projects considered, based on descriptions set out in planning policy at a local level (outlined in Appendix B), include:

- Type 1: AD projects using predominantly non-agricultural feedstocks or large-scale farm based AD projects.
- Type 2: small scale AD projects treating the waste from an individual farm through medium-sized centralised facilities dealing with wastes from several farms.

For type 1 projects, current planning policy at a local level seeks to locate such projects:

- On brownfield sites within or adjacent to industrial areas, or
- co-located with wood processing industries

Figure 13 identifies the location of industrial lands within the study area. In total 85.6 ha of land is zoned for such purposes.



On lands noted above, the principle of development would be acceptable in planning terms and the assessment of the proposal would consider the impacts associated with the proposal e.g.

- Is the proposal close to the point of demand & source material,
- Can the road network accommodate the increased traffic flow,
- Will the proposal impact residential or visual amenity, and
- Other material planning considerations

Type 1 projects may also be located on brownfield land in rural areas, but such proposals are considered on a case by case basis and the suitability of the site will be assessed by Kerry County Council.

Type 2 projects can be located in the same locations as type 1 projects and will also be subject to the same development management considerations. The projects additionally can be located on farms and where possible should be located close to farm buildings and the point of demand. The locations with the greatest potential have been identified above in the interpretation of the MCA results section. Case Studies for AD projects in rural areas in Ireland have been provided in **Appendix A** for reference.

The siting of an AD plant is a very sensitive matter that will require detailed spatial and environmental planning, and careful stakeholder engagement and consultation with the community. The spatial analysis conducted above provides a basis of knowledge and data to support exploring the issues concerned and potential locations. The next step for an AD project would be to undertake a more detailed feasibility study in terms of spatial analysis and assess potential locations identified from the MCA above, with a view to review at a higher resolution:

- The factors and constraints mapped during the MCA.
- The AD feedstocks available within an appropriate distance from the potential AD locations selected.
- Capacity to connect to nearby energy users, energy networks (electricity grid, gas grid, district heating, etc.), or potential refuelling points for vehicles.
- Access and the logistics of transporting the feedstocks to the proposed plants.
- Access and the logistics of transporting the biomethane produced by the plant to a distant user or injection point to the gras grid, as well as of distributing secondary products (digestate, compost, CO_2, etc.).

High resolution copies of the maps presented above are available to facilitate this work.

4. Key Considerations About the Sustainability of Developing Anaerobic Digestion in South Kerry

With a minimum of 1.6 TWh of biomethane likely to be developed by 2030, in line with the Government's National Energy and Climate Plan 2021-2030, Climate Action Plan and the Renewable Heat Obligation consultation, this could see the development of up to 80 medium-scale AD plants (with an average of 20 GWh/yr biomethane output). This target has been raised in July 2022 by Minister Ryan to 5.7 TWh/yr by 2030, with a potential for 150-200 AD plants (indicating a focus on larger plants).

In this chapter, we review key considerations for the sustainable development of AD in the study area, with a focus on the agri-based AD model utilising grass and slurry as primary feedstocks. Sustainability concerns relating to this model pertains to three key issues: feedstock procurement, nutrients management and greenhouse gas emissions. The associated regulatory and compliance framework associated with these issues will also be discussed. In addition, the integration of grass-based biorefineries with AD is considered in the context of farm diversification and a circular economy approach in the agricultural systems of South Kerry.

A. Sourcing AD feedstock sustainably

4. Grass silage

Grass silage is considered as the primary feedstock for AD development in the study area (and in Ireland) due to its wide availability and suitability for biogas production. As discussed in the feedstock assessment in Chapter 1.B.1, one scenario is to increase yields from existing grassland by an average of 4 tDM/ha/year. However, this assumes additional inputs of fertiliser and lime to **build soil fertility to optimum levels**, in a targeted manner (target index three). However, once soils have reached optimum fertility, only maintenance fertiliser will be required at higher productivity rates. Digestate, the by-product of AD can be used as a biofertiliser to displace chemical fertiliser use and if it has sufficient nutrient quality and availability, it may be suitable as a maintenance fertiliser.

In the context of recent agriculture and climate policy changes, the alternative scenario of reducing herd numbers and using the freed up grassland to produce good quality silage for AD plants seems more sustainable, working within existing productivity levels. Introducing clover or **Multi-Species Swards (MSS)**[7] has showed promising results for feedstock production at reduced fertilisers input. This combined with the use of AD digestate as an organic fertiliser will significantly improve the environmental impact of silage production and the sustainability of grass-based AD. Additional work from Dowth shows an increase in 300% of the earthworm population (an indicator species for soil health and biodiversity) under MSS compared to monoculture ryegrass, while MSS requires less pesticides and fertiliser than ryegrass. The requirement of regular application of lime was also found to reduce when optimal conditions have been achieved with MSS and may even be eliminated.

5. Slurry

As discussed in 2, slurry is an important AD feedstock first because its readily available as a 'by-product' of beef or dairy farming in the study area. However, slurry has a low dry matter content **and low energy density** (biogas potential per tonne

[7] Multi-species swards refer to a mixture of three or more species whose growth characteristics complement each other resulting in improved productivity compared to the typical ryegrass monoculture. Perennial ryegrass and timothy provide strong early-season growth and quality while legumes like white and red clover feed the sward with nitrogen fixed from the atmosphere and boost protein. As well as providing excellent quality, mineral-rich forage in the summer months, deep-rooting herbs like ribwort plantain and chicory are extremely drought tolerant which is an increasing concern for many Irish farmers (source: https://www.dlfseeds.ie/multi-species-r-d)

of fresh weight). This has serious implications in terms of digester size (and the associated capital cost) as well transport requirements in terms of cost, traffic and fuel use.

On the plus side, the **treatment of slurry with AD** and application of the digestate as an organic fertiliser to land[8] has a number of positive environmental impacts, compared to spreading raw slurry (KPMG Sustainable Futures, 2021):

- It reduces the pathogen load to the environment compared with the spreading of raw slurry.
- The digestate contains significantly less volatile organic acids and therefore less odour emissions.
- The digestion process organic nitrogen (N) is released as ammonium (NH4+), with more N available to plants[9].
- The digestion of slurry reduces significantly GHG emissions compared to raw slurry storage in typically open tanks and application to land (see Chapter 5, section D).

Slurry is also an important feedstock for the anaerobic digestion process as provides a good substrate for digestion of other materials. Slurry typically has a low dry matter content which allows the operator to maintain to correct dry matter levels within the digestor tanks. This co-digestion of grass and slurry is more stable process than mono-digestion of silage.

6. Sustainability Criteria of the Revised Renewable Energy Directive

For biomethane gas from AD plants to be classified as a zero-carbon renewable fuel, plants must be able to achieve strict sustainability criteria as outlined within the EU Renewable Energy Directive II ("RED II") and future RED III criteria. The RED II criteria stipulate that biomass fuels produced from agricultural biomass cannot be derived from raw material obtained from (1) land that was formerly peatland; (2) lands with a high biodiversity value; and (3) lands with a high carbon stock. In addition, RED II requires that all biomass fuels used for electricity, heating and cooling must achieve at least a 70% GHG emission saving, increasing to 80% for installations that start operating from 2026.

Capturing methane from slurry reduces very significantly the amount being released to the atmosphere, thereby having the effect of being carbon negative and improving the overall GHG savings of the AD facility. Analysis has demonstrated that it will be possible for Irish AD plants using grass silage as its primary feedstock to produce biomethane which meets RED II sustainability criteria if slurry is included as a co-feedstock. Studies conducted by XD Consulting, SEAI and KPMG converge in establishing the proportion of slurry required to meet the 2026 RED II Sustainability Criteria (80% GHG emission savings) to be ranging 40-55%.

7. Animal By-Products Regulations

The EU Animal By-products regulation classifies livestock wastes such as cattle slurry and manure, as Class 2 Animal By-products (ABP). Use of these feedstocks in a biogas plant is subject to several constraints including thermal treatment, size reduction, validation, storage, plant layout, plant management, monitoring, recording and reporting; all of which have substantial capital and operating cost implications. The implications of complying with the ABP regulations require a step change in the complexity of the plant. There is only one exception: small volumes of slurry from a single farm (< 5,000 tFM/year) can be processed by an on-farm biogas plant without conforming to the ABP conditions above, provided that the digestate is recycled to land of the same farm

For the AD pathways considered, agri-based AD plants will require very significant volumes of cattle slurry in addition to grass silage to meet the RED II Sustainability Criteria, which will have to be sourced from a number of farms. Compliance with the ABP regulations will be applied by default in the AD pathways considered.

[8] Digestate is a nutrient-rich substance which consists of the organic products of digestion, left over indigestible material, live and dead micro-organisms. All the nitrogen, phosphorous and potassium present in the AD plant's feedstock will remain in the digestate. However, the nutrients are more available to plant growth than the original material.
[9] Ammonium is ionized and has the formula NH_4^+.

J. Nutrients Management

1. AD digestate as an organic fertiliser

While digestate is a by-product of AD, it will play an important role in the industry. Digestate will supply sustainable quantities of the nutritional requirements of the plants forage feedstocks by being land spread at targeted stages in the crop's development cycle. As fossil-based fertilisers become more expensive, good management of the nutrient content of digestates will become important as a cost-saving measure for farms. Digestate is also packed with trace elements and potential animal and plant pathogens are significantly reduced, and in most cases are eradicated, due to the requirement to pasteurise the feedstock as required by the ABP regulations.

