XD Consulting
Sustainable Energy Engineers

Feasibility Study on Anaerobic Digestion for the Dingle Peninsula

Final Report

Client	**Consultancy Team**	**Date**
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An tAontas Eorpach
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List of Acronyms

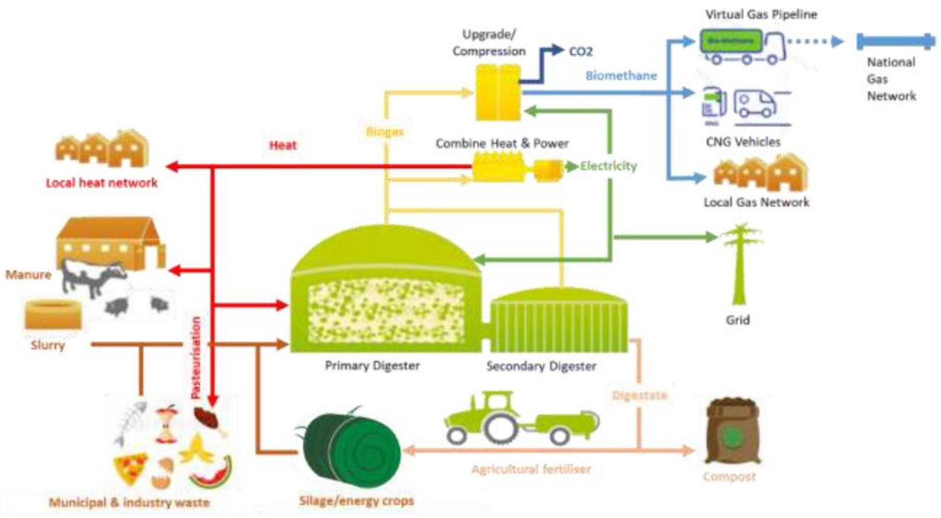
AD: Anaerobic Digestion
CBM: compressed biomethane
CH_4: methane (Biomethane)
CNG: compressed natural gas
DM: dry matter
ED: electoral district
EMP: Energy Master Plan
GWh: gigawatt-hour or a million kWh
GW: gigawatt capacity
kWh: kilowatt-hour or a thousand Wh of energy
kW: kilowatt capacity
kWe: kilowatt electrical capacity
IRR: Internal Rate of Return
LCOE: Levelised Cost of Energy
MWh: megawatt-hour or a thousand kWh
MWe: megawatt electrical capacity (1,000 kWe)
Nm^3: normalised cubic meter
NPV: Net Present Value
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
TWh: Terawatt-hour, or a billion kWh
tWM: tonne of wet matter

Executive Summary

Tackling climate change requires a radical transformation of Ireland's energy system towards decarbonisation by 2050. Dingle Sustainable Energy Community, led by the Dingle Hub/Mol Teic, aims to be at the forefront of this transformation in rural Ireland and has commissioned XD Sustainable Energy Consulting Ltd. to undertake a feasibility study on anaerobic digestion[1] in the Dingle peninsula. The Dingle Peninsula in the very southwest of Ireland has a population of about 13,000 and relies mostly on tourism and agriculture for its income. The local energy expenditure was estimated at €38.5 million per year, most of which comprises fossil fuels for heating and transport. The overall objective of the study is to investigate the potential for biogas production to contribute to meeting the community's energy needs in an affordable, secure and sustainable manner.

The first step of the study was to assess the potential feedstocks available on the peninsula for AD, including agricultural sources (grass silage and slurry) and municipal/industrial sources of organic waste (food & fish waste, sewage sludge and offal). The assessment, including field surveys and desktop research, concludes that the practical potential of AD feedstocks is equivalent to 305 GWh/year in energy content, slightly below the overall energy usage in the peninsula. Grass silage represents 93% of the practical potential, with cattle slurry another 5%. While industrial/municipal organic waste represent less than 2% of the total feedstock potential, their use in AD typically attracts gate fees and contributes to local, circular waste management in the peninsula.

The next step was to analyse and compare a range of technological pathways for AD appropriate for the peninsula. Biogas can be used as a renewable fuel for heat and power generation, or upgraded to compressed biomethane (CBM) to be injected into the natural gas grid2 or used locally as a vehicle fuel.



When identifying different possible technological pathways for analysis, a number of key factors were considered: a) the implications of the animal by-product (ABP) regulations on the type of feedstock used[3],

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

[2] The nearest potential injection point in the natural gas grid is at Listowel, some 80 km away from Dingle.

[3] In accordance with the EU animal by-products (ABP) legislation, feedstock materials of animal origin such as cattle slurry or food waste, are subject to stricter processing rules as opposed to AD plants utilizing solely grass silage.

b) the energy end-use of the biogas produced, c) the potential to valorise the digestate and other products derive from the AD system (e.g. heat, food grade CO_2, etc.). The material and energy flows as well as the balance sheet of eight different pathways were analysed for a standard year of operation in order to assess their viability. The techno-economic analysis of the pathways indicates that the standard combined production of electricity and heat is not viable financially.

The most profitable pathway involves the use of gate-fee paying feedstocks together with silage, for the production of compressed biomethane as a transport fuel and the valorisation of food-grade CO_2 and compost as by-product. The addition of on-site CHP to cover the electricity usage of the biogas upgrading and CO2 liquefaction plants, as well as the heat demand of the digester, further reduces operating costs. A more detailed assessment of the lifecycle costs of such fully-fledged AD plant indicate that the project's capital investment would be in the region of €5 million, the net-present value €3.3 million and the internal rate of return 18%.

An AD plant operating primarily on grass silage for biomethane production is less expensive to install and less complex to operate, although the overall viability of the project (internal rate of return of 10.5%) is very sensitive to the cost of silage. It is important to note that the Recast Renewable Energy Directive's Sustainable Biomass Criteria will likely require the addition of a substantial amount of slurry to the feedstock mix. This will in turn impose compliance with the ABP regulations in terms of feedstock treatment and administrative burden. It is therefore recommended to plan the development of AD in the peninsula with a plant capable to process a combination of agricultural and ABP feedstocks.

While injection of biomethane into the gas grid is the most straightforward end-use for the biogas produced, the gradual development of a local market and infrastructure for biomethane as a transport fuel would increase the economic viability and environmental impact of AD in Dingle.

A detailed spatial analysis of the peninsula was undertaken to identify most suitable locations for AD development using a geographical information system and considering a range of criteria including feedstocks availability, energy demand, environmental protection, land cover, road infrastructure, special amenity areas, etc. The spatial analysis indicates that areas in the environs of Dingle town perform best in terms of suitability due to the conjunction of energy demand, feedstock availability and infrastructure. 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.

A co-operative society structure is recommended as the most appropriate business model for the development of AD in the peninsula, promoting wide, democratic participation in ownership and control. It also more likely to engender local support and additional benefits for the community in terms of job creation, training and innovation, notably in terms of the green economy. Financing one or several AD projects will require combination of institutional financing instruments such as loans or debentures, as well as raising equity through community shares and subsidies. Partnership with a commercial developer is also an option in that it can bring valuable experience and financial capability, however this is likely to reduce potential dividends for the community.

Finally, a roadmap for community anaerobic digestion in Dingle outlines the typical project development stages, starting from community engagement to commissioning the project and the ongoing management of the AD community enterprise.

Chapter 1. Context, Vision and Key Principles for the Development of AD in Dingle

A. Introducing the Feasibility Study

The Dingle Sustainable Energy Community, led by the Dingle Hub/Molteic, has commissioned a feasibility study on the Development of Anaerobic Digestion[4] in the Dingle Peninsula with the aim to become a leader in the development of the rural bioeconomy in Ireland.

The following map represents the study area for the Dingle Peninsula, which is in line with the geographical area taken for Dingle's Energy Master Plan study. The Dingle Peninsula is in the southwest of Ireland, stretching from just outside Tralee Town to Dunmore Head in Dún Chaoin, the westernmost point of mainland Ireland. The peninsula stretches 40km into the Atlantic Ocean, and its geography contrasts high peaks with cliff edges and numerous beaches. The Dingle Peninsula has a population of about 13,000, of which 2,000 live in Dingle town, and is heavily reliant on both tourism and agriculture for its economy. The tourist economy in Dingle is seasonal, with the summer months providing much of the tourist footfall.

Figure 1: Areas of Dingle Peninsula assessed.

The overall objective of the study is to investigate the potential for biogas production on the Dingle Peninsula to contribute to meeting the community's energy needs in an affordable, secure and sustainable manner. It applies circular economy thinking, considering organic wastes as a valuable resource which can ultimately generate a high-quality fuel – enabling new economic opportunities locally.

The specific objectives of the feasibility study are:

- To conduct a comprehensive assessment of the biomass resource available in the peninsula to determine their practical potential for biogas, their spatial distribution and cost.
- To initiate engagement with key stakeholders with a view to define a shared vision for anaerobic digestion and identify the core principles which should govern its development.

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[4] Anaerobic digestion breaks down biodegradable materials in the absence of oxygen to produce biogas, a renewable fuel which can be utilised to produce heat, electricity and for transport. Anaerobic digestion is used worldwide in domestic, agricultural, municipal and industrial applications.

- To investigate and compare suitable technical biogas pathways, from feedstock to energy end-use, considering their environmental, social and economic impacts.
- To undertake a multi-criteria spatial analysis aiming to identify areas suitable for the development of anaerobic digestion plants.
- To conduct a preliminary design and a lifecycle cost analysis of anaerobic digestion systems based on the pathways deemed as being most feasible.
- To review business and financing models appropriate for community participation and provide the community with a roadmap for the deployment of anaerobic digestion on the Peninsula and guide the next steps for project development.

The study, funded by the LECO project and Gas Networks Ireland, 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.

A. Vision & Key Principles for Biogas Development in Dingle

In this section, a vision for the development of anaerobic digestion on the Dingle Peninsula is articulated on the basis of the national policy framework, local planning policy and, most importantly, in consultation with community stakeholders. The vision considers the results of the Dingle Energy Master Plan study commissioned by the Dingle Hub and Transition Kerry's Sustainable Energy Community Roadmap. In addition, key principles by which different pathways and business models for the development of AD will be assessed are defined.

1. Legislative and Policy Framework

Agenda 2030 [1] and the Paris Agreement [2] on climate change require a transformational shift of our economies and societies towards climate resilient and sustainable development. The Climate Action Plan [3] puts in place a decarbonisation pathway to 2030 which would be consistent with the adoption of a net zero target in Ireland by 2050. This will require a radical transformation of Ireland's energy system, including generating electricity from renewable sources, and moving to lower emissions fuels (e.g. from peat and coal to gas) and ultimately away from fossil fuels altogether. By 2017, Ireland's renewable energy (RE) in the total final energy consumption was 10.7% compared to the set EU RE Directive target of 16% by 2020. The biggest share of Ireland's RE production is renewable electricity (RES-e) at 62%, and renewable energy contribution to heat (6.9%) and transport (7.4%) fall significantly short of the 2020 targets of 12% and 10% respectively (SEAI, 2019). The revised Renewable Energy Directive adopted in December 2018 establishes a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023.

At a local level, the Kerry County Development Plan 2015 – 2021, Volume I, Chapter 13 "Development Management – Standards and Guidelines" [4] states that wind energy, geothermal, biomass, combined heat and power and all other forms of renewable energy will be considered in accordance with the Renewable Energy Strategy [5], adopted by Kerry County Council in 2012. According to the appraisals that were carried out as part of the RE Strategy, there is significant potential for the development of wind, bioenergy and, to a lesser extent, hydro power within the county. However, the plan recognises the constraints of preserving and protecting Kerry's landscapes and archaeological heritage will have a significant impact on the potential to develop further RE, in particular in the study area.

2. Dingle Sustainable Energy Community's Energy Master Plan

Dingle's Energy Master Plan (EMP) was commissioned by the Dingle Hub in 2019 with funding from SEAI. The EMP study provides an assessment of baseline energy usage for the year 2016 and defines ambitious energy demand reduction and renewable contribution targets by 2030. Overall, the energy expenditure in the peninsula was estimated at 38.5 million euro for 2016. The Dingle EMP recommends a large number of actions to deliver the targeted energy demand reduction and renewable energy production, including widespread uptake of deep energy retrofit in the residential and services sectors, as well as installation of renewable energy technologies in buildings (solar PV, heat pumps, biomass boilers) and at utility-scale for solar PV and anaerobic digestion. It estimates a total capital investment requirement of €211 million. This is made up of €166 million for energy demand reduction and €45 million for renewable energy generation (Kevin Curtin, 2019).

A separate analysis was undertaken by a Connor McGookin (Marei, 2020) which provides a baseline of energy demand in the peninsula for the year 2016, together with associated CO_2 emissions – see Figure 2 and Figure 3.

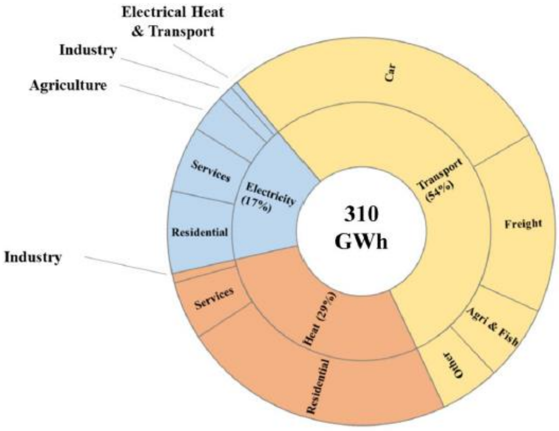

Figure 2: Distribution of energy usage in 2016

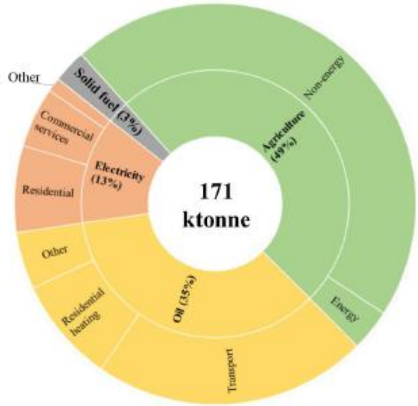

Figure 3: Energy related CO_2 emissions in 2016.

Figure 4 is a map showing the geographical distribution of final energy use within the study area.

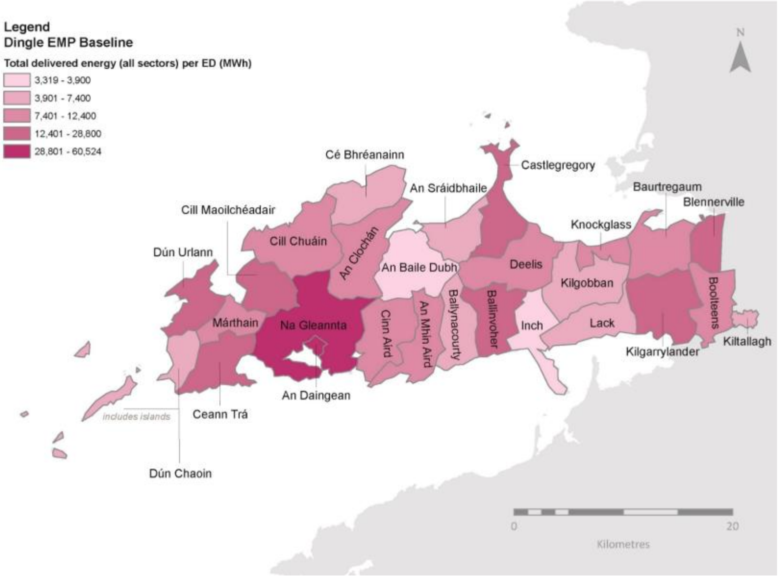

Figure 4: Map of total energy delivered per electoral district (ED) in Dingle.