Spreading digestate falls under the Nitrates Action Programme and must adhere to strict conditions. The nutritional value of digestate varies depending on the AD plant's diet. Farm based digestate values, which is based on slurry and forage, has a higher dry matter but lower total and available N (3.6kg N/t and 2.8kg N/t respectively). Typical P values are higher at 0.7kg/t while K comes in much higher at 3.6kg/t. Food-based digestate (unseparated) could have a total N value of 4.8kg/t with around 3.8kg/t of this readily available; typical P values comes in at 0.5 kg/t while K comes in at 2kg/t with typical dry matter of 3.8% (KPMG, Devenish, Gas Network Ireland, 2021; AHDB RB209 Organic Materials).

Managing the digestate is an important aspect of an AD project development and establishing a nutrient management plan in conjunction with farmers in the vicinity of the plant is an essential part of planning the project. Applying the digestate as an organic fertiliser to the grassland producing the grass silage used by the proposed AD plant will not only help close the nutrient cycle in the project catchment area, but also play an important role in improving the sustainability of the agricultural system underlying it.

The review conducted by KPMG, Devenish and Gas Network Ireland (2021) of best agronomic practices in Europe for nutrient management with AD highlights a number of key principles:

- Adherence to the Water Framework Directive as a minimum standard.
- The submission of a detailed nutrient management plan that addresses soil nutrient status, the nutrient value of the digestate and the nutrient requirements of the crop that is grown.
- Application techniques that minimise the risk of nutrient run-off and ammonia emissions are industry best practice and should be followed (see section 3 below).
- The provision of enough storage capacity at the AD facility and the facility's farms is of fundamental importance. All European countries have closed periods where no application is allowed.

2. Nutrients Recovery

Value of digestate depends on NPK content and nutrient availability, which can vary significantly with the feedstocks used, processing technology, application method and soil quality where is it applied. Nutrient recovery technologies aim to increase the availability of nutrients in the digestate and process it into a more concentrated form. The nutrients harvested from these processes can help improve the commercialisation of the digestate. As fossil-based fertilisers become more expensive, good management of the nutrient content of digestates will become important as a cost-saving measure for farms.

There are different nutrient recovery solutions commercially available in well-established markets such as France, Germany and the UK (e.g. Vapogant), and we refer to the work done in the framework of the Project Clover for recommended solutions and the associated business case (KPMG Sustainable Futures, 2021). In this feasibility study, the only digestate treatment considered is the separation of the solid fraction from the digestate and its composting to provide a horticulture grade compost to be commercialised as part of the proposed AD projects.

3. Impact of digestate on other farm emissions & eutrophication of waterways

While the AD digestate provides organic nitrogen more readily available to plants, there are concerns relating to the potential increase in ammonia (NH_3)[10] and nitrogen oxide emissions (NO_2) when applying straight digestate compared to animal slurries. This is because the AD process increases the pH of digestate (pH 7-7.5). However, mitigation strategies such as covered storage, trailing hoses/shoes, direct injection into soils and ammonia harvesting technologies will be standard on many plants. Nitrous oxide (N_2O) is a naturally occurring GHG released from soils. Excess N_2O is released when nitrogen fertilisers are added to soils. However, the use of digestate from AD has been shown to reduce N_2O emissions.

A major environmental concern with land application of digestate is the potential contamination of surface and ground waters with excess nitrogen and phosphorus. In terms of nutrient leaching, digestate is deemed to have at least a similar impact on water bodies as slurry. However, AD reduces the Biochemical Oxygen Demand (BOD) by circa 40% compared to slurries, thereby reducing the potential for water pollution. The nutrient leaching potential following the application of digestate depends on factors such as fertilisation strategies, soil texture, topography, precipitation and cropping systems.

Best management practices that mitigate nutrient leaching include nutrient management planning to predict the nutrient supply for the crop grown and the use of soil tests. Recommended digestate application techniques should follow Low Emission Slurry Spreading advice provided by Teagasc.

K. AD and grass-based biorefineries in South Kerry

In 2020, XD Sustainable Energy Consulting conducted a feasibility study on behalf of the Institute of Technology Tralee for the Biorefinery Glas project. The purpose of the study was to analyse the business case for the grass biorefinery system, assessing the potential for diversification from existing farming enterprises and recommend suitable business models for uptake and wider replication of the grass biorefinery.

The biorefinery system processes fresh grass as its primary feedstock to produce a number of products suitable for animal alimentation, as illustrated below. The following outputs are key products and by-products of the biorefinery plant:

- Protein concentrate: The protein concentrate is an excellent local, environmentally friendly replacement for imported soya meal to be used in the production of animal feed for cattle, pigs, poultry and pet food.
- Ensiled protein fibre: The press cake produced by the extrusion process is directly ensiled to preserve it. It serves as a roughage for cattle[11].
- Fructose Olio Saccharides (FOS): The FOS concentrate extracted from the juice by nanofiltration is a soluble dietary fibre with sugars that can improve the health of the intestine of both humans and animals., acting as a prebiotic.
- Phosphate and other minerals concentrate: This phosphate concentrate obtained by precipitation from the whey is a natural source of fertiliser equivalent to bone meal, albeit in liquid form.

[10] Ammonia is un-ionized and has the formula NH3. The major factor that determines the proportion of ammonia or ammonium in water is water pH.

[11] Feeding trials undertaken as part of the Biorefinery Glas project have shown that cows digest the ensiled fibre cake more efficiently than regular silage, with a positive effect on milk production and reduced ammonia and phosphate levels in the manure.

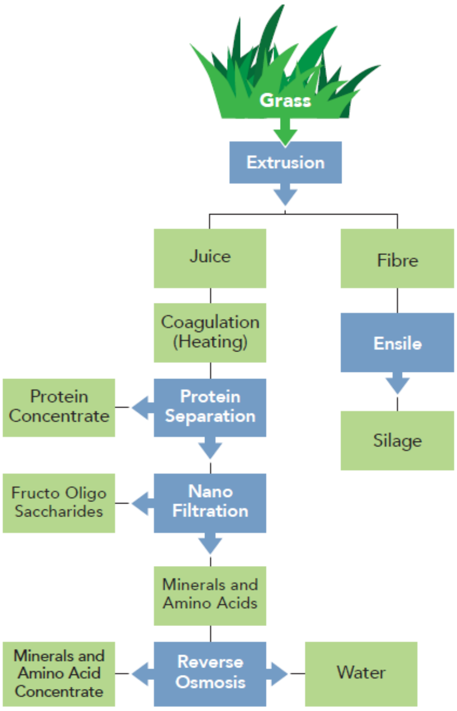


Figure 14: Grass biorefining process. Source: biorefineryglas.eu

Figure 15: Mobile, containerised grass biorefinery plant. Source: biorefineryglas.eu

Since the process is relatively energy intensive and the biorefinery whey is a good biogas potential, the feasibility study considered the integration of the biorefinery plant with an anaerobic digestion (AD) plant, equipped with a combined heat and power (CHP) unit to meet the heat and electricity requirements of the biorefinery system. Integrating AD with the biorefinery process has the additional benefit of increasing its circularity by treating its effluent to produce renewable energy, while reducing the requirement to divert an agricultural feedstock, grass silage, from food production.

To validate this, a mass and energy balance analysis of a semi-industrial biorefinery capable of processing 8 tonnes of fresh grass per hour, operating 16 hours per day, was conducted. An AD plant treats all of the biorefinery's effluent to produce biogas which is burned in a CHP unit. The further advanced is the biorefinery process, the lower will be the biomethane potential of the biorefinery effluent. If the biorefinery process doesn't include FOS extraction, the digestion of the effluent (the whey) produces enough biogas to meet the energy requirements of the biorefinery, leaving a surplus of approximately 100 kW of heat and 240 kW of electricity. If the biorefinery produces FOS in addition to the protein concentrate and the ensiled fibre, the digestion of the effluent (filtrate) will not produce sufficient biogas to meet the energy requirement of the biorefinery.

The financial analysis conducted as part of the above feasibility study concluded that the integration of AD with the biorefinery and the production of FOS are key to the profitability of a biorefinery project. In this context, the development grass biorefineries in South Kerry will not make a net positive contribution to the supply of renewable energy in the region, unless very significant energy efficiencies can be achieved in the process (e.g. heat recovery). This is compounded by the fact that AD projects, as they are envisaged in this study, and biorefineries will largely be competing for the same feedstock, grass.

5. The Greenhouse Gas Emissions Impact of Agri-based AD projects in South Kerry

This section investigates the potential for greenhouse gas (GHG) emissions reduction arising from the development of agri-based AD projects within the study area.

A. Methodological framework

1. AD system description and boundaries

There are three main areas within the GHG balance of an AD system to consider when attempting to quantify and qualify the potential for emission reduction:

1) The feedstock mix supplied to the digester, considering the GHG emissions produced or avoided with each feedstock sourced from farms, such as grass silage, slurry and manures. This analysis considers the inputs and outputs of the grass silage production system (grass cultivation, production of silage and transport to the AD plant), and changes in slurry emissions due to its use as an AD feedstock as opposed to conventional land spreading.
2) The potential for carbon sequestration in the soils receiving the digestate from the AD project, and the associated organic matter, accumulating and locking in carbon over long periods of time based on the growing methods of the associated crops, in this case grass, clover and potentially MSS.
3) The GHG avoided by substituting fossil fuels with the biogas or biomethane produced by the AD plant. In this part of the AD system, the energy inputs and outputs of the processes involved, and the final use of the biogas/biomethane produced are assessed.