3. Transition Kerry's Sustainable Energy Community Roadmap

This study [6] commissioned by Transition Kerry, a community initiative aiming to accelerate the change to a more resilient, sustainable future for the population of Kerry, was completed in 2013. The objective of the study was to set out a roadmap to plan the transition of the county towards 100% renewable energy by 2030, based on a 25% reduction in energy demand by the same year, using 2008 as the baseline year. The study estimated that the total annual energy spend in 2008 was €470 million and that the associated CO_2 emissions were 1.22 million tonnes of CO_2 per year (tCO_2/year) at a social cost of €28 million per year.

The total renewable energy resource potentially available in Kerry was estimated at 42 terawatt-hours (TWh) (the majority of it in its adjacent offshore area), or 10.6 times its final energy usage in 2008. The theoretical potential of biomass in the study area has been estimated at circa 2 TWh/year or 50% of final energy usage. The study carried out a lot of modelling to analyse different energy system transformation scenarios, out of which the following was recommended as the most advantageous: "By 2030, the county will be capable of becoming energy self-sufficient on the basis of its own renewable energy resource. Households, businesses and industry in larger towns will be supplied renewable heat via district heating systems harnessing heat from wood-fired power stations, industrial processes and large solar arrays. Rural dwellers will have switched to heat pumps and solar heating systems, supplemented with wood stoves. In terms of electricity supply, wind energy will cover up to 45% of total energy requirements of the county. Solar power will also play a significant role in the electricity mix (10-15% of primary energy supply). The technological transformation of the energy system of the county will require a long-term investment plan which could total up to €1.8 billion." The Kerry Renewable Energy Roadmap recognises that bioenergy (50% of final energy usage), notably anaerobic digestion, will play a significant role in the transition. Bioenergy in this context means using biomass resources such as forestry residues, energy crops (e.g. willow, short rotation coppice), grass silage, and organic wastes to produce heat, power and transport fuels.

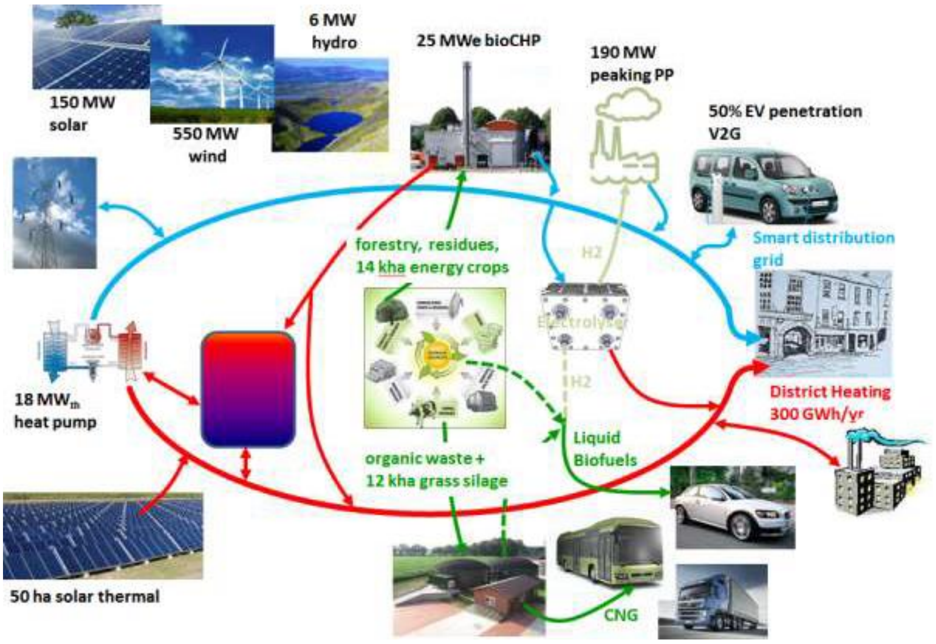

Figure 5: Kerry's Renewable Energy Roadmap – recommended energy system.

Biomass is the other pillar of future renewable-based energy system scenarios, as a primary fuel to supply heat, electricity and transport fuels (50% of the overall primary energy requirement). Meeting future biomass fuel needs will require an ambitious programme of supply chain development to mobilise existing feedstocks and create new sources with energy crop cultivation.

4. A Shared Vision

At a stakeholder workshop organised by the consultancy team in Dingle in early July 2019, several challenges faced by the community were raised, notably:

- The farming sector faces very serious challenges, with declining income in key areas (notably beef production)
- The increasing age profile of farmers on the peninsula with the majority at or close to retirement age, with limited prospects for a younger generation to take over.
- The lack of progression and employment opportunities for young people is generally a feature on the Dingle Peninsula.
- Climate change and other environmental issues, and the policy response, will likely lead to significant changes in agriculture, notably for beef and dairy farming.
- The Dingle Peninsula is very dependent on tourism economically (more than 30% of the local economy) and is vulnerable to rapid changes in the global economy.
- Tourism can also have a negative impact on local infrastructures and the natural environment.
- The Dingle Peninsula is very dependent on oil for heating (80%+ of households in 2016), transport and farming/fishing (the same is true for electricity used for power and lighting).

In this context, it is recommended that the vision for the development of biogas on the Dingle Peninsula should be for "Dingle to become one of the leaders in the development of the rural bio-economy in Ireland, with biogas and a circular economy helping to create new job opportunities and securing the future of farming, while contributing to meeting the community's energy needs in an affordable, equitable and sustainable manner."

The realisation of this vision should comply with the following key principles highlighted by the workshop participants:

- The biogas infrastructure should be community-owned based on a cooperative business model, with economic benefits of the transition to biogas staying in the local economy.
- The biogas supply chain should provide a stable and fair income for participants, notably for farmers providing the feedstocks.
- Biogas should be produced and used locally, reinforcing the local community's ability to secure its own energy future and reduce its carbon footprint.
- The economic value of the environmental gains associated with biogas and the circular bioeconomy should be retained within the local community.
- Biogas systems, including feedstock harvesting and supply, should cause no harm to the environment and surrounding communities, notably in terms of air and water quality, soil fertility and biodiversity.
- Funding opportunities for R&D, demonstration and education, from local, national and European sources, should be leveraged by the local community to enable investment in innovation and new enterprise creation.
- Biogas should be promoted as part of a drive for eco-tourism on the Dingle Peninsula and be an integral part of Dingle Sustainable Energy Community's development.

Further engagement with the community stakeholders during and after the study should aim to reinforce the vision and build a strong consensus around the above key principles. As the Feasibility Study progresses, quantitative targets for biogas development can set and inform the vision.

Chapter 2. Anaerobic Digestion Feedstocks Analysis

A. Introduction

The objective of the feedstock analysis is to understand the potential production of biogas, based on a detailed assessment of the organic materials available within the study area, 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), a field survey conducted by the team among farmers in the study area, as well as other published sources of data and information. Section Chapter 2.C focuses on non-agricultural feedstocks in the peninsula – municipal wastes and industrial wastes. Section Chapter 2.D gives a brief summary of the key findings. Table 1 below shows the characteristics of feedstock used in this report. Litres of methane per kilogram of volatile solids (LCH_4/kgVS) is the usual method of defining the biomethane potential of feedstock.

Table 1: Characteristics of certain feedstocks

Feedstock	DS	VS	VS/DS	Specific Methane Yield
	(%wwt)	(%wwt)	(%)	(LCH_4/kgVS)
Grass Silage	23	20.93	91%	400
Cattle Slurry	7	5.25	75%	143
Food Waste	30.6	27.0504	88%	274
Fish Waste	32.2	17.8	55%	390

B. Agricultural Feedstocks

1. Feedstocks Considered

Two 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.
b) Slurry from cattle: Captured when the cattle are housed during the winter and generally stored under the cattle shed, or in adjacent above or below ground tanks in some cases.

Manure from sheep is not considered as practical feedstock for AD. According to the EPA, there are no significant piggeries or poultry farms in the study area [7], [8]. Therefore, pig manure and poultry manure were not considered for this study.

2. The agricultural context in Dingle

Out of 1169 farms (CSO Agriculture Census 2010), three farming enterprises dominate agriculture in the study area[5]: cattle rearing and finishing (approx. 550 farms), dairy farming (approx. 210 farms) and sheep farming (200 farms). The remaining farms include land used for mixed grazing and mixed crops [9]. There were over 25,237 heads of cattle in 2010[6] in the study area, including 5,795 dairy cows, and 123,617 sheep (67,642 ewes). The following map shows the nature of the land cover in Dingle.

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[5] The distribution of farm type in % herewith is taken from CSO Agriculture Census 2010 for the county, but it is assumed to be very similar for the study area.

[6] While there are nationwide statistics available for livestock numbers, the latest data available for the Dingle Peninsula specifically is the 2010 CSO Agricultural Census.

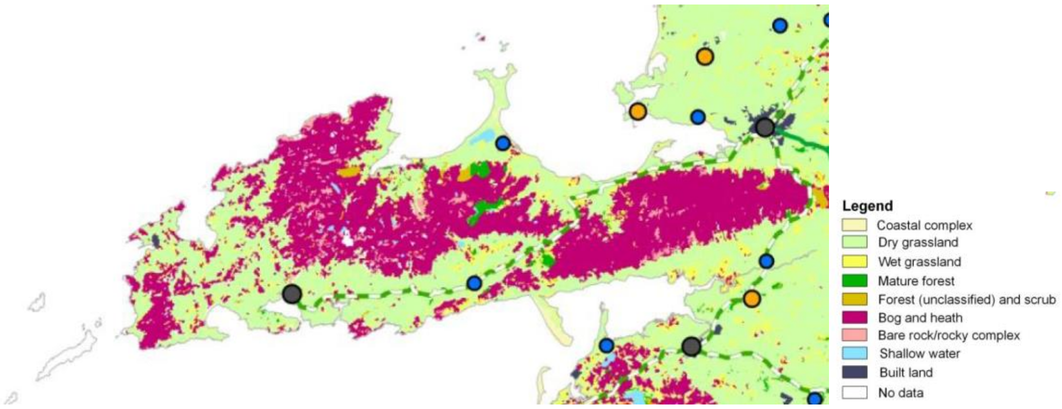

Figure 6: Vegetation type and land cover *[9]*.

The agricultural land use and farm size is distributed as follows according to the Teagasc Agricultural Census 2010.

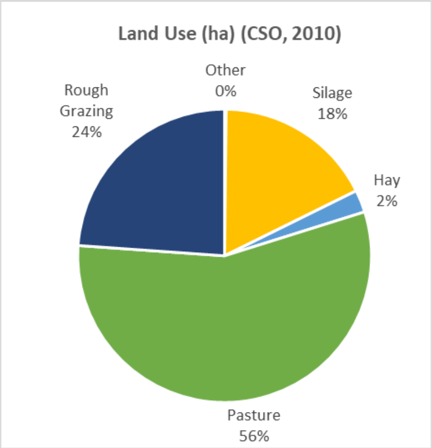

Figure 7: Distribution of land use in Dingle

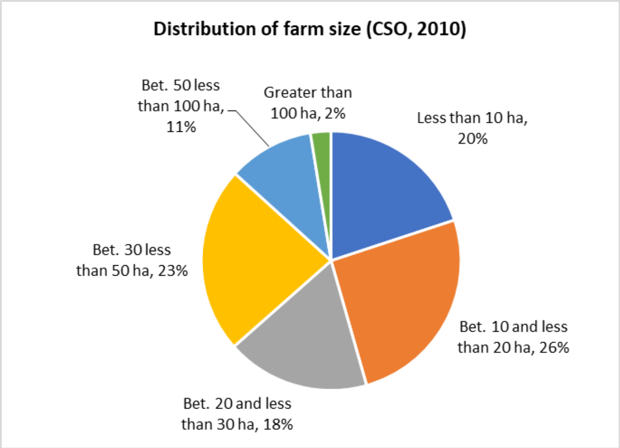

Figure 8: Distribution of farm size in Dingle

It appears that there is a certain amount of agricultural land in lowland areas on the peninsula that is not used to the full extent of its potential productivity. Reasons for this are not clear but can include: low farming efficiency, inability or lack of necessity to fully utilise owned land. Low silage productivity is being addressed by Teagasc in their Grass10 initiative [10]. An initial assessment conducted by XD Consulting of the potential amount of land in this category by using satellite imagery indicates that this could be as much as 10% of all pastureland used for farming.

There are a number of important **socio-economic factors** that influence the farming community in the Dingle Peninsula that need to be considered when assessing the potential for agricultural feedstocks for biogas:

a) Gross margin by farm enterprise and direct payment contributions to family farm income in the South Region[7] [11]:

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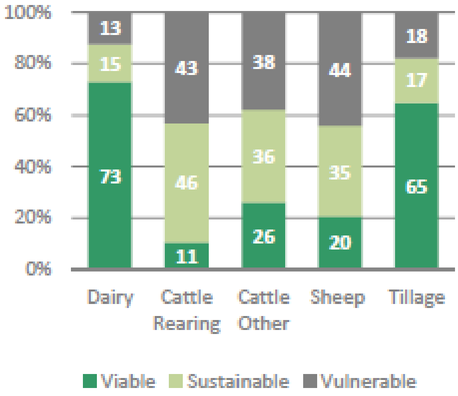
[7] The South Region is defined by the Nomenclature of Territorial Units for Statistics (NUTS) as a group of the following counties: Carlow, Clare, Cork, Kerry, Kilkenny, Limerick, Tipperary, Waterford and Wexford [28].

Regional Farm Structure 2018 – South Region (average per farm)				
	Cattle Rearing	Cattle Other	Dairy	Sheep
Utilised Agricultural Area (ha)	33	40	58	49
Livestock units	38	51	76	52
Family Farm Income (FFI)	€9,409	€15,883	€63,001	€13,769
Gross output/ha	€1,203	€1,403	€3,187	€1,010
Gross margin/ha	€726	€899	€2,018	€625
Direct Payments (DP) per ha	€415	€432	€364	€235
FFI/ha	€287	€399	€835	€281
DP contribution to FFI	145%	108%	44%	84%

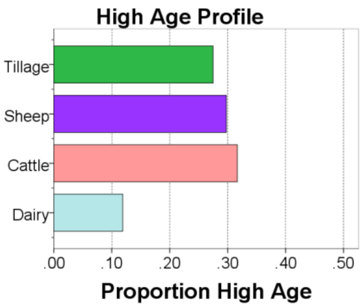
- The table above indicates that, in the South Region, dry cattle farms are highly dependent on Direct Payments for their subsistence. Single Farm Payments constitute about 60% of the Direct Payments on dry cattle farms and 78% on dairy farms. At national level, the average suckler farm with a FFI of €8,318, lost over €4,500 of direct payments over the course of the year. The picture is similar on other dry stock farms.

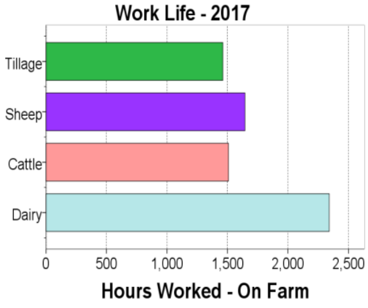
b) Proportion of farms viable, sustainable and vulnerable per enterprise type [11] in the south region:



In the context of the study area, this indicates that a significant proportion of dry cattle and sheep farms are economically vulnerable and less than 25% are viable. 13% of dairy farms are also likely to be in a difficult financial position.