In order to reduce the complexity of such analysis, we have defined the AD system and its boundaries as follows:

- The AD system uses a combination of grass silage produced within a radius of 10 km on grass land with good level of fertility, and cattle slurry sourced from farms within a 5 km radius.
- The AD system produces a total net amount of biomethane equivalent to 20 GWh/yr, with the system including biogas cleaning and upgrading to high-grade biomethane, the recovery of the CO_2 fraction of the biogas at a food-grade standard, and the separation of the solid fraction of the digestate.
- The AD system processes are as energy efficient as possible in terms of heat production/recovery as well as electricity for pumping, mixing, compressing, etc. Where cost-effective, the use of combined heat and power is integrated into the system to supply the electricity requirements of the plant (if this leads to excess heat being available, it is assumed that it will be used locally).
- The AD system's digestate (liquid and solid fraction) is returned to the lands surrounding the plant, within a 10 km radius, assuming that it replaces mineral fertilisers and contributes to the carbon cycle of the land used to produce the grass silage supplied to the AD plant.
- The AD system's biomethane output is compressed and stored onsite, before being transported to user site(s), or a natural gas grid injection point, within a 50 km distance, using a set of Bio-CNG trailers with the trucks fuelled with biomethane.
- The biomethane produced substitutes LPG, gasoil or natural gas in thermal or transport applications.

Figure 16 below illustrates the nature of the 'case study' AD system considered for this analysis.

2. Modelling approach and assumptions

The mass flow, energy balance and GHG emissions of the case study AD system has been modelled, considering the main inputs and outputs associated with the value chain from grass production to biomethane end-use. Please note that the embodied energy and carbon of the system's hardware (the physical capital of the plant such as the materials going into the AD plant construction, the machinery used, etc.) have not been considered as part of the analysis. The analysis focuses on the operational flows of the AD system (equivalent to Tier 1 and Tier 2 emissions).

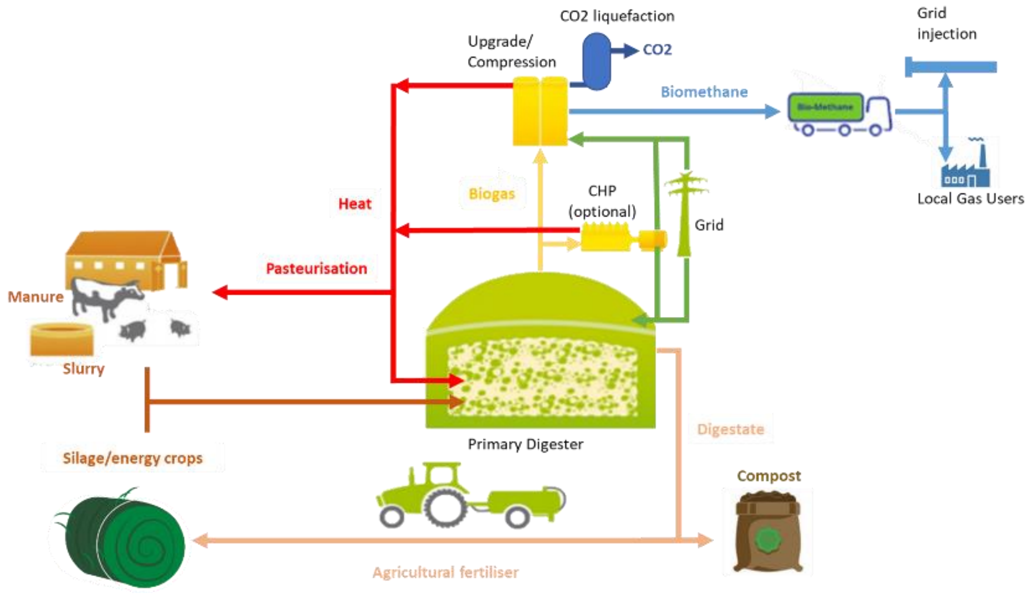


Figure 16: Case study AD system for GHG balance analysis.

The GHG emissions of the proposed AD systems are calculated using the REDII Methodology, using primarily the BioGRACEII model. The GHG emissions associated with the biomethane produced are compared to fossil methane with a specific emission factor of 72 g CO_2eq/MJ, to calculate the greenhouse gas emissions avoided and check compliance with the REDII target of 80% emissions saving for 2026.

It is assumed that the AD facility is built to best industry standards with gas-tight digestate storage is used. These assumptions are important as this allows for the best practice rate of fugitive emissions of 1%. Fugitive emissions have been documented at 3% in some cases which has a major detrimental effect on GHG emissions savings.

L. GHG balance of AD feedstocks

The main feedstocks modelled for use by the case study AD system are animal slurry and grass silage. REDII allocates a credit of –45 gCO_2/MJ of biomethane for the digestion of slurry. This accounts for the emissions which are avoided from slurry storage and spreading which would otherwise occur.

Silage however has upstream emissions associated with growing the grass, harvesting, preservation and transport. Lime is assumed to be applied every year at a rate of 1.2 tonne per hectare to improving soil health (applied in all scenarios for consistency). Potassium and phosphorus are applied to balance the off-takes of silage using typical nutrient values. The N_2O emissions are calculated using the IPCC method.

Three different perennial feedstocks are evaluated here based on the approach and results from Devenish experiments in Dowth (KPMG, Devenish, Gas Network Ireland, 2021): a) perennial ryegrass (PRG) as representative of the typical existing farm system used in Ireland; b) a grass-clover (GC) mix and c) a multispecies sward (MSS) have been evaluated under reduced nitrogen application scenarios. The specific grass silage yield and nitrogen application rates used in the analysis, are given in Table 7 below.

Table 7 Grass Sward types, yield and applied Nitrogen

	MSS	Grass-Clover	PRG
Yield Dry Matter (tDM/ha)	11.6	14.1	11.9
Total Applied Nitrogen (kgN/ha)	90	135	195

Nitrogen is a key driver of forage growth rates however the application rate of synthetic nitrogen is also a major driver of emissions . Nitrogen fertiliser is a made in an energy intensive process normally using fossil gas. The nitrogen fertiliser also has an effect on the N_2O emissions which have a multiplier of 298 time the global warming effect of carbon dioxide.

The advantages of GC and MSS is that it is possible to achieve good yields with greatly reduced additional nitrogen application due to the leguminous crop's symbiotic relationship which nitrogen fixing bacteria. Indeed Moloney et al found yields from MSS greater than 11 tDM/ha,yr without the addition of nitrogen. While a reduced amount of nitrogen application has been assumed with GC and MSS (in line with Devenish findings in their experiment), further reduction of nitrogen usage are possible with improved management.

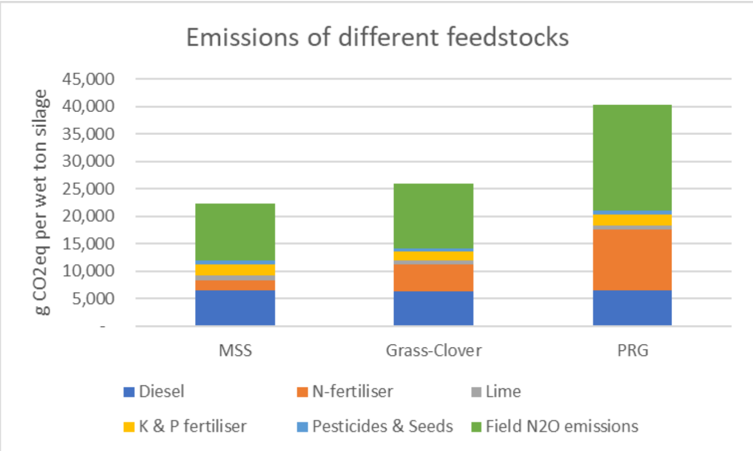


Figure 17: GHG Emissions of silage made from different sward types. Source: XD Consulting.

The GHG emissions associated with the three silage feedstocks were analysed as part of this study, and are presented in Figure 17 above. The biggest contribution is made by N_2O emissions in the field, which is particularly pronounced with increasing rates of synthetic nitrogen fertiliser application as with PRG. This followed by the significant GHG emissions associated with the manufacture of this nitrogen fertiliser. The diesel used for the harvesting and transport of the silage is also significant. This is a consistent across the 3 feedstocks and is unlikely to improve significantly in the future, unless tractors powered by biomethane are used.

M. Carbon sequestration potential on grassland

Interest in measuring, verifying and monetising soil carbon sequestration is rapidly growing among the farming industry. Carbon sequestration is where carbon dioxide in the air is captured by plants and then stored in the soil. For example, grass, tillage or cover crops take in carbon dioxide and the plant material helps to build soil organic carbon (SOC), which is directly related to soil organic matter. Soil carbon sequestration is noted as a crucial climate mitigation measure in the most recent IPCC report, as well as being highlighted in the EU Farm to Fork Strategy, Ag-Climatise and the Climate Action Plan. Anaerobic digestion (AD)'s digestate is a homogenous material that makes for an excellent bio-fertiliser and can assist in soil carbon sequestration due to its addition of organic matter back into the ground.