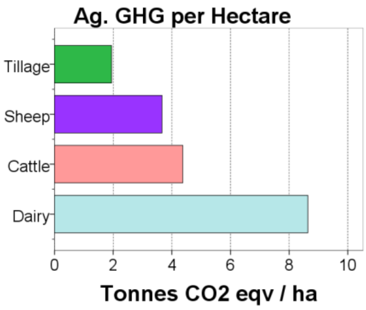
c) Social sustainability for farms can be looked at in terms demographic trends and work-life balance among farmers [12]:

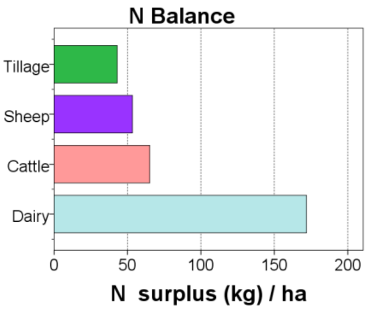




This indicates that a significant proportion of farmers in the study area are likely to be at retirement age or above. According to the CSO Agriculture Census 2010, about 33% of farmers were above retirement age in the study area and another 33% are likely to have reached retirement age since then. Dairy farmers work very long hours on the farm, on average above 6 hours every single day of the year.

d) Environmental Sustainability Criteria (agricultural greenhouse gases emissions (GHG) and nitrogen (N) balance):





The environmental impact of farm enterprises, in relation to climate change and water pollution, will continue to be a growing concern at national level and there will increasing pressure to account for the environmental cost of producing meat and milk, in particular, in economic terms. This has the potential to increase the cost of related food products by internalising a CO_2 tax for example.

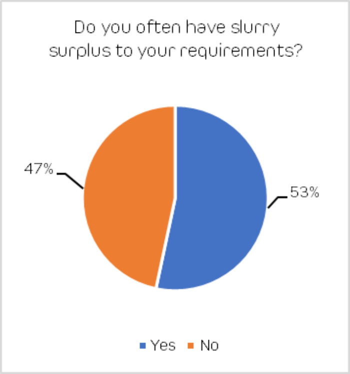
3. Field survey of farmers in the study area

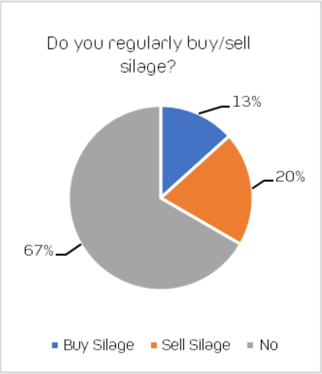
A semi-formal survey was designed by the team to ascertain the potential feedstock availability from the farming sector in the study area. The survey was specifically aimed at dairy farmers or dry cattle farmers, farming more than 50 hectares as this group of farmers was considered most likely to participate to the development of AD in the study area. A questionnaire (see Appendix A – Survey) was distributed among a total of 20 farmers via direct contact or via email. 15 questionnaires were completed either during face-to-face interviews, or individually and returned by post or email by respondents. Table 2 below shows the average, minimum and maximum values gathered from the relevant survey questions. As farmers don't know their exact slurry production, it was assumed for the following calculations that each farmer's slurry tank is filled by their cattle over the winter season. For privacy reasons, individual survey responses are not outlined in this report.

Table 2: Consolidated Survey Results.

	Average	*Min*	*Max*
Hectares farmed	*61*	*21*	*129*
Hectares rented	*14*	*0*	*60*
Number of cattle	*94*	*25*	*200*
Months collecting slurry	*5*	*5*	*7*
Tank size (m^3)	*626*	*98*	*1,500*
Tonnes slurry per head of cattle	*7*	*2*	*17*
Hectares used for silage	*20*	*6*	*36*
Number of times per year harvested	*2*	*1*	*3*
Estimated pit tonnage (per year)	*658*	*450*	*850*
Estimated bale tonnage (per year)	*412*	*72*	*855*
Given tonnage (per year)	*600*	*600*	*600*
Estimated total tonnage (per year)	*684*	*180*	*1,010*
Estimated DM tonnage (per year)	*156*	*41*	*232*
t DM / ha / year	*8*	*5*	*13*

The following graphs show the distribution of responses to questions on the availability of surplus slurry or silage to existing requirements on the farms surveyed in terms of fertilisation and cattle (and in some case sheep) feeding respectively.





The face-to-face discussions at the time of survey or during a follow-up phone call have also provided valuable information. Generally, respondents are very interested in the survey topic. While most of them think that farming is currently viable, the general consensus is that it will become less and less viable in the medium term. Rules and regulations, as well as environmental impacts of farming, notably in terms of greenhouse gas emissions, are all key concerns. 9 of 15 respondents envisage changes to their farming practices, ranging from retirement, change of cattle type, diversification, becoming organic focused, investing in renewables, farm sharing, etc.

In addition, the cost of silage was discussed with farmers. Silage is being traded at about 25 euro per bale and the cost of baling silage is generally between €13.50 to €16.50 per bale. Producing pit silage was said to cost €280 to €300 per hectare. In our techno-economic analysis of different AD pathways in section , we have assumed a silage cost of €30/tonne of wet weight.

4. Biogas potential of agricultural feedstocks

a) Methodology

Data acquired from the CSO Agricultural Census 2010 was used to determine the land available under suitable land use (in this case, primarily land currently under grass silage and possibly land categorised as pasture) as well as the amount of livestock on the Dingle Peninsula. The smallest area containing detailed figures of crops and livestock are electoral divisions. 27 electoral divisions were assessed. These electoral divisions can be seen in Figure 1 above.

With regard to grass silage, research by Teagasc shows that annual silage harvests of 10 t_{DM}/ha are achievable in Ireland based on two silage cuts per year on regularly reseeded grassland [10]. Fresh grass silage has a typical moisture content of 60-70% and can yield 400 Nm^3 CH_4/t_{VS} (tonne of volatile solid), at 91% VS per dry matter weight. This is equivalent to 364 Nm^3 CH_4/t_{DM}.

The theoretical biogas potential of grass silage in the peninsula was calculated by assuming:

a) All land under silage, according to CSO Census 2010 will yield 10 t_{DM}/ha
b) All land under pasture will yield 10 t_{DM}/ha

The practical potential for grass silage is taken as:

a) The potential additional output from existing land used for grass silage from increased productivity from the current average of 8 t_{DM}/ha,year as per the survey results in Table 2 to 10 t_{DM}/ha,year.
b) The potential increase in land used for silage from land currently with low productivity use, estimated at about 10% of land used for permanent pasture, with a potential silage yield assumed to be 8 t_{DM}/ha if appropriate land improvement and grass management measures are taken.
c) The potential for silage production above cattle feeding requirements due to a reduction in herd size. As shown in Chapter Chapter 2.B.2, approximately 40% of dry cattle farms, 44% of sheep farm and 13% of dairy farms are vulnerable economically and could be incentivised to diversify towards the production of silage for biogas. Forecasting the potential switch is difficult,

considering other potential alternative land use such as afforestation and dairy farming. However, the assumption has been made that the practical potential for silage from farming enterprise change is 30% of permanent pasture in the study area, or a total of 5,900 ha from which the assumed silage yield is taken as 8 t_{DM}/ha (in line with survey results in Table 2).

The theoretical potential of cattle slurry for biogas was calculated on the basis of the numbers of cattle per type taken from the census 2010 data and indicators of slurry production by cattle type taken from a study by Teagasc [13], see Table 3 below. The DM content of slurry was taken to be 7%. The biomethane potential of slurry was taken to be 107 Nm^3 CH_4/t_{DM}. The practical biogas potential from slurry considers that slurry loses (10%) of gases during storage. The figures in Table 3 below are used to calculate slurry production on the peninsula as opposed to the survey figures, as to not over-estimate the slurry available in the region.

Table 3: Slurry Production by cattle type.

Cattle Type	Slurry Production (tonnes/year/head)
Dairy Cows	5.84
Bulls	5.84
Other Cow Slurry	5.20
Other Cattle Slurry	4.10

The above calculations of theoretical and technical potential were conducted in per Electoral Division (ED) within the study area, which represents the lowest geographical resolution for the CSO Agricultural Census data.

b) **Results**

The table below presents the results of our analysis of the potential agricultural feedstock for biogas, per ED, including:

a) Theoretical potential based on all land currently (2010) under ‘silage’ and ‘permanent pasture’ is used for silage production for biogas.
b) Practical potential based on surplus silage output from increased yield from land currently under ‘silage’.
c) Practical potential based on land turned back to productive use for silage.
d) Practical potential based on the equivalent of 30% of permanent pasture switched to silage for biogas.
e) Practical potential based on cattle slurry harvested during wintering season.

Table 4: Analysis of potential agricultural feedstocks.

	Theoretical Silage Potential		Practical Silage Potential				Practical Slurry Potential
	(t_{DM}/year)		(t_{DM}/year)				(t_{DM}/year)
Electoral Division	(A.1) Pasture	(A.2) Silage	(B) Increased Yield	(C) Back to production	(D) 30% switch	(B-D) Total	*Assuming losses of 10%*
An Baile Dubh	11,480	1,660	332	918	2,755	4,006	160
An Clochán	6,580	1,150	230	526	1,579	2,336	112
An Daingean	-	40	8	-	-	8	15
An Mhin Aird	9,090	3,610	722	727	2,182	3,631	655
An Sráidbhaile	7,770	1,520	304	622	1,865	2,790	345
Ballinvoher	9,440	2,560	512	755	2,266	3,533	502
Ballynacourty	7,030	3,310	662	562	1,687	2,912	440
Baurtregaum	3,490	1,190	238	279	838	1,355	344
Blennerville	2,190	740	148	175	526	849	40
Boolteens	6,730	2,320	464	538	1,615	2,618	286
Castlegregory	6,790	1,930	386	543	1,630	2,559	300
Cé Bhréanainn	3,480	740	148	278	835	1,262	515
Ceann Trá	5,380	3,340	668	430	1,291	2,390	720
Cill Chuáin	10,980	2,390	478	878	2,635	3,992	317
Cill Maoilchéadair	9,200	2,660	532	736	2,208	3,476	92
Cinn Aird	9,050	4,560	912	724	2,172	3,808	492
Deelis	7,030	2,180	436	562	1,687	2,686	218
Dún Chaoin	3,810	690	138	305	914	1,357	177
Dún Urlann	8,100	3,110	622	648	1,944	3,214	112
Inch	8,590	1,810	362	687	2,062	3,111	229
Kilgarrylander	6,620	1,770	354	530	1,589	2,472	250
Kilgobban	8,370	1,460	292	670	2,009	2,970	1,299
Kiltallagh	8,260	4,680	936	661	1,982	3,579	146
Knockglass	3,390	1,010	202	271	814	1,287	412
Lack	4,570	1,300	260	366	1,097	1,722	170
Márthain	7,090	1,540	308	567	1,702	2,577	701
Na Gleannta	23,300	8,720	1,744	1,864	5,592	9,200	330
Total (t_{DM}/year)	**197,810**	**61,990**	**12,398**	**15,825**	**47,474**	**75,697**	**9,378**
Total (Nm^{3}CH4/year)	**72,372,745**	**22,680,281**	**4,536,056**	**5,789,820**	**17,369,459**	**27,695,335**	**1,617,729**

C. Non-Agricultural Feedstocks

1. Food Waste

Food waste is suited to biogas plants as it can have a high biomethane potential, is readily available and plays a part in the circular economy of a region. Food waste coming into a biogas plant can be subject to gate fees, which help support the plant economy.

a) Methodology

The **theoretical biogas potential** from collectable domestic food waste in the study area was calculated on a per electoral division basis according to population data from the Census (2016) and an annual food waste production factor of 84.5 kg/person or 0.23 kg per person per day [14]. The quantity of food waste available from businesses (restaurants, hotels, shops, etc.) and non-permanent residents (holiday homes) was estimated according to the number of domestic and overseas visitors to the study area using data from the County Kerry's Tourism Strategy and Action Plan 2016-2022 [15] i.e. 1.311 million bed nights at 0.23 kg food waste per unit. A DM content of 30.6%, and a biomethane potential of 242 Nm^3CH4/t_{DM} was used [16].

The **practical potential** for food waste was determined by surveying the two main food waste collection businesses operating in the study area, indicating that:

- Domestic households: 700 tonnes of wet matter annually, or 214.2 t_{DM}/year.
- Business customers: 2 tonnes of wet matter per week during the winter, and 4 during the summer (May to August), equivalent to 136 tWM/year, or 41.6 t_{DM}/year.

b) Results

The following table presents the theoretical and practical food waste potential for biogas in the study area: Detailed results per electoral division can be found in Appendix B – Municipal Feedstock per Electoral Division.

Table 5: Food waste production in the Dingle Peninsula.

Food Waste Feedstock	Theoretical (t_{DM}/year)	Practical feedstock potential (t_{DM}/year)	Practical biomethane potential (Nm^3CH4/year)
Permanent residents	369	214.2	51,883
Businesses & holiday homes	101	41.6	10,080
Total	**470**	**255.8**	**61,963**

2. Sewage Sludge

a) Methodology

The **theoretical potential of using sewage sludge** for biogas has been calculated based on population figures from the CSO and visitors data as per the food waste methodology above, an a figure of dry sewage sludge produced per person of 14.6 kg/person [17]. This theoretical potential assumes that all sewage sludge can be recovered, even from private septic tanks. Many households in the Dingle Peninsula use private septic tanks (65% according to 2016 Census), and many septic tanks and other wastewater treatment facilities that serve villages around the peninsula are old, and some overflowing. Private septic tanks should, in theory, be inspected and de-sludged (where necessary) at least once a year [18]. In reality, collecting sewage sludge from all private homes would be unfeasible as there is no data available on what septic tanks in the study area are emptied every year, if at all.

The **practical potential for sewage** has been calculated based on quantities of sewage sludge removed from wastewater treatment plants in the study area provided by Irish Water. There is also a 12,000 person equivalent waste-water treatment plant in Dingle town, to accommodate the tourist influx in the summer [19]. Data acquired from Irish Water for DM production in wastewater treatment plants in the Dingle Peninsula is in Table 6.

Table 6: Wastewater treatment plant sludge production in Dingle.

Plant Location	Sludge Production (tDM/year)
Ballyferriter	5.5
Annascaul	4.8
Ventry	1.3
Dingle	62.5
Castlegregory	2
Feohanagh	3.9
Total	**80**

The biomethane potential factor used for sewage sludge is 120 Nm^{3}CH4/t_{DM}.

b) Results

The following table presents the theoretical and practical sewage sludge potential for biogas in the study area:

Table 7: Sewage sludge production in the Dingle Peninsula.

Sewage Sludge Feedstock	Theoretical (t_{DM}/year)	Practical feedstock potential (t_{DM}/year)	Practical biomethane potential (Nm^{3}CH4/year)
Permanent residents	191	80	9,600
Businesses & holiday homes	52		
Total	**243**	**80**	**9,600**

3. Fish Waste

Fish waste is well suited for anaerobic digestion when co-digested with other feedstock such as food waste. Fish waste can release carbon emissions when disposed into a landfill and not utilised. Gate fees taken from fish waste can support the biogas plant economy.

a) Methodology

The total weight of live fish landings into Dingle harbour was 10,500 tonnes in 2016 [20]. Generally the amount of fish waste produced is 35% of the total weight of fish caught [21]. Not all fish brought to Dingle Harbour are processed there, but at this stage of the analysis it was assumed that they are. A DM content of 32%, and a biomethane potential of 216 Nm^{3}CH4/t_{DM} was used [22].

b) Results

Table 8: Fish waste in Dingle harbour.

Feedstock	Quantity	Quantity	Biomethane
	(t)	(t_{DM})	(Nm^3 CH4)
Fish Waste	3,675	1,176	255,119

4. Offal

There is no abattoir or slaughterhouse operating on the Dingle Peninsula at the moment – livestock from the Peninsula are brought to another region in the county – usually Killorglin. There, the livestock can be sold to the abattoir at factory prices, or the livestock can be slaughtered, and the offal disposed of at a high cost. Farmers in the region consider this situation less than ideal, but if an AD plant in the region could take that offal from the farmers to use for biogas production, then the issue would be resolved. Offal is generally used as a small percentage of the overall feedstock, due to strict regulations and the hazards of ammonia [23].

a) Methodology

As there is no abattoir in Dingle, there are no statistics directly available on the quantity of slaughtered livestock in the region. The livestock population in County Kerry in 2010 was obtained from the CSO Agricultural Census. The livestock slaughtered in the county in 2005 was obtained from the EPA [24]. There was no data available for the same year. The ratio of livestock slaughtered to total livestock population was then calculated and applied to the livestock population on the Dingle Peninsula.

b) Results

Table 9 below shows the estimated slaughter number of cattle and sheep on the Dingle Peninsula.

Table 9: Estimated slaughter on the Dingle Peninsula.

Offal	Cattle Population	Slaughtered Cattle	Sheep Population	Slaughtered Sheep
Kerry	323,957	7,890	433,546	29,491
Dingle Peninsula	31,137	758	136,637	9,294

Generally, 61% of a live weight 632kg beef cattle and 67% of a live weight 42kg sheep would be considered edible [25]. Table 10 below shows the estimated weight of inedible material from livestock slaughtered.

Table 10: Estimated inedible material weight on the Dingle Peninsula.

Offal	Number Slaughtered	Inedible Material (t)
Cattle	758	187
Sheep	9,294	129
Total	10,053	316

The amount of offal from livestock is very small compared to all other feedstock being considered for AD in this study area and would be used in concentrations that would avoid any adverse effect on the digestion process, while improving trading conditions for farmers for their animals. The belly grass fraction of the offal has been considered as practical potential for AD i.e. 167 tonnes WM with a biomethane potential of 5,355 Nm^3 CH$_4$ per year.

5. 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 Dingle 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 on the peninsula, as well as the unlikelihood of it being financially viable, seaweed was not quantified as a feedstock for AD in this study. More can be read on marine algae for AD plants in **Appendix C – Potential for Algae**.

D. Summary of biogas feedstock analysis

Table 11: Summary of biogas feedstock analysis.

Feedstock	Theoretical Resource		Practical Resource	
	t_{DM}/year	Nm^3 CH$_4$/year	t_{DM}/year	Nm^3 CH$_4$/year
Silage	259,800	95,053,026	75,697	27,695,335
Cattle Slurry	10,420	1,797,450	9,378	1,617,729
Food Waste	470	78,960	256	61,963
Sewage Sludge	243	29,160	80	9,600
Fish Waste	1,176	255,119	1,176	255,119
Offal			17	5,355
Total	**272,109**	**97,213,715**	**86,587**	**29,639,745**
Total (MJ)		**3,596,907,437**		**1,096,670,569**
Total (PJ)		**3.60**		**1.10**
Total (GWh)		**999.1**		**304.6**

The survey data indicates that slurry yields on the peninsula are considerably higher than what research would suggest, though this is most likely due to the assumption that each farmer's slurry tank is full every year. The survey data also indicates that silage yields in the peninsula are lower than what is theoretically possible from the data in the census. Silage yields of 10 t_{DM}/ha are a theoretical value that requires excellent fertilisation and intensive harvesting, and, as farmers only harvest as to their requirements, it is not unexpected that the current silage output is lower than what is theoretically possible from the same land. Another factor not considered at this stage of the analysis is the quality of the soil, which would have an impact on silage yields.

Generally, it is clear from the above analysis that agricultural feedstocks will play an important role in the production of biogas on the peninsula. 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 €50 and €75 per wet tonne. By comparison, silage is relatively costly as a feedstock, which would have a significant impact on the viability of an AD plant. 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 on the peninsula.

The seasonality of feedstocks must also be taken into consideration. Food waste and sewage sludge production on the peninsula are significantly seasonal due to the large influx of tourists in 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.

Finally, it is worth noting that the practical AD feedstock potential in the study area estimated at 27.7 million Nm^3 CH$_4$ has an energy content of 304.6 GWh, compared to 310 GWh of final energy usage in the study area according to Dingle's EMP. This is promising in terms of the potential for AD to contribute to meeting the local energy needs in a sustainable manner. The next step will be to assess the different technological pathways whereby biogas can be converted to useful energy for heat, electricity and transport.

E. Spatial Analysis of Biogas Feedstock

Census data acquired from the CSO gives information for every electoral division (ED) in Ireland for population (Population Census, 2016) and for hectares under silage and number of livestock (Agricultural Census, 2010). The CSO provide GIS data in conjunction with the census data. This data was mapped using QGIS software. For total biomethane production, biomethane from fish waste was added to the ED of An Daingean. The ED of Na Gleannta, which surrounds An Daingean, has both more cattle and more hectares under silage than any other ED in the peninsula. This, in conjunction with Dingle Town's high population relative to the rest of the peninsula, means that An Daingean and Na Gleannta together have the highest biomethane potential of the peninsula. This spatial data will be used further in Work Package 4 as part of the overall spatial analysis of biogas in the study area.

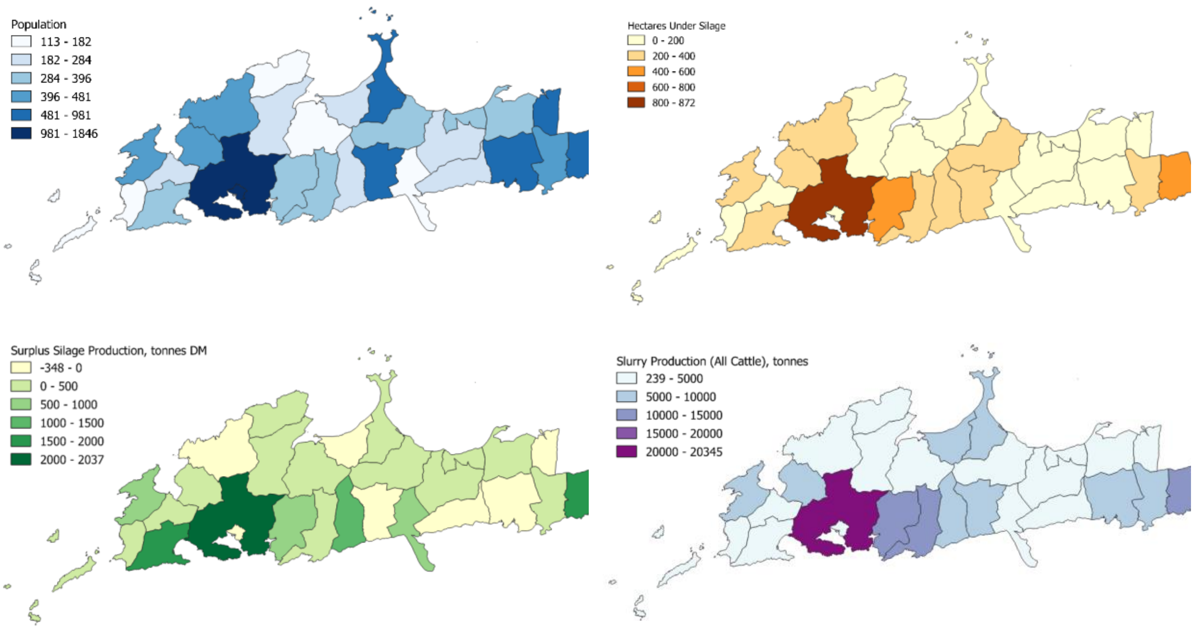


Figure 9: spatial analysis of feedstocks distribution in the study area.

Chapter 3. Technological Pathways Analysis

A. Introduction

In this chapter, the methodology and results of the AD technological pathways analysis are reviewed. The objectives of the analysis were to:

- Map out AD technological pathways with a potential to become effective solutions for the peninsula, identifying key elements of their value chain from feedstock harvesting to final energy distribution.
- Determine key inputs and outputs of selected technological pathways along their entire value chain, in terms of feedstocks quality and quantity, AD technologies' energy outputs as well as non-energy products (chemicals, fertilisers, food, etc.) and services (carbon capture, waste management, etc.).
- Conduct a high level techno-economic modelling of selected AD technological pathways to identify viable pathways and key factors impacting on their viability.
- Conduct a SWOT analysis and compare selected technological pathways, using modelling outputs.

B. Selection and description of the technological pathways analysed

There were two primary considerations used when shortlisting the AD pathways to be analysed: a) the nature of the feedstocks used and b) how the biogas is used to produce useful energy. Figure 10 provides a general view of the different AD pathways analysed in the following sections, based on variations around the core anaerobic digestion system in terms of feedstocks (farmyard waste, municipal & industrial waste, grass silage) and their pre-digestion treatment, energy processes and outputs (heat, electricity, biomethane) and non-energy outputs (liquid digestate, compost, CO_2).

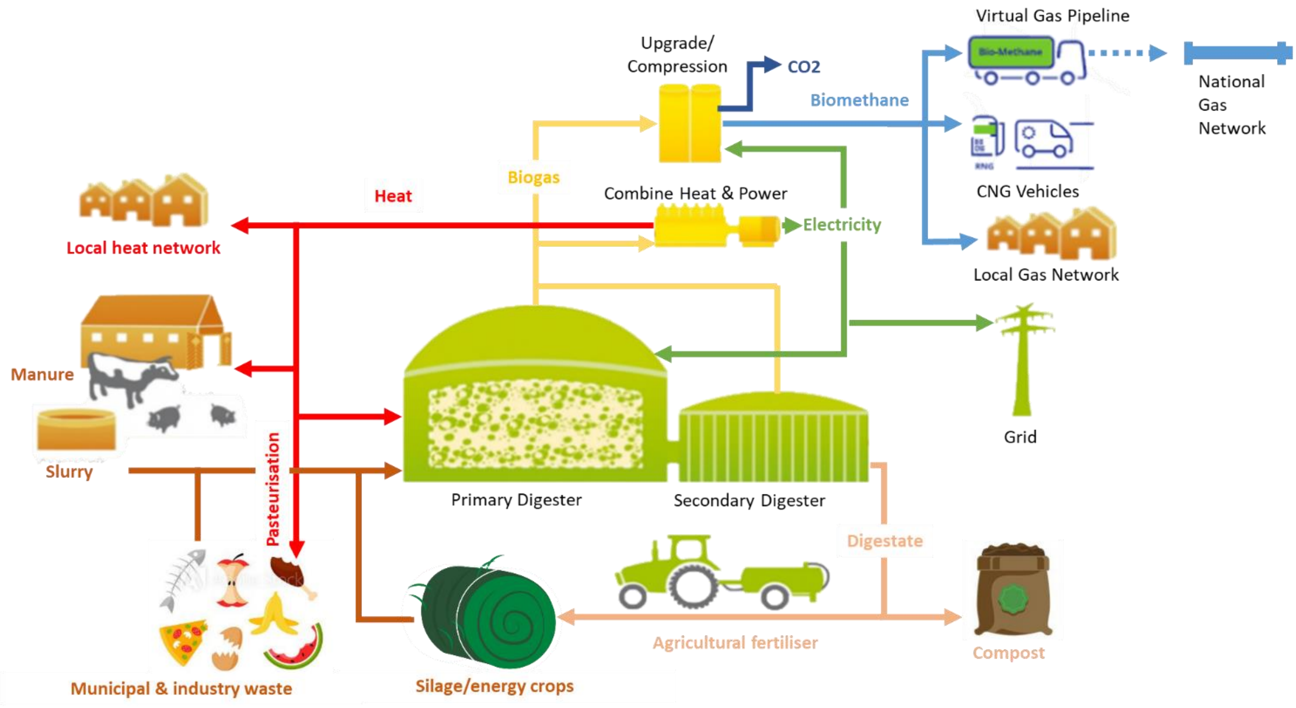


Figure 10: Overview of the AD pathways analysed. Source: XDC

1. Primary pathway selection based on feedstocks used

According to EU animal By-products (ABP) legislation[8] livestock wastes such as cattle slurry and manure, of which there are substantial amounts on the peninsula, are classified as Class 2 Animal By-products (ABP). Use of these feedstocks in 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. There is only one exception: small volumes of slurry from a single farm (< 5,000 tWM/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.

Other situations are subject to the onerous conditions of ABP legislation:

1. Livestock wastes amounting to more than 5,000 tWM/a
2. Livestock wastes of any amount if arising from more than one farm and/or requiring transport to another site.
3. Any amount of digestate from a biogas plant which processes livestock wastes (of any amount) which requires recycling to land of more than one farm

Given the ABP regulation restrictions discussed above, two primary pathways were considered in the techno-economic analysis that follows, based on the nature of the feedstocks used:

- **Pathway 1 (non-ABP)** using grass silage which has a significant production cost. If livestock wastes are used, this would restrict the scale of the AD plant to a small, on-farm unit processing less than 5,000 tWM/a, with all the digestate shall be spread on the same farm.
- **Pathway 2 (ABP)** using municipal and industrial organic wastes (food waste, sewage sluge, fish waste, etc.) supplemented with agricultural feedstocks (livestock wastes and/or grass silage). In this case, the AD plant provides waste management services for which gate fees are taken for the organic waste processed. This pathway requires pasteurisation, which together with increased health and safety regulatory requirements, add significantly to the capital and operational costs of ABP plants. Economies of scale are therefore required to achieve economic viability in ABP plants.

In pathways 2 (ABP) above, the feedstock mix was taken to take advantage of 100% of the practical potential of the food/brown bin waste and sewage sludge. Varying amounts of fish/offal waste to keep their share in the overall mix below 8% to maintain good anaerobic digestion conditions and avoid excessive smell from the plant and disposal of digestate.

2. Secondary pathways selection based on the biogas conversion to final energy

For each of the primary pathways above, three energy technology pathways were considered:

- **Sub-pathway A** where the biogas produced by the digesters is cleaned and injected in a gas engine driving an electricity generator, with heat recovery from the exhaust gas and engine cooling. This is referred to as a combined heat and power (CHP) plant. The electricity generated can be used on site if there is a sufficient demand (e.g. large processing plant) or exported to the electricity distribution grid. The heat recovered from the CHP unit can be used at the AD plant to

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[8] The European Union (Animal By-products) Regulation 2014 (S.I. No 187 of 2014) and in accordance with Regulation (EC) No.1069 of 2009 and Regulation (EU) No. 142 of 2011.

heat the digesters, pasteurise the feedstocks if necessary and/or can be exported to heat nearby buildings or industrial processes via a local heat network.

- **Sub-pathway B** where the biogas produced by the digesters is upgraded to compressed biomethane (CBM) in a process which cleans the biogas, removes its CO_2 content (between 40-50% of the biogas content by volume) and other contaminants, and compresses it to a high pressure. The compressed biomethane can be injected into the natural gas grid or used locally to fuel vehicles whose engines have been specially manufactured to use Compressed Natural Gas (CNG) engine, or in vehicles that are converted to dual fuel use. The AD plant and the upgrading & compression process's significant electricity requirements are met by the grid. The upgrading/compression plant produces heat which contributes to the AD plant thermal requirements.
- **Sub-pathway C** is similar to sub-pathway B above but also includes a CHP plant using the biogas from the digester to generate a large proportion of the electricity used by the AD plant (digester and feedstock pasteurisation where it applies) and the upgrading/compression plant. The heat output from the CHP unit and the upgrading/compression plant is used on site. If there is surplus, it can exported via a local heat network.