Irish grassland soils contain approximately 120 tonnes of carbon/ha which equates to around 30 years of Ireland's GHG emissions. It is estimated that Irish grasslands maintain an average saturation of 48%, highlighting the potential opportunities to increase carbon sequestration in both cases (KPMG, Devenish, Gas Network Ireland, 2021). It is widely agreed that soil carbon does not increase without limit, but eventually reaches a saturated level. By using farm digestate as a substitute or partial substitute to chemical fertiliser, along with the adoption of grass-clover and multi species swards in the production of food or feedstock, farmers can increase SOC levels over time (Ecological Continuity Trust, 2022).

Soil organic carbon levels in grassland are influenced by a range of factors including soil type, use, fertiliser management, liming, cultivate on, re-seeding, grass species, use of mixed swards etc. In general, as land productivity, soil health and fertility increase, so too does soil organic carbon levels. Increasing soil organic carbon levels in turn improves soil cation exchange capacity (CEC)[12] which increases its nutrient availability, water holding capacity and overall fertility. Healthier soils create larger crops which increases root and crop residue carbon input into soil, see Figure 18. This is particularly important for grassland soils which generally do not have the option of increasing SOC via straw chopping or cover crops. However, as a result, well managed and healthy long-term grassland soils may be limited in its SOC increase ability.

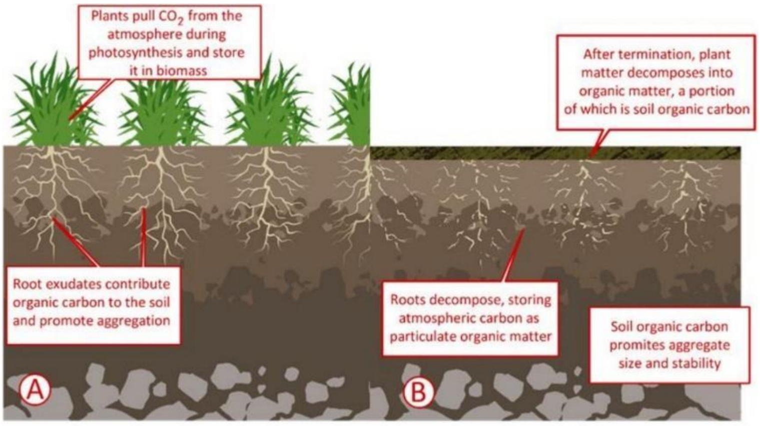


Figure 18: Soil organic carbon on grassland soils. Source: Gas Network Ireland.

The addition of organic manures is key to increasing SOC levels (M.I. Khalil, 2020). For example, adding farmyard manure or slurry over consecutive years results in a large build-up of soil organic carbon. AD digestate also includes a significant amount of stable carbon which when spread on grassland will contribute in a similar fashion to the build-up of SOC in soils over time. Overall, careful nutrient management is required to ensure crop nutritional requirements are met, soil indices and nutrient loading rates are not exceeded while enough of the digestate is still applied to build SOC levels.

It is also worth noting that hedgerows play an important role in carbon sequestration, with a sequestration rate at least comparable to SOC build-up in grassland soils. Well managed hedgerows have other multiple benefits including providing wildlife habitats and increasing biodiversity, improving rain retention and filtration, reduced soil erosion, as well as providing shelter for cattle.

It is important to note that ploughing and soil disturbance breaks up soil aggregates, and exposes the organic carbon in the soil to microbes. Microbes in turn use this organic carbon as an energy source, resulting in the respiration of CO_2. The practice of regular reseeding of grassland including the application of herbicide and ploughing negates the potential for carbon sequestration under grassland.

N. Overall GHG balance of case study AD systems

1. Definition of the systems:

Two types of AD system have been analysed (referred to as scenarios hereafter), both producing a net amount of 20 GWh/yr in biomethane exported from the plant, both using a mix of grass silage and cattle slurry as their feedstock:

- Scenario 1 is an farm-based 20 GWh plant with a slurry (45%) and silage (55%) mix sourced from multiple farms (pasteurisation is applied to meet the ABP regulations requirement). The biogas is converted into compressed biomethane and injected into the gas grid at the nearest injection point available (assumed to be Macroom at circa 50 km)[13]. Carbon dioxide is captured during the upgrading of biogas to biomethane and used as an industrial gas in the food/drinks industry (typically a by-product of hydrogen production from natural gas). The electrical power required is taken from the grid while excess heat from the upgrading plant and compressors is recovered to supply the most of the heat demand of the digester.
- Scenario 2 is similar to scenario 1 except for the addition of a combined heat and power (CHP) unit to meet the electricity requirement of the AD system. The provision of biogas to the CHP plant requires an increase in

[12] For further info on CEC, see https://en.wikipedia.org/wiki/Cation-exchange_capacity
[13] The compressed biomethane is stored in high pressure tanks mounted on a trailer and transported by truck.

digestor size and feedstock supply. The other difference is that the biomethane produced is sold to a local energy user within a 30 km distance, transported on a trailer & truck unit.

2. GHG balance analysis results

A GHG balance analysis was conducted for the co-digestion of animal slurry and silage on a fresh weight ratio of 45:55 using the three different types of silage as described in section Chapter 1.B above. There is a bonus for the digestion of cattle slurry of 45 g CO_2eq/MJ manure which is set out in the Renewable Energy Directive (REDII) for improved agricultural and manure management. This takes into account the reduction in emissions of methane when animal slurry is anaerobically digested in a sealed tank compared to the normal practice whereby the slurry is stored in slurry tanks and methane is emitted to the atmosphere.

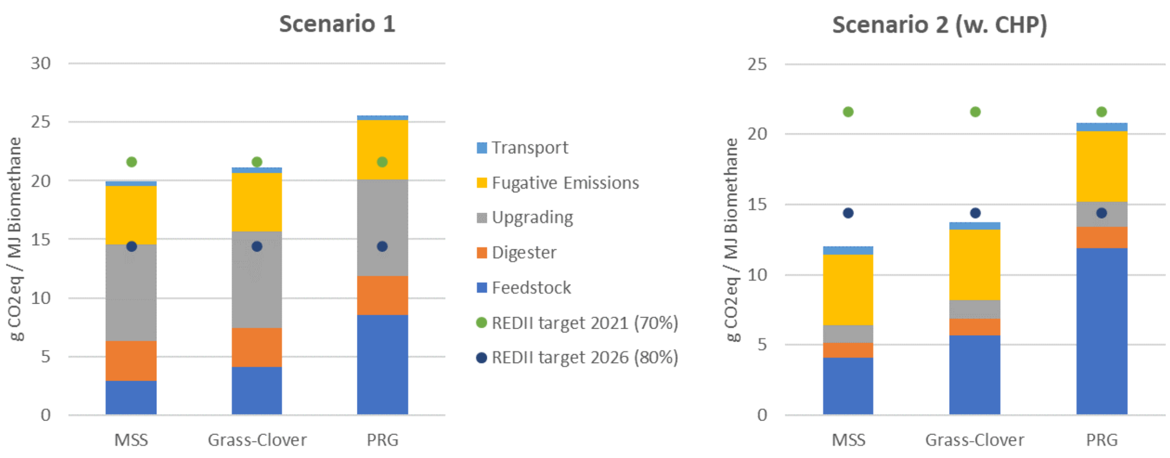


Figure 19: GHG emission balance of case study AD system.

In Scenario 1, the main contribution to carbon emissions comes from the energy consumption of upgrading biogas to biomethane. The electricity in this scenario is taken from the national grid and the associated specific emissions are taken using the average of the grid in 2020 (82 gCO_2/MJ as per SEAI, 2022). Fugitive emissions equally make a large contribution to emissions, and while best practices have been assumed in this case, it should be noted that poor management of fugitive emissions would make it the largest contributor to emissions.

When comparing feedstocks, it is clear that Perennial Ryegrass (PRG) makes the largest contribution to emissions compared to MSS and Grass-Clover, largely due to the use of nitrogen fertiliser and associated increase in $N0_2$ emissions. In this scenario, the emissions savings for biomethane are complaint with REDII for 2021 (70% reduction in GHG emissions, see Chapter 1.A.3 for details); however from 2026, none of the feedstock mixes would achieve the 80% reduction that will be required by REDII. From 2026, the ratio of animal slurry in the feedstock mix would need to be raised to 70% in the MSS and GC mix, to achieve this target.

In scenario 2, a CHP plant is used to provide the electrical power required by the digester and the biogas upgrading unit substituting the grid electricity used in scenario 1. Since the CHP unit uses biogas, this reduces the emission intensity of the overall AD system. While fugitive emissions remain a significant contribution, the role of emissions linked to feedstocks becomes more significant, particularly in the PRG scenario which achieves compliance with REDII for 2021 but not for 2026.

3. Carbon Saving from CO_2 capture and replacement.

There is a further emissions saving approved by REDII when the carbon dioxide recovered from the biogas upgrade is used as a replacement for industrial CO_2 from fossil-fuel origin. Currently, a large proportion of CO_2 supplied to industry originates from the manufacture of synthetic nitrogen using natural gas. The ongoing shortages and high increase in costs for natural gas have pushed the price of CO_2 through the roof. Combined with the long-term goal of the EU Farm to Fork strategy to reduce synthetic fertiliser usage in agriculture by 20% by 2030, and the New Green Deal's aim for a climate neutral agriculture by 2050, the importance of biogenic CO_2 as a 'by-product' of biomethane production will become even stronger. This analysis indicates that using a standard factor of 33.61 gCO_2/MJ biomethane would push certain biomethane pathways in negative emissions territory.