3. Summary of pathways analysed

The following table summarises the pathway options investigated:

	Feedstocks		Processes & energy systems			
Pathway Name	Agricultural feedstocks	Animal By-Products	Pasteurisation	CHP	CBM (+CO_2)	Heat Network
1.A Agri & CHP	V			V		V
1.B Agri & CBM	V				V	V
1.C Agri & CHP+CBM	V			V	V	V
2.A Agri+ABP & CHP	V	V	V	V		V
2.B Agri+ABP & CBM	V	V	V		V	V
2.C Agri+ABP & CHP+CBM	V	V	V	V	V	V

In addition to assessing the pathways in terms of feedstocks used, the types of energy produced and their end-use, we have also considered the following by-products of the AD pathways:

- The digestate, a nutrient-rich substance produced by anaerobic digestion that can be used as a fertiliser to replace synthetic fertilisers. It consists of left over indigestible material and dead micro-organisms - the volume of digestate will be around 90-95% of what was fed into the digester.
- The solid fraction of the digestate (15-20%), separated by a screw press and composted to provide a very valuable soil fertiliser and enhancer for use in gardening and horticulture.
- Carbon dioxide, a by-product of the biogas upgrade to biomethane, can be compressed, stored at high pressure in steel containers and sold in horticulture or industry. Certain biogas upgrade technologies can produce high concentration CO_2, with virtually no contaminants, which can be used in the food & drinks industry and attract a high price.

As we will see in the cost/benefit analysis of the different pathways, valorising these by-products should play an important role in the financial viability of any proposed AD project in the peninsula.

C. Technical Assessment of AD Pathways

The purpose of the pathway analysis is to enable a financial cost-benefit comparison between different feedstocks and energy use scenarios. To do this required a fixed biogas biogas plant capacity with a fixed nominal biogas/methane output from the biogas plant available for upgrading. The size of plant chosen was the most popular size in the EU which equates to a nominal 500kWe electrical output requiring a nominal average gross biogas output of 4,900 Nm^3/day at 55% methane.

The quantity of feedstocks required in each pathway were calculated to provide the biogas required for the CHP operation (pathways 1.a and 2.a) or the compressed biomethane (pathways 1.b and 2.b). Pathways 1.c and 2.c required additional feedstock to meet the biogas requirements of the CHP units installed to fulfil the electricity requirements of the digesters, upgrading and compression plant, as well as CO_2 production where it applies. The following assumptions were taken in relation to the feedstocks' biomethane potential, delivered cost or gate fees:

Biomethane Potential of Feedstock					Delivered feedstock cost or gate fees
Feedstock	DS (%wwt)	Methane Yield (Nm^3 CH_4/tDS)	CH_4 in biogas (%)	Biogas yield Nm^3/tWM	€/tWM
Grass Silage	23.0%	364	60%	140	30
Cattle Slurry	8.0%	107	60%	14	5
Farmyard Manure	20.0%	232	60%	77	5
Food Waste	30.6%	242	60%	124	-70
Sewage Sludge	17.0%	120	60%	37	-60
Fish Waste	32.2%	216	60%	116	-20

Other technical assumptions made with regard to different elements of the AD pathways systems are outlined hereafter. These are based on typical industry standards and technical specifications received from technology suppliers:

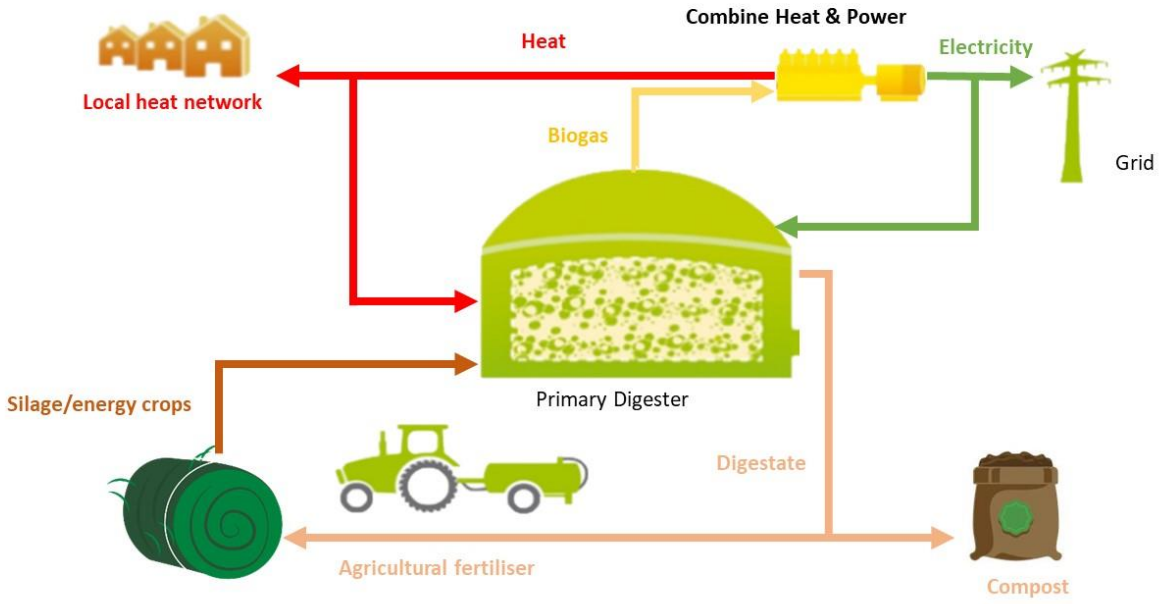
- Electricity usage:
  - Digester: 0.438 kWh per m^3 of digester volume
  - Biogas upgrading: 0.3 kWh/Nm^3 biogas
  - Biomethane compression: 0.3 kWh/Nm^3 biogas
  - CO_2 liquefaction: 1.4 kWh/Nm^3 CO_2
- Heating requirement:
  - Biodigester: 10% of gross energy output (biogas)
  - Pasteurisation: 10% of gross energy output (biogas)
- Heat output:
  - CHP: 39% of gross energy input (biogas)
  - Biogas upgrading: 0.25 kWh/Nm^3 biogas
  - Biomethane compression for storage: 0.25 kWh/Nm^3 biogas
  - CO_2 liquefaction: 1.4 kWh/Nm^3 CO_2
- Average operating times:
  - Biodigester: 8760 hours
  - CHP unit: 8000 hours
  - Biogas upgrade and CBM compression plant: 8000 hours

Each of the 6 pathways investigated has been illustrated in Table 12 hereafter which includes:

- A drawing illustrating the components of the AD system as well as the energy and material flows associated with each pathway.
- A schematic diagram showing the details of the energy and material flow of each pathway.
- High-level performance specifications for the key components associated with the energy system.
- Key figures on the annual energy and material flows associated with each pathway.

Table 12: Illustration and performance specifications of the AD pathways investigated.

Pathway 1.A. Agricultural feedstocks with Combined Heat & Power (CHP)



Energy system performance specifications:

Digester volume: 1400 m^3

Combined heat & power:

- Electrical capacity: 500 kWe (40% efficiency)
- Thermal capacity: 488 kW (39% efficiency)

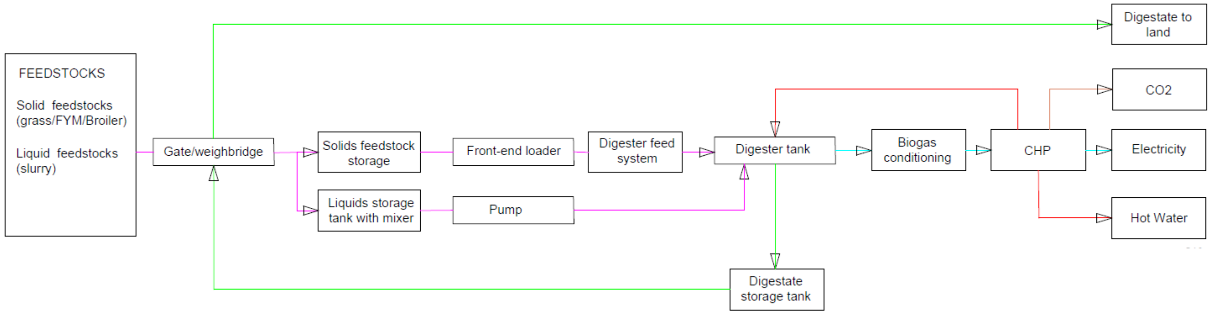
Average digester heat requirement: 123 kW
Average surplus heat available: 354 kW
Biomass boiler capacity: 0 kW

Material & energy flow:
Biogas output: 4,900 m^3 per day

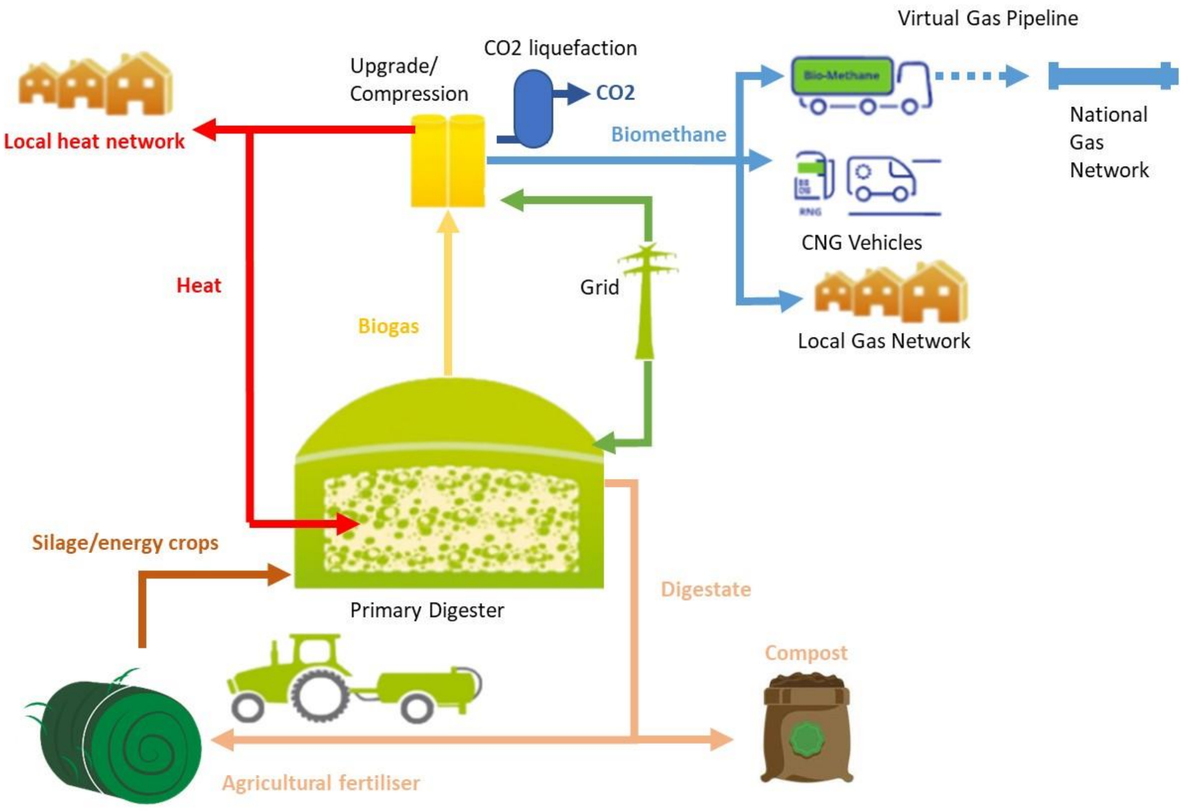
Feedstock mix:
Grass silage: 35.1 tWM/day or 12,812 tWM/year

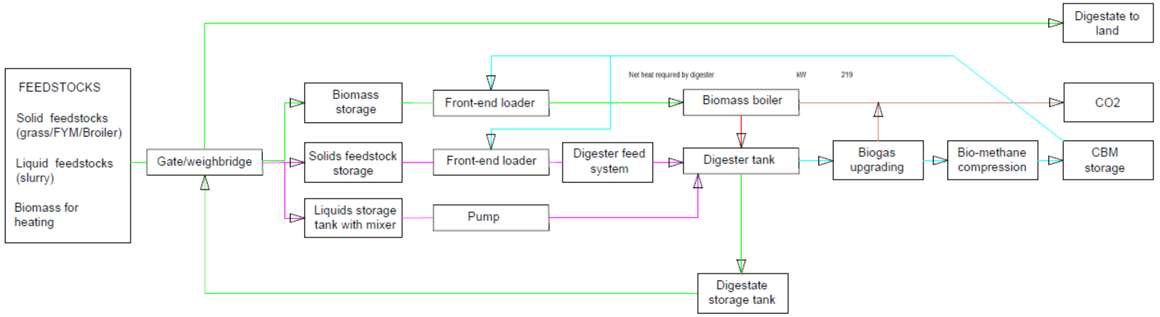
Heat available for export: 2,827 MWh/year
Electricity available for export: 8,000 MWh/year

Digestate output: 12,812 tWM/year
Compost output: 2,242 tWM/year



Pathway 1.B. Agricultural feedstocks with upgrade & compression to biomethane (CBM)





Energy system performance specifications:

Digester volume: 1750 m^3

Combined heat & power: none

Average electricity requirement:

- AD plant: 90 kW
- Upgrading/compression plant: 134 kW
- CO$_2$ liquefaction plant: 14 kW

Average digester heat requirement: 123 kW
Average heat output upgrading/compression: 300 kW
Average heat output CO$_2$ liquefaction: 125 kW
Average surplus heat available: 170 kW (300 kW with CO$_2$ liquefaction)
Biomass boiler capacity: 0 kW

Material & energy flow:

Feedstock mix:

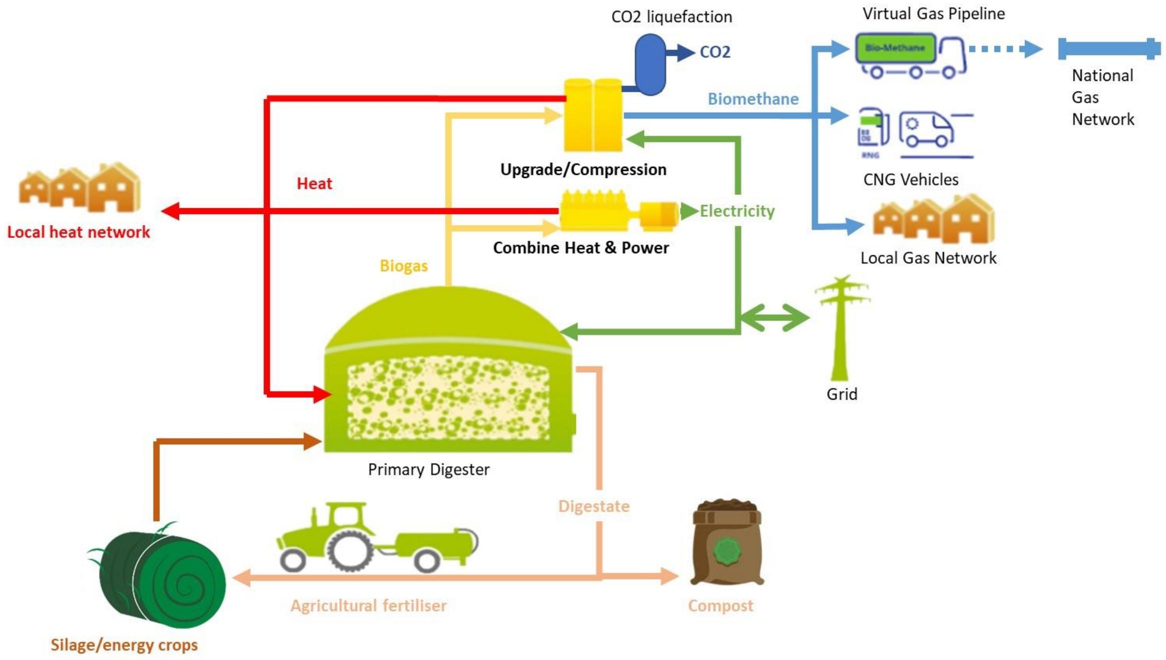
- Grass silage: 35 tWM/day or 12,775 tWM/year