4. AD creating a Nitrogen Surplus in Digestate

The application of digestate from an AD plant using a mix of silage and slurry on perennial ryegrass brings back a significant proportion of the nitrogen to the grassland. However, the application of additional nitrogen from mineral sources is still required to achieve optimum yields (190kg N/ha in the scenario analysis above). In an AD plant using silage from grass-clover and MSS swards (requiring significantly less nitrogen), there could be an excess of circa 200kg of nitrogen per ha in the digestate which could be spread on other farmland where it would substitute mineral nitrogen. Considering that 1 kg of nitrogen is responsible for 5.3 $kgCO_2eq$ (KPMG, Devenish 2021) (SEAI, 2022), substituting perennial ryegrass silage with grass-clover or MSS silage would result in about one tonne of CO_2 equivalent in avoided greenhouse gas emissions per hectare. These are preliminary results which might not apply in all situations, but there is likely to be value to be realised from the carbon savings associated with the improved nutrient management resulting from more sustainable grass silage production.

O. Measurement & verification of associated carbon credits

Many actions which farmers currently are engaged in via the Common Agricultural Policy's environmental schemes, have inferred carbon savings, including the straw incorporation scheme, the multi-species sward scheme. In order to get the maximum value for the carbon credits generated, they need to be measured and verified. There are different methods for measuring and verifying carbon credits in agriculture e.g. from soil carbon sequestration, and the choice of method has a direct impact on the value of the carbon credit. The world standard Intergovernmental Panel on Climate Change (IPCC) process covers three tiers of carbon accounting. Tier 1 (bronze) and tier 2 (silver) both generate inferred carbon savings and don't physically measure carbon. However, under Tier 3, the sequestered carbon is physically measured and verified. Tier 3 measures carry a considerably higher premium on the market (carbon savings in Tier 3 return five times the revenue compared to Tier 1 or 2). However, while the return is higher per carbon avoided, the cost of measuring, verifying and trading carbon credits under Tier 3 is also high and the process is complex. Figure 19 illustrates this for soil carbon sequestration.

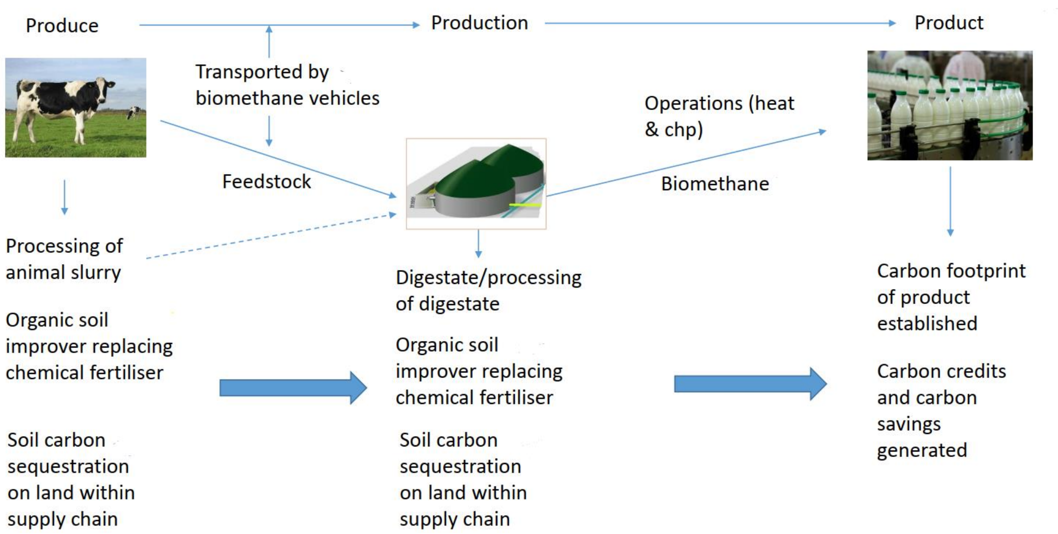


Figure 20: AD farm carbon sequestration model. Source: Gas Networks Ireland.

P. Potential additional farm income arising from environmental services associated with AD

The monetisation of the environmental services associated with the biomethane produced (greenhouse gas emissions avoided) is likely to take place under a biomethane certification scheme, with the associated carbon credits traded under the renewable heat obligation scheme or a biofuel obligation scheme. Under this system, organisations that use biomethane from the gas grid or directly from an AD facility will buy biomethane certificates from the producer. The reduction in emissions associated with storing slurry and digesting it is an important source of carbon credits, however they are associated with the production of biomethane and do not accrue to the farmer supplying the slurry as a feedstock for the AD plant. The main areas where greenhouse gas emissions reduction and carbon credits could be attributed to farmers participating to an AD project are:

- Switching from perennial rye grass to grass-clover or multi-species swards for the production of the silage supplied to the AD plant, leading to reduced synthetic nitrogen use (-105 kgN/ha as standard, down to zero nitrogen input in best practice situations, while maintaining reasonable yields). This could generate carbon credits up going from 0.55 to 1 tCO_2 equivalent per ha. The switch could also be extended to the entire farm thereby increasing the potential revenue in carbon credits for the farmer.
- The adoption of MSS together with improved soil fertility and grazing management, underlined by better farmer's knowledge, should lead to increase grassland productivity and maximised photosynthesis. This in turn should lead to significant gains in the amount of carbon sequestered in the soil pool under the grassland (between 1.1 and 3.3 tons of carbon dioxide equivalent per hectare [Fornara et al 2016]). Please note it could take up to five years of measurement before the amount of carbon sequestered can be verified and traded. The digestate produced from multi-species swards silage contains the equivalent of 200 kgN/ha in excess of the nitrogen used to grow the silage digested. If the digestate is used elsewhere and displaces synthetic nitrogen, this could lead to 1 tCO_2 in emission reduction (Ricardo Energy & Environment, 2017).
- The planting of hedgerows will not only contribute to carbon sequestration in and around the grassland, but will also have a positive impact on biodiversity, the landscape and rainwater retention and infiltration. Green et al estimate the sequestration potential at hedgerows as 0.66 - 3.3 tCO_2/ha.

Depending on the scenario of production of grass silage, either by productivity improvement or by reduction in stock numbers there will be further reduction in methane via enteric fermentation. Should farmer choose to reduce stock numbers and feed the resultant excess of silage to an AD plant it remains to be seen if carbon credits can be claimed by the farmer or the AD plant. In the scenario of reduction in stock numbers across the country of 15%, the farm that is growing feedstock for AD may reducing stock as opposed to increasing productivity of sward. For this scenario the reduction methane emissions via enteric fermentation is calculated based on the assumption that 50% of the farm is destocked to dedicate to silage production. The typical suckler farm with an average stocking rate of a 1.15 LU per ha is used while the emissions are calculated using 2020 national inventory enteric methane emissions per suckler cow (0.8 LU) (EPA, 2021).

Below summarises the potential CO_2 emissions resulting from the adoption of the above practices. If a typical family farm with 31 ha of productive grassland dedicates 50% to growing MSS for AD with 0.75 ha of hedgerows, and if a conservative value of carbon credits of €50 per tonne of CO_2 is assumed, this could lead to 100 tCO_2 of carbon credits generated per year at a value of over €5000 or €163 per ha. It is worth noting that carbon credits in the European Carbon Credit Market under the Emission Trading Scheme has been trading at between €75 and €80 over the last year, while nature-based carbon offset projects attract between €8 and €16 per tCO_2 for projects that fall under the Agriculture, Forestry, or Other Land Use (AFOLU) categories. As discussed above, the value of carbon credits depend very much on which level of measurement and verification regime they follow and therefore on the level of Tier they are traded.

Measure	tCO2eq avoided per ha	Ha	Total CO2 eq. avoided
Nitrogen Reduction	0.55	31	17.05
Nitrogen Substitution	1	15.5	15.5
Soil Carbon Sequestration	2.2	31	68.2
Hedgerows	1	0.75	0.75
Total			**101.5**
Livestock Reduction	1.48	31	45.9
Total (Incl Livestock Reduction)			**147.4**

6. Feedstock supply agreements models and cost/benefit for producers

Q. Introduction

Securing a reliable feedstock supply is fundamental to the viability of an AD project and obtaining a long-term supply contract from feedstock producers on acceptable terms is critical. The arrangement can have many benefits for each party. The AD plant operator has certainty of feedstock supply, at an agreed price and defined quality standards, over an appropriate period of time. The supplier, a farmer supplying slurry and/or silage to the AD plant, has a degree of certainty on his/her future income from his land and can better plan and manage his/her farming enterprise. Many farmers feeding fodder crops such as maize and beet enter into agreements where a tillage farmer grows a fodder crop for the livestock farmer. The livestock farmer gets a tillage farmer with crop husbandry experience and tillage equipment to plant and look after the crop.

R. Feedstock Supply Contract templates

Farmers supplying an AD plant with feedstock such as grass silage and purpose grown energy crops should develop and sign a feedstock supply contract. While any feedstock contract should be developed in conjunction with a solicitor, similarities can be drawn between said contract and the feedstock supply contracts developed by Teagasc. Teagasc has a sample contract template for growing maize, and this could also apply to other crops, such as grass silage.