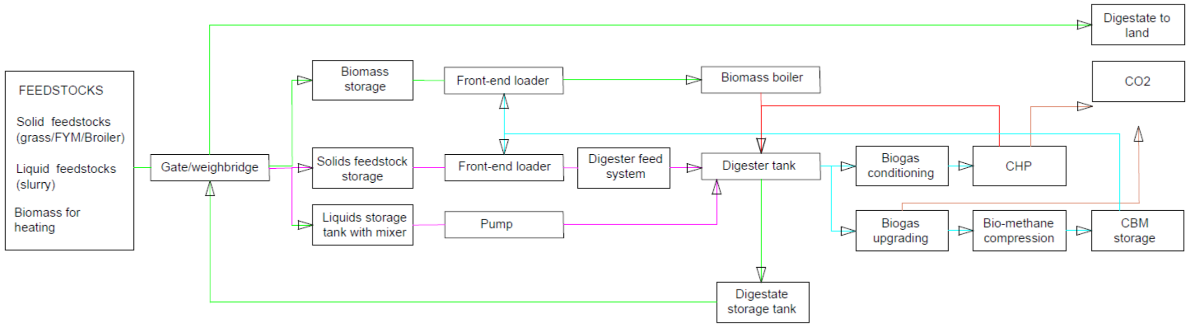
Biogas output: 4,900 m^3 per day
Biomethane output: 2,940 m^3/day
CO$_2$ output: 1960 m^3/day (44 kg/hr)

Heat available for export: 1,377 MWh/year (2,378 with CO$_2$ liquefaction)

Digestate output: 12,775 tWM/year
Compost output: 2,235 tWM/year

Pathway 1.C. Agricultural feedstocks with CBM & on-site CHP





Energy system performance specifications:

Digester volume: 2800 m^3

Combined heat & power:

- Electrical capacity: 300 kWe (40% efficiency)
- Thermal capacity: 290 kW (39% efficiency)

Average electricity requirement:

- AD plant: 140 kW
- Upgrading/compression plant: 130 kW
- CO_2 liquefaction plant: 15 kW

Average digester heat requirement: 195 kW
Average heat output upgrading/compression: 300 kW
Average heat output CO_2 liquefaction: 125 kW
Average surplus heat available: 370 kW (500 kW with CO_2 liquefaction)
Biomass boiler capacity: 0 kW

Material & energy flow:

Feedstock mix:

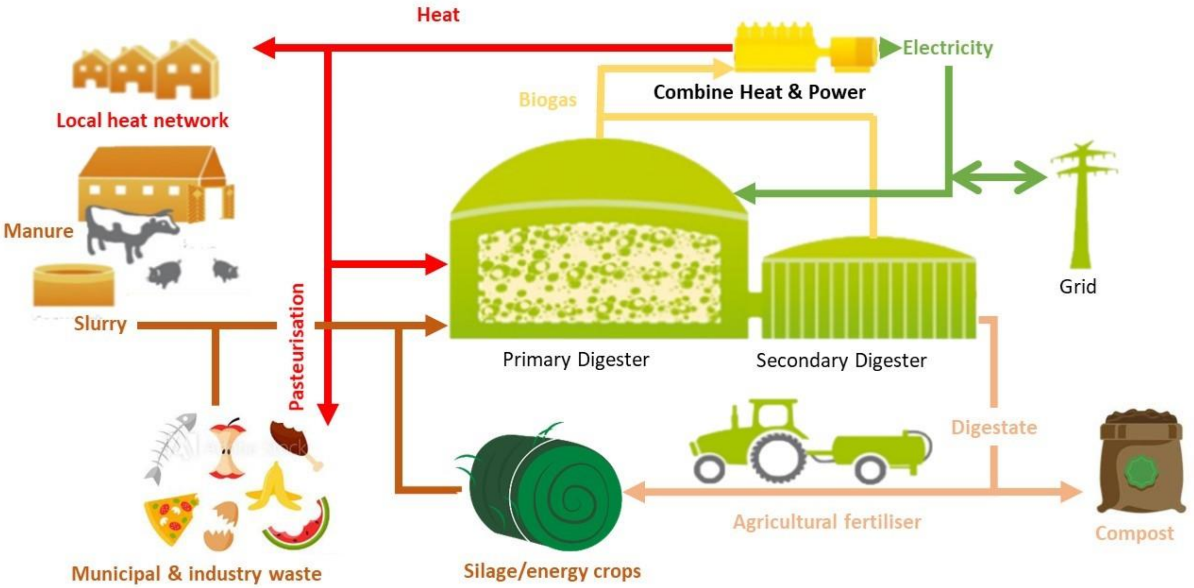
- Grass silage: 56 tWM/day or 20,440 tDW/year

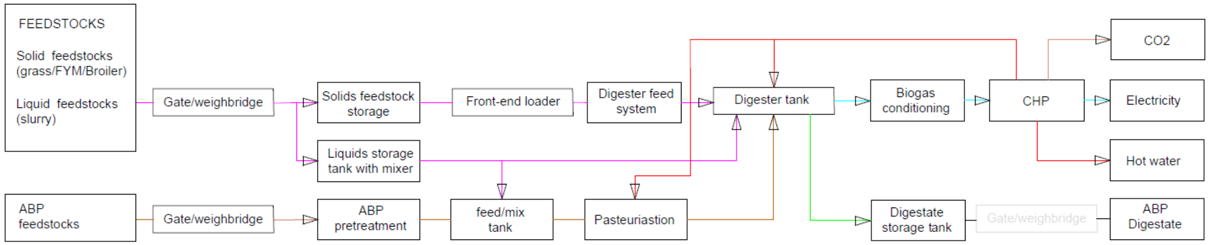
Biogas output: 7,780 m^3 per day
Biomethane output: 2,940 m^3/day
CO_2 output: 1960 m^3/day (44 kg/hr)

Heat available for export: 2,900 MWh/year (4,040 with CO_2 liquefaction)

Digestate output: 20,440 tWM/year
Compost output: 3,577 tWM/year

Pathway 2.A. Animal Byproducts (ABP) + agri feedstocks with Combined Heat & Power





Energy system performance specifications:

Total digester volume: 2,000 m^3

Combined heat & power:

- Electrical capacity: 500 kWe (40% efficiency)
- Thermal capacity: 488 kW (39% efficiency)

Average digester & pasteurisation heat requirement: 250 kW
Average surplus heat available: 219 kW
Biomass boiler capacity: 0 kW

Material & energy flow:
Biogas requirement: 4,900 m^3 per day

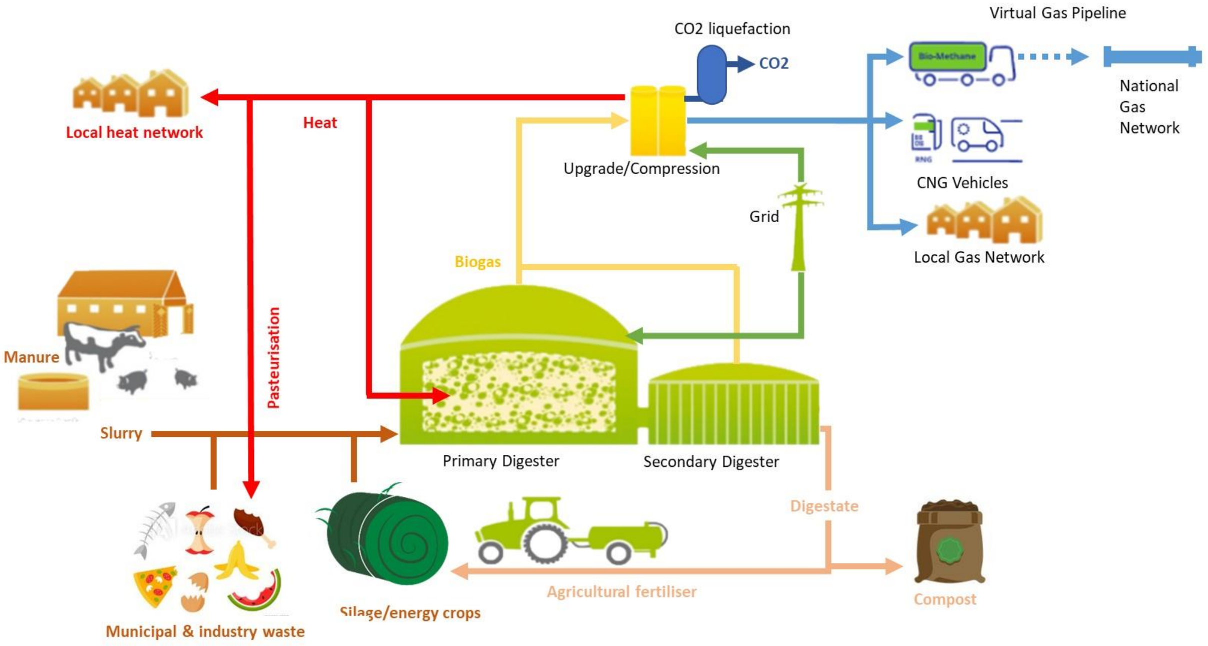
Feedstock mix:

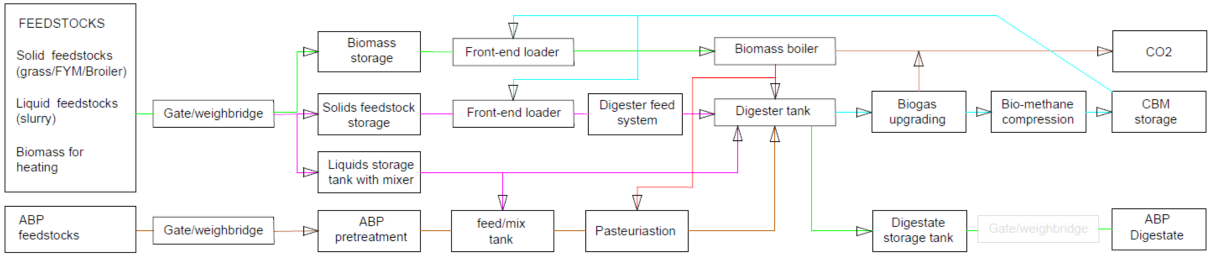
- Grass silage: 27 tWM/day or 9,855 tWM/year
- Cow slurry: 5 tWM/day or 1,825 tWM/year
- Farmyard manure: 5 tWM/day
- Brown bin waste: 2.3 tWM/day
- Sewage sludge cake: 1.3 tWM/day
- Fish waste/offal: 3.0 tWM/day

Heat available for export: 1,754 MWh/year
Electricity available for export: 4,000 MWh/year

Digestate output: 15,907 tWM/year
Compost output: 2,784 tWM/year

Pathway 2.B. ABP & agri feedstocks with upgrade & compression to biomethane





Energy system performance specifications:

Digester volume: 2,200 m^3

Average electricity requirement:

- AD plant: 110 kW
- Upgrading/compression plant: 134 kW
- CO_2 liquefaction plant: 14 kW

Average digester heat requirement: 123 kW
Average heat output upgrading/compression: 300 kW
Average heat output CO_2 liquefaction: 125 kW
Average surplus heat available: 38 kW (163 kW with CO_2 liquefaction)
Biomass boiler capacity: 0 kW

Material & energy flow:

Feedstock mix:

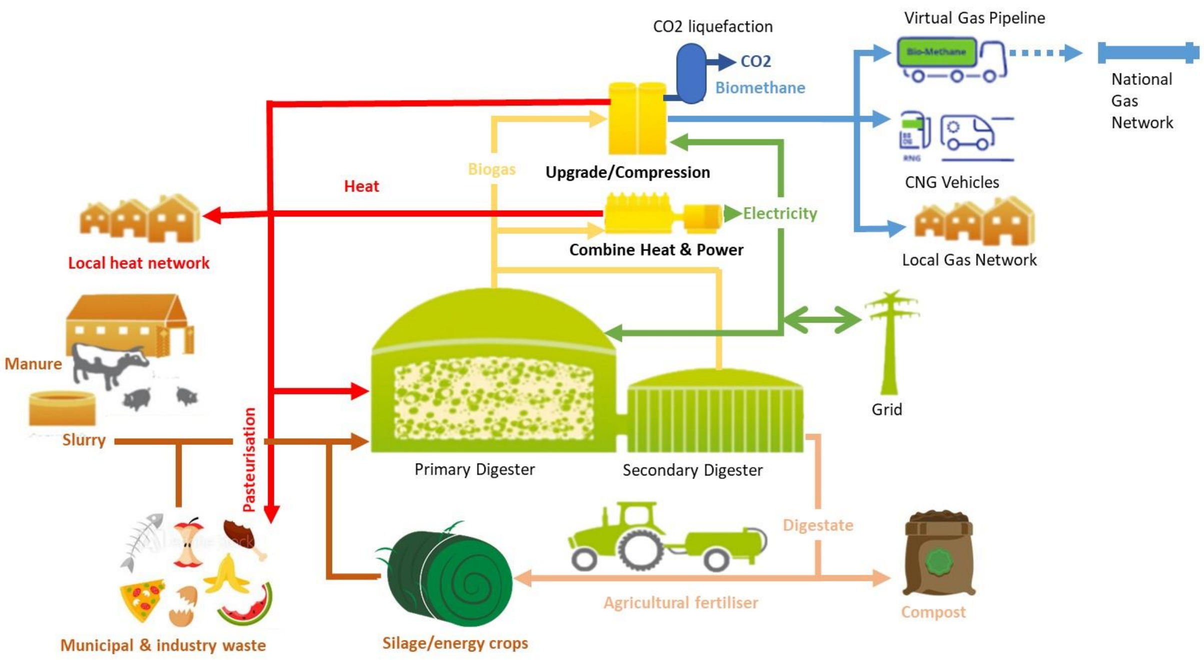
- Grass silage: 27 tWM/day or 9,855 tWM/year
- Cow slurry: 5 tWM/day or 1,825 tWM/year
- Farmyard manure: 5 tWM/day
- Brown bin waste: 2.3 tWM/day
- Sewage sludge cake: 1.3 tWM/day
- Fish waste/offal: 3.0 tWM/day

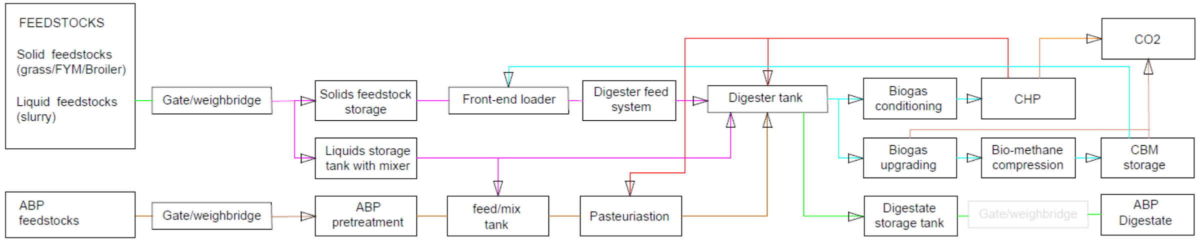
Biogas output: 4,900 m^3 per day
Biomethane output: 2,940 m^3/day
CO_2 output: 1960 m^3/day (44 kg/hr)

Heat available for export: 300 MWh/year (1,300 with CO_2 liquefaction)

Digestate output: 15,900 tWM/year
Compost output: 2,783 tWM/year

Pathway 2.C. ABP and agri feedstocks with CBM & on-site CHP





Energy system performance specifications:

Digester volume: 3600 m^3

Combined heat & power:
- Electrical capacity: 350 kWe (40% efficiency)
- Thermal capacity: 320 kW (39% efficiency)

Average electricity requirement:
- AD plant: 150 kW
- Upgrading/compression plant: 130 kW
- CO_2 liquefaction plant: 14 kW

Average digester heat requirement + pasteurisation: 410 kW

Average heat output upgrading/compression: 300 kW
Average heat output CO_2 liquefaction: 125 kW
Average surplus heat available: 350 kW (480 kW with CO_2 liquefaction)
Biomass boiler capacity: 0 kW

Material & energy flow:

Feedstock mix:
- Grass silage: 49 tWM/day or 17,900 tWM/year
- Cow slurry: 10 tWM/day or 3,650 tWM/year
- Farmyard manure: 5 tWM/day
- Brown bin waste: 2.3 tWM/day
- Sewage sludge cake: 1.3 tWM/day
- Fish waste/offal: 4.0 tWM/day

Biogas output: 8,200 m^3 per day
Biomethane output: 2,940 m^3/day
CO_2 output: 1960 m^3/day (44 kg/hr)

Heat available for export: 1,370 MWh/year (2,370 with CO_2 liquefaction)

Digestate output: 26,150 tWM/year
Compost output: 4,800 tWM/year

D. Techno-economic assessments of the different pathways analysed

1. Methodology and assumptions

A preliminary techno-economic analysis was conducted for each pathway to assess the financial operating balance (effectively a profit and loss account) on a typical year of operation of the associated AD systems. This analysis considers the following variables:

- **The capital expenditure** required to build and commission the AD system:
  Turnkey (supply/install/commission) budget costs were sourced for the ***biogas plant***[9], the biogas ***upgrade/compression*** and CO_2 ***liquefaction*** plants[10].
  Cost estimates for the supply and install of ***CHP plants*** were taken from previous projects.
- The annual operating cost including:
  - Cost of acquiring ***feedstocks*** including production (in particular silage) and transport costs, considering gate fees for municipal & industrial organic waste, taken from the feedstock analysis undertaken in WP2.
  - ***Energy*** costs (electricity, biomass fuels, etc.) taken from SEAI's Commercial Fuel Costs publication and other market prices. Imported electricity has been priced at €0.1588/kWh for dayearate and €0.08/kWh for night rate.
  - Cost of disposing of ***the digestate*** at the end of the process, based on transport and application to land costs of €2/tonne.
  - ***Repairs and maintenance*** costs, based on information provided by suppliers and general biogas plant operating costs relative to plant capital costs
  - Plant operators, management, administrative ***staff costs based on typical biogas plant operational requirements, plus*** overheads (30% of staff cost) and ***insurance*** (based on typical insurance costs in UK for similar plants).
  - Cost **of biomethane delivery and injection** into natural gas grid (GNI, 2019):
    - Biomethane haulage: 160 km at €0.055/MWh,km
    - Biomethane injection: €4.5/MWh
  - The cost of ***financing*** the capital expenditure above, based on debt to equity ratio of 80:20, interest rate of 6%, loan repayment period of 10 years.
  - Depreciation based on ***straight-line depreciation*** over 15 years for machinery (CHP, pumps, compressors, upgrading plants, etc.) and 20 years for buildings, digesters and other non-mechanical plant.
- The potential revenues derived from:
  - Production of energy including:
    - ***Electricity*** produced by biogas CHP for export (pathways 1.a and 2.a), priced at the existing feed-in tariff of €0.15/kWh
    - ***Surplus heat*** available for export (sum of outputs from CHP, biogas upgrading, compression and CO_2 liquefaction, minus digesters and pasteurisation heating requirements). Heat as been valued at €0.05/kWh to allow for additional cost of heat distribution (assume €0.03) and remain competitive with pre-existing heating costs (oil and LPG). No revenue from the Support Scheme for Renewable Heat was considered.
    - ***Compressed biomethane*** exported for grid injection, with revenue calculation considering €0.02 per kWh of CBM injected, based on wholesale price of natural

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[9] Preliminary quotations by Tank Storage Systems of Ireland, and Host-Bioenergy, UK
[10] Preliminary quotations by Bright Biomethane

gas, and a subsidy of €0.088/kWh[11]. The same pricing has been applied to the CBM if it is sold locally as a transport fuel.

- The sale of food grade CO_2 as a by-product of the biogas upgrade process, taken as €3/Nm^3.
- The sale of the ***compost*** produced at €25 per tonne (sale in bulk).

The following key performance indicators (KPIs) were derived from the cost/benefit analysis of 6 pathways reviewed in section Chapter 3.B above, with their variations incorporating the sale of liquified CO_2:

- **Profit & Loss (P/L) account** for an average year of operation, **before tax**, including total revenues, operational expenditure, depreciation and interest payments (for mid-repayment period year).
- **Return on Capital (ROC, %)** as a measure of the profitability and value-creating potential of companies relative to the amount of capital invested by shareholders and other debtholders. The ROC is calculated by dividing the sum of [initial capital expenditure and interest payment] by the P/L value.
- The **breakeven value (€/kWh)** of the primary energy sold (electricity for CHP pathways 1.a and 2.a; biomethane for pathways 1.b&c and 2.b&c), calculated by adding all operating costs (including finance and depreciation), substracting secondary revenues (e.g. heat, compost, CO_2, …) and dividing by the amount of primary energy sold.
- The **Levelised Cost of Energy (LCOE, €/kWh)** of the primary energy sold (same as above), is calculated using the equivalent annual cost method, based on discounted cash flow analysis, spreading the capital cost over the lifetime of the project (taken as 20 years). The annualised capital cost[12] calculated with a discount rate of 8% is added to the annual (operational) costs, non primary energy revenues are subtracted, and the total is divided by the amount of primary energy sold.

2. Results of the techno-economic pathway analysis

The results of the techno-economic analysis of the pathways assessed, is summarised in Table 13 page 38. The results of the cost/benefit analysis undertaken indicate:

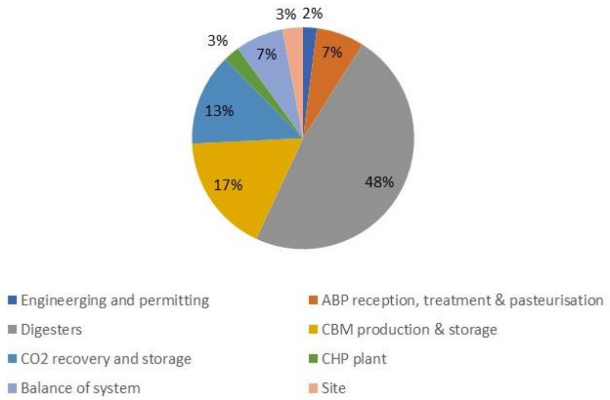

Figure 12: Capital cost breakdown of pathway 2.c with CO_2

Figure 11: Breakdown of CAPEX of ABP CBM + CO2 pathway

- The capital investment required varies from €2.3 million to €4.9 million, with capital costs escalating rapidly for more complex processes requiring upgrade of biogas to biomethane and its storage (+ €865,000), treatment of ABP feedstocks (+ €1 million), CO_2 liquefaction and storage (€670,000).
- As exemplified in Figure 12 for the most complex and expensive pathway ABP CBM Site CHP + CO_2, the biodigesters contribute most to the capital expenditure

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[11] Values for the price of compressed biomethane and subsidy were taken from discussions with Gas Network Ireland. These were comparable to CBM pricing and subsidies in application in the UK.

[12] Using the formula $P_a = \frac{C_o(1+r)^N r}{[(1+r)^N - 1]}$ where Pa is the CAPEX; Co is the investment cost; N is the number of years and r is the discount rate.

of the given plant (48%), with CBM production and storage coming second, and CO_2 liquefaction & storage third.

- The annual profit and loss account of the different pathways indicates clearly that the pathways based on the combined production of heat and power (pathways 1.a and 2.a) are not viable financially.
- CBM pathways treating ABP generate the highest profit due to the reduction in feedstock costs due to gate fees income (see Figure 13). This is compounded by the use of a site CHP unit (pathway 2.C) to meet the electricity requirements of the plant and contribute to the availability of excess heat for export.

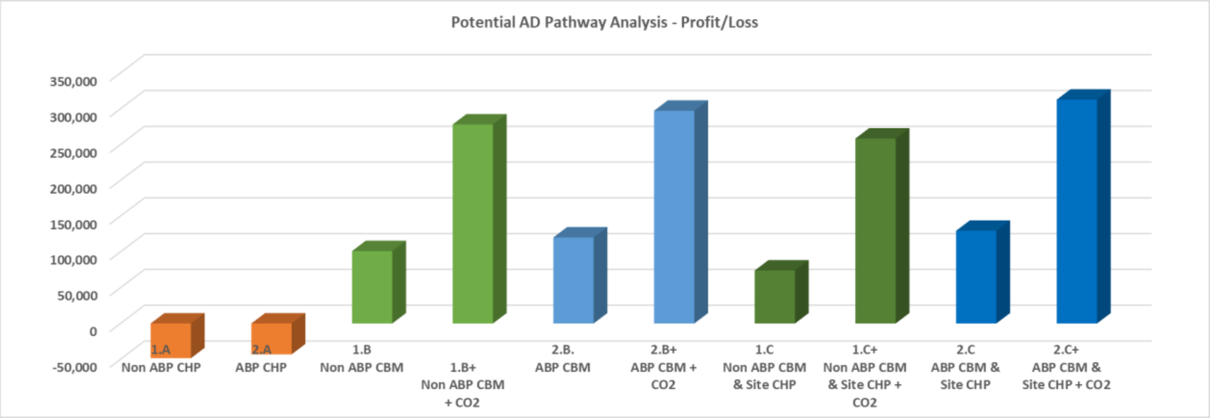


Figure 13: Comparison of annual P/L account for the different pathways.

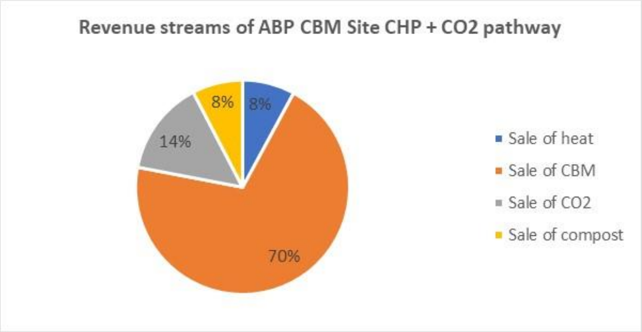


Figure 14: Breakdown of revenue streams for pathway 2.C.

- Among all potential sources of revenue (see for pathway 2.C), the sale of compressed biomethane contributes the most (70%) to the income of CBM pathways.
- However, the sale of CO_2 gives a considerable uplift in the profitability (Figure 13) and return on capital (between 3.4 and 4.1% acc. Table 13).
- The LCOE of biomethane in the different pathways analysed varies from c€8.2/kWh for the non ABP CBM + CO_2 pathway to c€11.3/kWh in the ABP CBM CHP + CO_2 pathway (Figure 15), to be compared with the unit revenue of €0.108 per kWh of CBM assumed (value of gas injected and subsidy).

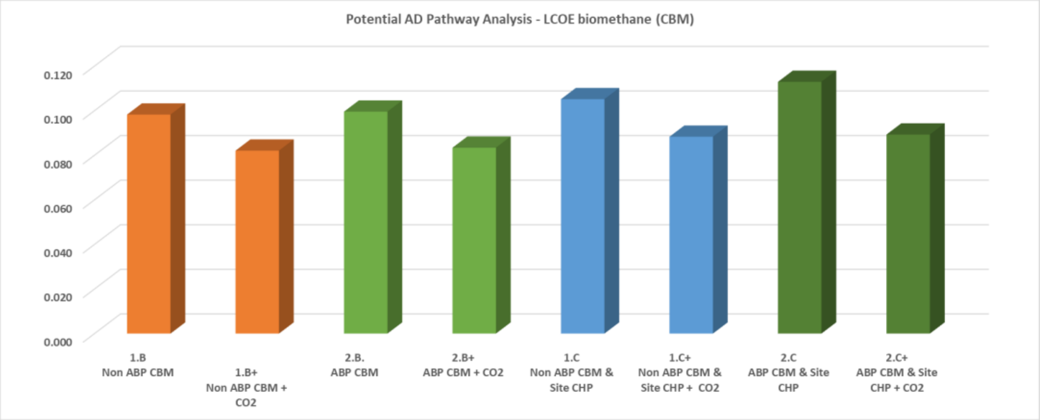


Figure 15: Comparison of LCOE of CBM pahtways.

Table 13: Summary of the AD pathway techno-economic pathway analysis.