The following are key elements of the contract and how they apply to supply grass silage and other possible crops to an AD plant:

- The first thing is to agree on the tonnage that will be supplied (if tonnage refers to fresh matter, the dry matter content of the crop should be specified). Teagasc has advised that this is stated in a range to allow for seasonal fluctuations.
- The contract should clarify if the grass will be supplied as a standing crop or will be delivered to the AD plant, and by what date it will be delivered. This should be a conservative estimate.
- Whether the silage is stored at the farm or at the AD plant needs to be ascertained, and the conditions of storage should be agreed on (length of storage, use of additives, density, etc.).
- The crop will be grown in accordance with best practice for grass production in Ireland (see 'Biomethane Charter' hereafter).
- The stage of the grass at harvest should also be stated as this has a significant impact on the digestible energy of the silage. The variety or varieties of grass, clover, herbs, legumes, to be grown should be stated.
- The grower will retain the entitlements and basic payment on the land used to grow the forage crop.
- An agreement to weigh the harvested grass silage, for all loads delivered or a minimum percentage.
- The grower and the purchaser agree that an independent third party should assess the quality of the crop on the basis of representative samples, and send a sample to a certified lab for dry matter and starch analysis.

Both parties should agree to a base price using the annual costs and returns values (most recent analysis conducted by XDC have assumed that the cost of silage ranges from €30-35/tonne of silage). There can be a plus or minus bonus or penalty based on agreed quality standards (e.g. dry matter, starch content, etc.), which should vary to reflect inflation. A deposit should be paid to the grower, as it acts as an insurance for the farmer.

A sample contract from Teagasc can be viewed in The Maize Guide. https://www.teagasc.ie/media/website/publications/2017/The-Maize-Guide.pdf . Another example of a general feedstock agreement can be found here. https://www.teagasc.ie/media/website/rural-economy/farm-management/Contract-Cropping-Template-Agreement-V1_May-2018.pdf

S. The Co-operative Model

Agricultural co-operatives have been very successful in Ireland and employ over 12 thousand people, with an annual turnover of €15 billion. The co-operative model has also been widely adopted for renewable energy development by communities across Europe, with over 3000 energy co-operatives with hundreds of thousands members.

David Shortall conducted research in the attitude of Irish farmers to the co-operative model for anaerobic project development as part of his Master Thesis research at NUIG, which indicates a strong appetite for AD co-operatives. The key reasons mentioned included (Robb, 2022): reduced financial risk, farmer collaboration, availability of fertiliser. 60% of farmers interviewed said that a co-operative model was the best way to establish an AD plant as it ensured continuity of supply of the feedstock, for silage as well as slurry.

The seven core principles of co-ops are:

- voluntary and open membership.
- democratic member control—one member, one vote.
- member economic participation.
- autonomy and independence—never owned as a subsidiary.
- education, training and information.
- co-operation among co-operatives.
- concern for community.

It is clear that these principles fit easily with the values of community-based organisations and provide a good structure for carrying out a business enterprise for the benefit of the community. The corporate structure and governance model, as well as financing options, for AD co-operatives are explored in detail in Annex C of this report.

A third of farmers surveyed by David Shortall state that a contract to supply feedstock was the most important factor to them. While contracts are not a big part of Irish agriculture, the survey showed that farmers want certainty of demand and a committed price for their produce. Having a contract to supply would allow farmers to calculate their actual costs of production and may also strengthen their borrowing capacity with financial institutions. A contract to supply scored higher than owning a shareholding (24%) or return on investment (27%) in the survey, showing that farmers want a fair price for the feedstock they would supply (Robb, 2022).

T. The Biomethane Charter

To ensure the successful roll-out of an agri-based biomethane industry, and protect against unintended negative consequences, GNI' Sustainability of Biomethane Report suggest the development of a Biomethane Charter which would apply to biomethane projects being developed in Ireland. The aim of such a Charter would be to outline the key requirements that participants in the biomethane industry should adhere to. The Charter could be developed to cover AD plant developers and owners, those supplying feedstock into AD plants, plant operators, and those farmers acting as off-takers for the digestate (KPMG, Devenish, Gas Network Ireland, 2021).

A potential approach which would incorporate a two-tier approach to ensure compliance is proposed: (i) Tier 1 (compulsory compliance), (ii) Tier 2 (optional best practice). Each level of compliance will cover the following broad areas:

TIER 1 – COMPULSORY COMPLIANCE				TIER 2 – OPTIONAL BEST PRACTICE			
Sustainability Criteria				Improved Land Management Programme		Advanced Measurement, Reporting & Verification (MRV)	
RED II alignment	Nitrates Action Programme compliance	SMR/GAEC alignment	EU Farm to Fork goal reduced nutrient loss	Advanced EU Farm to Fork goals	Soil Improvement Programme	Biodiversity Richness	Soil Carbon

Figure 21: Biomethane Charter's levels of compliance. Source: KPMG, 2021.

If subscribing to the charter, farmers participating to AD projects for the supply of feedstocks and off-take of digestate will have to adhere to a key requirements:

- Compliance with REDII and future REDIII Sustainability Criteria for the feedstocks supplied, including biodiversity, greenhouse gas content, etc.;
- Compliance with the Nitrates Action Programme (NAP) regulations, such as livestock stocking rates, maximum fertilisation rates and closed periods for spreading fertilisers as well as compliance with NAP reporting requirements, such as area farmed, storage facilities and livestock numbers on farm.

- Participating farmers would also be expected to align with the Statutory Management Requirements ("SMR") and Good Agricultural and Environmental Condition ("GAEC") standards associated with the Cross Compliance requirements of the CAP reform[14].
- Compliance with more ambitious Farm to Fork goals, including carbon sequestration, circular bio-based economy, reduce pesticide use and excess nutrients, reduce fertiliser use, increase organic farming. It is suggested that participating famers agree to target two of the above goals in addition to the displacement of an agreed proportion of chemical fertiliser with processed digestate - depending on farm type, soil quality and location.
- In addition, participating farmers will be expected to optimise soil health, nutrition and minimise soil compaction.
- It is proposed that Tier 2 participating farmers be required to provide periodic reports and sampling on the wider sustainability performance of their farm, adhering to a more comprehensive measurement, reporting and verification (MRV) framework to monitor the performance of participating farms, covering biodiversity richness and soil carbon levels.

[14] Cross Compliance introduced measures which are important for society in general, such as nitrate limits in fertilisation practices, protecting NATURA 2000 areas, food safety, animal welfare and the traceability of food from animals, biodiversity and climate change.

7. Exploring an agri-environmental pilot scheme to support AD deployment in the region

Agriculture as with other industries have been given targets to reduce emissions by 2030 and have a target of being climate neutral by 2050. The biggest emissions are related to enteric fermentation, N_2O and synthetic nitrogen usage. While some agriculture practices cause emissions, farms and farmers can reduce these emissions and also are in a relatively unique position of also being able to sequester and store carbon in soils. As climate change has become increasingly important, there is a growing focus on solutions agriculture can contribute and a lot more research is currently trying to identify, develop and demonstrate such solutions.

With the adoption of the Sectorial Carbon Budget for agriculture, cattle herd size reduction will become a reality for farmers in the region. There is a risk that many smaller farmers will simply abandon farming as it becomes more and more uneconomic to farm. This raises the potential that land might simply be abandoned and become overgrown/unproductive and unsuitable for many species etc. Such a scheme would help mitigate this as it might make other farm enterprises more viable.

Supplying quality grass silage as a feedstock for AD plants in the region presents an opportunity for alternative income, building on their existing farming infrastructure while adopting new environmental practices. In addition to the sale of silage, payments and funding from the new CAP will compensate farmers by rewarding them for reducing their GHG emissions, carbon sequestration, improving water quality and biodiversity.

An agri-environmental pilot scheme to support the deployment of AD in the region would pay landowners to produce silage for an anaerobic digester sustainably, at a fixed price for a period (subject to quality and quantity). Such a scheme would ensure a long term supply of feedstock for an AD plant WITHOUT the need to increase grass production in the region. This would ensure that land continues to be maintained and properly managed in the long term as payments to farmers would be directly linked to this. The potential benefits of such as scheme include:

- Reduced methane output from animals in the region, leading the transition to low-carbon agriculture nationally.
- A secure business model for the development of AD plants given input costs would be fixed for a period and supply of feedstock would be secure.
- Demonstrate how biomethane can support the decarbonisation of the energy system in the region and the country.
- Better land management leading to a greater level of biodiversity and more carbon storage.
- Reduced mineral fertilizer demand by using AD digestate as the primary source of organic fertiliser in the region, bringing environmental benefits as well as reducing production costs.
- Potential to keep rural populations in place by encouraging farmers to remain on the land – secure, sustainable long term income.
- Potential to encourage farmers to look at other renewable energy options to further help reduce GHG emissions.

A model such as this could be trialled in the region, using the recommendations of this report, paving the way for its deployment across the country. based on the outcomes of the AD report.

One of the challenges for agriculture to monetise the emission reduction it delivers, is the cost of measuring, verifying and trading carbon credits. These are well beyond what an individual farmer can afford as these costs can outweigh the value of carbon credits at that scale. This is related to typically the small size of farms in Ireland and the complexity of verification of the carbon credits. While a detailed cost/benefit analysis would be required to determine the minimum scale for a carbon credit management system to be viable in the region, a co-operative approach under one or several farm-based AD projects of 20 GWh/yr biomethane capacity each is a good candidate to make this work for the project developers and the farmers involved.

The measurement and verification processes could be administered centrally, and would fit nicely under the proposed Biomethane Charter (see Chapter 1.D) alongside auditing requirements for compliance with the REDII Sustainability Criteria as far as AD feedstocks are concerned. This may provide an opportunity to access the carbon credit market at premium rates, which previously would be unobtainable to the typical individual farmer. As discussed in Chapter 5, the regenerative practices which reduce emissions could be deployed on the entire farm holdings and not just the specific areas supplying feedstock for the AD facility. The support of an agri-environmental scheme would be crucial in undertaking baseline assessments and expanding the scope in which carbon credits are accrued to the farmers.

To achieve the optimal production of feedstocks while adopting carbon-reduction practices such as switching to multi-species swards will require upskilling farmers and knowledge dissemination. A regional agri-environmental scheme supporting the development of sustainable farm-based AD projects in South Kerry should also encompass outreach, training and advisory services for farmers, in addition to the carbon management system mentioned above.

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8. Appendices

1. Appendix A – AD Projects Planning Permission Case Studies

A.1 GreenGas, Dunmoylan, Shanagolden, Co. Limerick

Is a farm based AD Plant constructed in 2010. Planning Permission (ref: 03623) was originally approved in 2004 for the construction of a digester to process farm slurry for production of renewable energy and fertiliser. The scheme was revised twice (ref: 062936 & 10364) and extended in May 2012 (ref: 12154).

The biogas plant processes manure and slurry from McDonnell Farms poultry and dairy farm as well as other imported feedstock. It receives 21kt feedstock per year (Poultry manure 1 kt, Dairy manure 7 kt, Food waste 10 kt, and Dairy sludge 3 kt). It can produce over 2,400,000m3 of renewable gas per annum. The biogas is used as fuel in the onsite Combined Heat and Power Engine (CHP) which produces electricity and heat. They use some of the electricity produced for onsite and the majority is exported to the national grid. The nutrient rich digestate is used on local farm land as a high quality eco fertiliser.

A.2 GLENMORE ESTATE, AGHAVEAGH, DONEGAL

Glenmore Generation Limited operates a biogas facility on a site at Glenmore Estate. It commenced operations in 2017. Planning Permission was originally approved in 2014 (ref: 14/51399) for a commercial centralised anaerobic digester to produce renewable energy and fertiliser. The scheme was amended twice (ref: 15/51366 & 18/50910) and approval was received for an expansion in 2021 following appeal (ref: 1950042).

The AD plant accepts and treats 90kt of feedstock primarily comprising agricultural and food waste from within a 2 hour drive radius. It has a yield estimate of 8,000,000m3 of renewable gas per annum. The nutrient rich digestate is used on local farm land as a high quality eco fertiliser.

A.3 GREEN GENERATION, GURTEEN LOWER, NURNEY, CO. KILDARE

Planning Permission for this biogas facility was granted in 2003 (ref: 03/734). There were two subsequent planning permissions granted for amendments and extensions (ref: 06/2950 & 09/1058) and permission for an increase in the imported organic feed and associated development was granted in 2010 (10/846).

The site comprises a piggery and a biogas plant. They import 25kt of organic feed per annum from predominantly within 30km. The existing farm produces 24kt of pig manure each year. The AD has an estimated yield of 4,500,000m3 of biogas per annum. Half of the biogas is used to produce renewable electricity in a CHP which is connected to the national grid. A 1MW CHP biogas plant is operated on the site. The rest is upgraded to "biomethane" which is then used as either; a clean transport fuel or injected into the natural gas grid.

2. Appendix B – Planning Policy Summary

B.1 NATIONAL AND REGIONAL POLICY/GUIDELINES

At a national level, Ireland's Climate Action Plan 2021 (2021), National Planning Framework (2018), Our Rural Future - Rural Development Policy (2021), and A Waste Action Plan for a Circular Economy – Ireland's National Waste Policy 2020-2025 set out strategic goals in respect of transitioning to a low carbon circular economy and climate resilient society and sustainable management of waste resources. Each policy document supports increased uptake of anaerobic digestion. The Climate Action Plan notes the target is to contribute agricultural feedstocks and waste resources to the production of 1.6 TWh per annum of indigenous sustainably produced biomethane. Energy and Biomethane production are encouraged as part of diversification opportunities on farms.

B.2 REGIONAL POLICY/GUIDELINES

At a regional level, the Regional Spatial and Economic Strategy for the Southern Region supports the transition towards a low carbon and circular economy The Plan also promotes the efficient use of bio-based in waste resources and the development of indigenous renewable biogas production including biogas derived from waste. The Southern Region Waste Management Plan 2015-2021 includes as a key measure, growing the biological treatment sector, in particular anaerobic digestion (and composting).

B.3 DEVELOPMENT PLAN

Policies at a local level are more focussed on addressing the specific impacts and identifying appropriate locations for development including anaerobic digestors. The Kerry County Development Plan 2015-2021, sets out the current Core Strategy for the County including the study area. This will be replaced in 2023 by the new Kerry County Development Plan which is currently being prepared.

Within the current Core Strategy specific policies for biomass, combined heat and power (CHP), and anaerobic digestion are set out in the Renewable Energy Strategy 2012 (RES). Of particular relevance are RES policies NR 7-46 to NR7-53. In summary these policies seek –

- Commercial bioenergy plant will be considered on brownfield sites which are adjacent to industrial areas or on lands which are reserved for industrial uses in any development plan. Brownfield sites in rural areas may also be considered subject to the relevant development management standards. Commercial bioenergy should be close to the point of demand.
- Small scale developments close to the source material and where possible, be located in proximity to existing agricultural buildings.
- Bioenergy developments will not be permitted:
- in Natura 2000 sites or within designated and proposed Natural Heritage Areas or, ex situ of these ecologically sensitive areas,
- if the public roads do not have sufficient capacity to safely absorb increased traffic flows and adjacent to transport corridors, or
- where they affect residential or visual amenity.

When considering whether a development would impact visual amenity in rural areas, the relevant landscape designations contained in the County Development Plan will be a key consideration. Sites in 'Rural General' locations are the least sensitive to change. Sites which are in 'Secondary Special Amenity Areas' or protected by a designated 'Views and Prospects' can accommodate limited development and will be subject to careful consideration by the Planning Authority. Sites which area located within 'Prime Special Amenity Areas' have little or no capacity to accommodate development.

3. Appendix C: Business & Financing Models Appropriate for Community-Owned Anaerobic Digestion Project Development.

The objective of this chapter of the study is to review business and financing models appropriate for community participation in the development of anaerobic digestion in South Kerry, in consultation with key stakeholders. Models of community ownership promote wide participation in ownership and management, engender local support, are inclusive and deliver tangible and intangible local benefits, particularly for individuals that do not have sufficient funds to invest.

2. Ownership & Organisational Model

There are two possible structures to raise equity in the framework of a community-owned project: a limited company or a co-operative, also known as an Industrial and Provident Society (I&Ps). These two organisational structures are governed by separate legislation but subject to broadly similar requirements.

Both types of organisations provide 'limited liability', which means that members/ shareholders cannot be sued for more money than they have invested in the organisation. This protection is important for any group but particularly for community ventures. The organisation becomes a 'legal person' that has its own identity and can enter into contracts of various sorts including owning property, buying and selling. If things go horribly wrong, the organisation 'dies and members lose the money they have invested but there is no recourse to individuals' personal wealth.

The main differences that impinge on this project are the governance, the number of members and requirements regarding share offers. Some other differences regarding shares may also be relevant in terms of ensuring a truly community enterprise.

a) Governance & Membership

Both companies and I&P societies are managed on a day-to-day basis by a board of directors, elected by general meetings of the shareholders. Both need to have a governing document that is registered with the Company Registration Office. Both need to report annually to the CRO. Both can raise share capital, and both can make payments to shareholders.

Companies are controlled by their members (or shareholders) and controlled on the basis of share ownership; those who hold more shares wield more votes and exercise greater control over the company. The maximum number of members that a company can have is 100. This could be a major limiting factor as community projects aim to have hundreds of members.

Co-operatives are controlled by their members, who are also the shareholders. Each member has one vote, regardless of how many shares they hold. This prevents a small number of members from seizing control. There is no limit to the number of members that a Co-op can have.

b) Share Raising

Companies raise capital by selling shares, which they can do on an informal basis with small numbers of engaged people but if they issue a public share offer, they will need to comply with detailed legislation that will require lawyers and accountants at significant expense. European Securities and Markets Authority (ESMA) list all European share prospectuses.

Co-ops can issue a share offer without great expense and raise the required capital. Interest can be paid on this to incentivise investment although the rate paid should only be sufficient to obtain and retain the investment. The finances should be sufficient to pay an average (IRR) of about 6% and be sufficiently attractive to raise the equity necessary.

c) Registering an I&Ps

Co-ops or I&Ps are governed by Rules and the Irish Co-operative Organisation Society (ICOS) has Model Rules that can be used as a basis for many new societies. They have helped a dozen energy co-ops to register, using bespoke Rules. This is the advised route and ICOS would be supporting the group to develop the necessary Rules. There are plenty of useful documents on the ICOS website, including a guide to starting a new co-op.

I&Ps are registered with the Registry of Friendly Societies, which is held by Companies Registration Office (CRO). They charge €100 to register a new society.

The following table provides a summary and comparison of the key characteristics of Co-operative and Company legal structures.

Table 8: key characteristics of Co-operative and Company legal structures

	I&Ps/Co-operative	Company
number of members	7 to unlimited	1 to 100
governing document	Rules	Memorandum and Articles of Association
registration	Registrar of Friendly Societies (RFS)	Companies Registration Office
can raise shares	✓	✓
requirements	share offers >€30k must have the intention registered with RFS	share prospectus >€1M must comply with the new Prospectus Regulation
returns	interest and dividends	dividends
taxable	interest no; dividends yes	yes
pros	Model Rules available good support from co-operative organisations inexpensive registration process lightweight reporting requirements interest to members is an allowable expense secure community ownership possible with 'asset lock' can raise equity and loans simply from its members simple share offer document that ordinary people can understand	well recognised organisational form Mem' & Art's can be written to permit anything [legal] can invest in other enterprises can be junior partner in a joint venture can invest for profit
cons	community shares not well understood by many interest payments limited must be in control of its own trade—cannot be a junior partner in a joint venture	shareholder membership is limited to 100 for private limited companies onerous reporting requirements share prospectus expensive to develop

d) Co-operative principles

An Industrial and Provident Society embraces the co-operative principles set out by the International Co-operative Alliance. The seven core principles of co-ops are:

- voluntary and open membership.
- democratic member control—one member, one vote.
- member economic participation.
- autonomy and independence—never owned as a subsidiary.
- education, training and information.
- co-operation among co-operatives.
- concern for community.

It is clear that these principles fit easily with the values of community-based organisations and provide a good structure for carrying out a business enterprise for the benefit of the community.

3. Financing A Community Owned Anaerobic Digestion Project

There are various types of agreement that can be used to secure the required capital for an anaerobic digestion project. Broadly, these can be classified as debt and equity. Debt involves money from a creditor or 'lender', who will expect to be repaid with interest and this can be in the form of a loan, bond or debenture. Equity means ownership and it is typically expressed as shares, with each person owning one or several shares of the total project being an 'investor'.

Debt carries higher risk for the lender, who in turn demands greater returns. Generally speaking, interest payments on debt is an allowable expense for tax purposes but dividends to shareholders is paid from the after-tax profits. The exception is community shares where interest on shares is an allowable expense for tax purposes.

The amount borrowed or invested is termed 'capital' or 'principal'; the extra payments made to the lender or investor are 'interest', 'returns', 'coupon rate' or 'dividend' (although this is technically distinct). Some terms are used interchangeably but the following are descriptions of the main distinctives as generally understood.

a) The specificities of financing a community renewable energy project

Research into the experience of community owned renewable energy projects in securing finance has indicated a number of commonalities (Ricardo Energy & Environment, IEA-RETD Operating Agent, 2016). Debt financing is often expensive for communities due to the risks perceived by commercial investors such as banks and pension funds. Co-operatives might have a reputation to offer lower investment returns, and the corresponding cultural acceptance of community RES projects with lenders and investors, creates barriers to securing financing. Debt is also often more expensive for smaller community RES projects because lenders are not offered a portfolio of many projects to spread their risk. In a larger, more diversified investment portfolio, the risk of default on the entire principal is much lower.

Development costs include feasibility analysis, project management, securing financing, planning, and advisory fees. There are issues with availability and cost of debt financing for communities, especially for the planning and development stage of projects. Cash poor, and general risk averse communities, will have much less cash available. In addition, small RES projects are unable to leverage economies of scale for construction and developmental costs. Shared ownership models that required complex agreements or community-owned projects that did not have previous experience had a greater need for advisory support by the community.

However, there are plenty of positives:

- Community projects inevitably use volunteer time from the member base at different stages of the project. If volunteer labour is used during the construction phase it can help reduce installation costs.
- Communities also usually have personal relationships with various local businesses and stakeholders, which can enable them to get good deals, for example on equipment rentals or leases on land.
- Community RES projects can sometimes be seen as a demonstration project and can attract discounts on equipment, donations of materials, and funding.
- Various grants and additional funding are available for the development of community projects, especially for feasibility assessments as a critical component of on-going community energy planning projects.
- On the other hand, community consultation costs may be small or negligible for community-owned or shared community projects depending on the level of engagement of the community. However, the process may often be protracted.
- Complete community ownership of the project can then be seen as an even greater participation with the benefits and challenges of such projects and if there is capacity and commitment within the community to embrace this, they will be the richer for it.

b) Financing instrument options

Developing a community-owned project typically involves a combination of equity, generally 20 to 30% of the investment, and the balance is financed by debt. We review hereafter the common financing instruments available for renewable energy projects such as anaerobic digestion plants:

(1) Loans

Loans are the most familiar type of borrowing arrangement. The lender offers money, and the borrower commits to repaying the capital and interest. In this case, the loan is likely to be taken with a bank or other financial institution and be secured in that it is backed by some form of collateral. Loans are generally not tradable.

(2) Bonds

Bonds are certificates of debt that are issued specifically to raise funds. They should be secured against the assets of the company. Some people refer to unsecured bonds, but these are better described as debentures. There will be a clear repayment schedule for the interest and capital is generally repaid 'on maturity', i.e., at the end of the loan term. Bonds will have the same terms and conditions for all bondholders of that particular bond. They can generally be traded.

(3) Debentures

Debenture is a general term for bespoke debt instruments used to raise capital for an enterprise. They are generally unsecured (against assets of the company) but may include some type of security arrangement in case problems arise. As with all debt mechanisms, they do not give any ownership of the company. There will be a detailed offer document that explains the terms and conditions of the agreement. Debentures may be allowed to be traded. The rate of interest can sometimes be referred to as the coupon rate and may be fixed at the outset or variable according to the performance of the enterprise.

(4) Shares

Companies can raise capital by offering a stake in the enterprise. Investors become linked to the fortunes and misfortunes of the company. If the company does well, they will be paid a dividend and the value of the shares may increase above the price paid for them. This 'capital gain' is only realised when the shares are sold. Conversely, if the company does poorly, there may be no return on the investment and the value of the shares may reduce, even to zero. If the company is liquidated, the shareholders get a slice of the residual value once all other liabilities have been fulfilled. Shares can be bought and sold and may appear on public trading platforms like Euronext Dublin.

(5) Community Shares

When an I&Ps issues shares, different rules apply. The shares still give a part-ownership of the enterprise, but the value of the shares can never increase above the face value, referred to as 'par value'. The shares cannot be freely traded, and all transfers of ownership must be managed by the society's board. They can also transfer the shares back to the society whereupon they are cancelled. These mechanisms prevent the financial speculation that can happen with company shares. Both interest (in proportion to investment) and dividends (in proportion to interactions with the society) can be paid. Interest is an allowable expenditure for tax purposes, but dividends are generally paid from taxed profits.

Community shares are often referred to as 'patient capital' as the investors are not out to make 'a quick buck' but are keen to support a community enterprise and are willing to let their money be used for this over an extended period of time.

4. Community buy-in to commercial projects

There may be some cases where a commercial developer will offer communities a stake in a renewable energy development and communities should look carefully at all such offers. The main advantage of such a scheme is that an experienced developer has carried out the hard work of investigating the potential and developing the business case; they have taken the risk and secured the various permissions necessary. In addition, partnering with commercial developers makes access to affordable debt easier, but often decreases the share owned by the community, and hence the benefits. Partnering also imposes new challenges in terms of framing the partnership and engaging on an equitable footing with better-resourced and more-experienced commercial developers and financiers.

It is difficult to find good models for such part-ownership and the terms and conditions of the offer will need to be assessed on their own merit. Wholly owned community projects are of more benefit to communities but require much more work.

When a community has ownership in a renewable energy project, there is an income stream that can pay interest to the local investors and, depending on the energy distribution arrangements (e.g. heat distribution, transport fuel, etc.), there may be benefits in terms of reduced energy costs in the community. It has been well demonstrated that when people have a stake in a development, they are much less focussed on any downsides and much more conscious of the benefits that arise. There is also better engagement with the underlying issues that the development addresses, be it climate change, fuel poverty or community enterprise when individuals in the local community are members of the organisation and own part of the development.

All investment carries risk and with community schemes, the risk is mainly carried by the members. If something goes wrong or if the generator does not perform as expected, the investor members may not receive the returns that they expect and may need to dip further into their pockets to rectify problems that become evident. It is at least theoretically possible that the investors could lose all of their investment.

When things go according to plan and when a well-researched scheme is implemented, local people benefit financially from their local energy resources and that in turn translates into more money in the local economy for purchases and other investments. Depending how the co-op is set up, there could be explicit funding for local community projects as part of the designed outcomes. Communities have gone on to build various community facilities where there is such an established income stream.

Where a commercial developer offers a share of the project to a community group, they will have factored that into their business model and unless the pay-outs are linked to performance, the income that comes to the community may be minimal because the developer will need to give some type of commitment to pay a certain amount and that will therefore be at the lower end of the range of what they can afford so that years of poor performance do not bankrupt the project. It is therefore expedient to negotiate a true equity stake where the community share in the fortunes (and misfortunes) of the project.