Pathways financial summaries		1.A Non ABP CHP	2.A ABP CHP	1.B Non ABP CBM	1.B+ Non ABP CBM + CO2	2.B. ABP CBM	2.B+ ABP CBM + CO2	1.C Non ABP CBM & Site CHP	1.C+ Non ABP CBM & Site CHP + CO2	2.C ABP CBM & Site CHP	2.C+ ABP CBM & Site CHP + CO2
CAPITAL EXPENDITURE											
Planning/project approvals	€	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Project management	€	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Digester turn-key (ex CHP/Upgrading)	€	1,300,000	1,800,000	1,300,000	1,300,000	1,800,000	1,800,000	1,900,000	1,900,000	2,400,000	2,400,000
ABP reception, pretreatment & pasteurisation	€	-	350,000	0	0	350000	350000	0	0	350,000	350,000
CHP plant and gas conditioning	€	400,000	400,000	0	0	0	0	120,000	120,000	120,000	120,000
Biogas-to-CBM upgrading & compression plant	€	-	-	785,500	785,500	785,500	785,500	785,500	785,500	785,500	785,500
CBM storage	€	-	-	80,000	80,000	80,000	80,000	80,000	80,000	80,000	80,000
CO2 recovery and storage	€	-	-	0	670,000	0	670,000	0	670,000	0	670,000
Digestate screwpress and solids storage	€	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Grid connection	€	70,000	70,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Civils	€	200,000	250,000	200,000	200,000	250,000	250,000	200,000	200,000	250,000	250,000
Site acquisition	€	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000	150,000
Total Capital Expenditure	€	**2,270,000**	**3,170,000**	**2,715,500**	**3,385,500**	**3,615,500**	**4,285,500**	**3,435,500**	**4,105,500**	**4,335,500**	**5,005,500**
OPERATION EXPENDITURE											
Feedstocks (costs of feedstocks less gate fees)	€/y	384,345	205,245	383,250	383,250	205,245	205,245	613,200	624,150	447,970	458,920
Recycling digestate	€/y	25,623	31,813	25,550	25,550	31,813	31,813	40,880	40,880	52,253	52,253
Cost of heat	€/y	0	0	0	0	0	0	0	0	0	0
Cost of electricity	€/y	74,778	104,449	223,695	236,919	246,543	259,767	0	0	0	0
Staff cost (operator, management, admin)	€/y	34,000	40,000	49,000	49,000	55,000	55,000	49,000	49,000	55,000	55,000
Overheads & insurance	€/y	60,200	62,000	64,700	64,700	66,500	66,500	64,700	64,700	66,500	66,500
Maintenance and repairs	€/y	85,400	103,400	51,965	51,965	61,965	61,965	86,960	86,960	100,372	100,372
Cost of CBM haulage & grid injection		0	0	48,298	48,298	48,298	48,298	48,298	48,298	48,298	48,298
Total O&M expenditure	**€/y**	**664,346**	**546,907**	**846,459**	**859,682**	**715,365**	**728,588**	**903,038**	**913,988**	**770,393**	**781,343**
REVENUES											
Sale of electricity	€/y	600,000	600,000	0	0	0	0	0	0	0	0
Sale of heat	€/y	141,345	87,690	68,845	118,920	15,190	65,265	124,416	179,657	68,334	118,409
Sale of CBM	€/y	-	0	1,047,816	1,047,816	1,047,816	1,047,816	1,047,816	1,047,816	1,047,816	1,047,816
Sale of CO2	€/y	0	0	0	204,908	0	204,908	0	204,908	0	204,908
Sale of compost	€/y	56,050	69,591	55,891	55,891	69,591	69,591	89,425	89,425	114,304	114,304
Total revenues	**€/y**	**797,395**	**757,281**	**1,172,552**	**1,427,535**	**1,132,597**	**1,387,581**	**1,261,657**	**1,521,806**	**1,230,454**	**1,485,437**
Profit/Loss											
Total revenues	€/y	797,395	757,281	1,172,552	1,427,535	1,132,597	1,387,581	1,261,657	1,521,806	1,230,454	1,485,437
Total operation expenditure	€/y	664,346	546,907	846,459	859,682	715,365	728,588	903,038	913,988	770,393	781,343
Depreciation	€/y	113,500	158,500	143,533	188,200	188,533	233,200	181,533	226,200	226,533	271,200
Interest payment (average)	€/y	68,100	95,100	81,465	101,565	108,465	128,565	103,065	123,165	104,052	120,132
Profit/Loss before tax	**€/y**	**-48,551**	**-43,226**	**101,095**	**278,088**	**120,234**	**297,228**	**74,021**	**258,453**	**129,475**	**312,762**
Return on capital	**%**	0.9%	3.6%	6.7%	11.2%	6.3%	9.9%	5.2%	9.3%	5.4%	8.6%
LIFECYCLE COST ANALYSIS											
Breakeven value of biogas (CHP) // biomethane (CBM)	€/kWh	0.066	0.066	0.088	0.072	0.086	0.070	0.091	0.074	0.086	0.068
LCOE of final energy output (electricity or CBM)	**€/kWh**	**0.189**	**0.196**	**0.098**	**0.082**	**0.100**	**0.083**	**0.105**	**0.088**	**0.113**	**0.090**

Chapter 4. Design of AD system & Life Cycle Cost-Benefit Analysis

This chapter builds on the AD pathways review and cost/benefit analysis undertaken in Chapter 3 and explores in more detail the design of a non ABP AD system (corresponding to pathway 1.b) and an ABP AD system (corresponding to pathway 2.c). A lifecycle cost of analysis will also be undertaken on both systems to provide an indication of what the future cash flow of the proposed system deployment might ultimately be.

A. Preliminary design of the proposed AD system

This section provides a process flow diagram, a layout drawing and a description of the plant operation has been prepared for the following systems:

1. AD system for the production of CBM using non ABP feedstocks (grass silage essentially)
2. AD system for the production of CBM and with a combined heat and power unit designed for local energy use, using ABP feedstocks.

The design of the CO_2 liquefication plant will be illustrated separately as it is an option for both systems.

1. Non ABP CBM plant

Since animal slurry is classed as an animal by-product (ABP), this simple biogas plant uses silage only (plus potential other plant-only biomass) to avoid the need for expensive ABP treatment and plant layout requirements. Here is a functional description of the plant:

a) **Feedstock reception:** Grass silage (delivered by contractors and directly by farmers) is brought into the plant and weighed at the weighbridge. The storage facilities will be similar to any large farm with silage storage, except that the facilities must be large enough to store silage sufficient for day-to-day operation all year.
b) **Digester feeding:** A front-end loader operated by the plant manager, feeds silage into a large 20-tonne feed-hopper which is equipped with weigh-cells; allowing a controlled amount of silage to be fed into the digester every day.
c) **Digester:** The digester is a large insulated tank which is heated and mixed. As the grass silage digests, the organic solids in the grass are converted to biogas, and the waste becomes more liquid. The digester is mixed by a large propeller mixer. The digester has to be maintained at the operating temperature of 40 °C, and this is done by recovering heat from the biogas-biomethane upgrading facilities and circulating this as hot water to the digester. The digester roof is a double-membrane system in which the inner membrane rises and falls to allow for gas storage.
d) **Upgrading biogas to biomethane:** Biogas is produced continuously. Biogas comprises mainly methane (55-60%) with most of the balance being carbon dioxide and some water. It also has trace compounds of which the most important is the corrosive gas hydrogen sulphide. Biogas is processed semi-continuously by the biomethane upgrading facility (see appendix Bright-Biomethane). This has several stages as follows:
    a. Clean the biogas removing mainly hydrogen sulphide and moisture
    b. Separation of carbon dioxide and methane. The biogas is pressurised and passed through a series of membranes which separate these gases with a high degree of efficiency.
    c. Heat recovery. Heat produced by compression of biogas (to pass through the gas separation membranes) is recovered for use in the digestion and pasteurisation process.
e) **Compression of biomethane into high-pressure storage cylinders:** The high-purity separated biomethane is compressed to a high pressure of typically 250bar and stored in high-pressure cylinders for transport to the site of gas use (GNI grid injection point, or local CNG/CBM pump at

service stations). The significant amount of heat recovered from this compression stage is also circulated to the digester.

f) **Digestate and products**: The digested waste (digestate) produced from the digester amounts practically to the same tonnage as the feed (less the weight loss of biogas which is not very significant). The digestate is passed through a screw-press to separate the fibrous solids from the liquid portion. The high-fibre digestate solids are stored and stabilised in covered bays with a view to producing a valuable peat-like compost which can be sold as a by-product for horticulture. The liquid digestate is stored in a large storage tank (90 days winter storage) for recycling back to the fields which produced the silage for the digester. This nutrient recycling process reduces the need for farmers to use fertilisers by an average 80-90%; in turn reducing silage production costs.

The following process flow diagram illustrates the different stages described above:

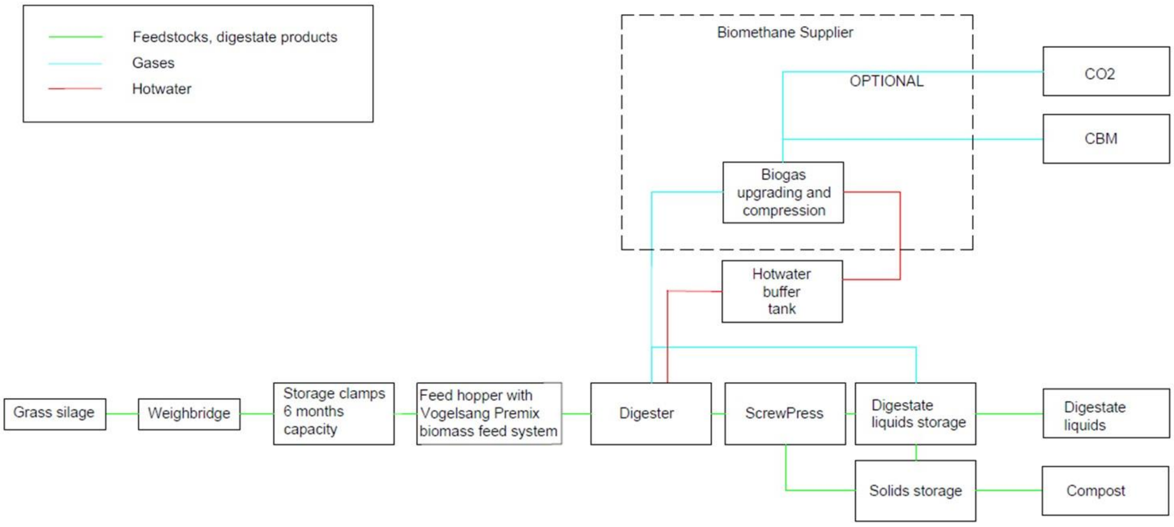


Figure 16: Process flow diagram of AD Non-ABP CBM pathway. Source: WasteWorks, 2020.

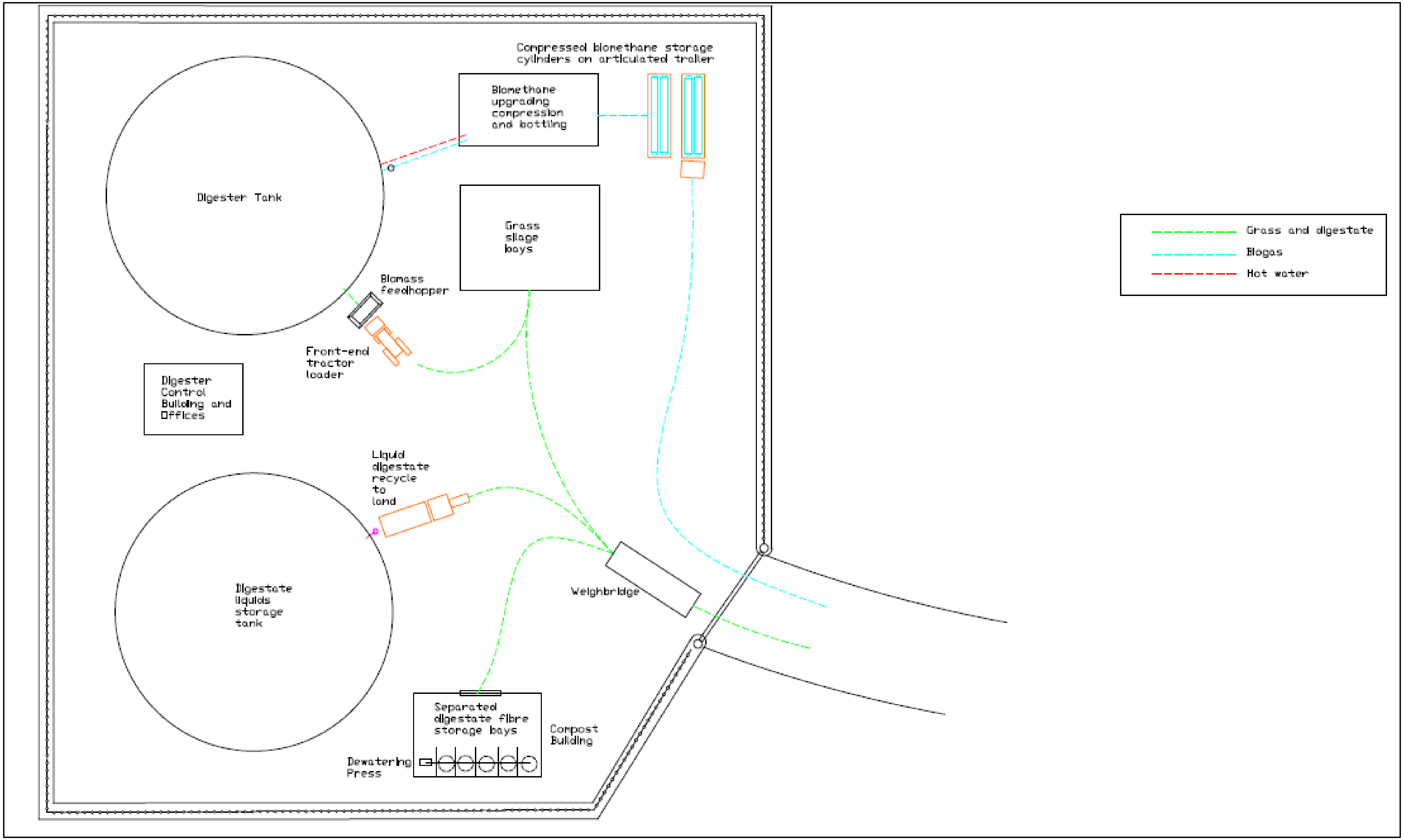


Figure 17: non-ABP CBM AD plant layout. Source: WasteWorks, 2020.

2. ABP CBM Plant

The processing of animal by-products is subject to the strict EU ABP regulations overseen by the Department of Agriculture (veterinary department) and has a considerable impact on the design and operation of an AD plant. This includes the following requirements:

- Monitoring and recording of all wastes received
- Pre-treatment (size reduction) and pasteurisation of all feedstocks (70'C for 1 hour)
- Strict feedstock reception conditions (building layout and enclosure)
- Strict plant layout conditions (no short-circuiting), entrances and double-fencing
- Recording and pathogen testing/validation of all batches of waste processed by the plant
- Strict conformity to HACCP (hazardous operation procedures)
- Recording of the destination of all digested waste products

Another major difference is that the added heat requirements of pasteurisation (in addition to digester temperature control) plus the very significant electrical requirements of the overall process (digester, pasteurisation and upgrading) which suggests the inclusion of a site co-generation plant (CHP) to generate the system electrical and (a portion of the) heat requirements. This is typical of many biogas-biomethane plant operating elsewhere such as the UK. However, the CHP requires additional biogas production; which in turn requires more feedstock and a larger digester system.

The result of all the above measures is a very substantial increase in capital and operating cost compared to non ABP biogas plant. The advantage is the gate fees arising for processing ABP wastes, and the provision of a service such as treatment of abattoir wastes – facilitating the installation of a local abattoir (for increased sustainable local food production).

Here is a functional description of the plant:

a) **Feedstocks and reception:** In this plant layout design, two plant entrances have been included; one for ABP feedstock reception, and the other for non ABP feedstocks and activities. Grass silage is stored in facilities described above for the non ABP CBM plant. All animal by-products are delivered to the ABP entrance, weighed and recorded. Dairy cow slurry, sewage sludges, and fish wastes (ABP) are received into a liquids storage tank. Food waste (ABP) is separately received into the waste reception building and processed immediately. Reject materials (plastics, and other rejects) are stored in a skip for disposal off-site.

b) **Primary digester:** In this design, the digester is larger than the Non-ABP system (due to the need for extra biogas to run the CHP), and has been divided into two tanks. The advantage of this (WasteWorks) design is that the pasteurisation plant can be inserted between the digesters providing significant process benefits.

c) **Pasteurisation:** Digestate from Digester 1 is processed by the pasteurisation plant. The temperature of the wastes is raised from 40 °C to 70 °C and held for one hour in compliance with ABP regulations. Each batch is tested for pathogens and the particle size is monitored.

d) **Secondary digester:** Hot pasteurised digestate passes to the second digester where it is retained for an extra period to complete digestion.

e) **Site CHP (optional):** The site CHP provides all the electrical requirements of the site, together with most of the heat. The balance of the heat is supplied by the biomethane upgrading and compression plant.

f) **Biogas upgrading and digestate:** Following treatment in the digesters, the subsequent stages of biogas upgrading and digestate processing are the same as the Non ABP plant.

The following process flow diagram illustrates the different stages described above:

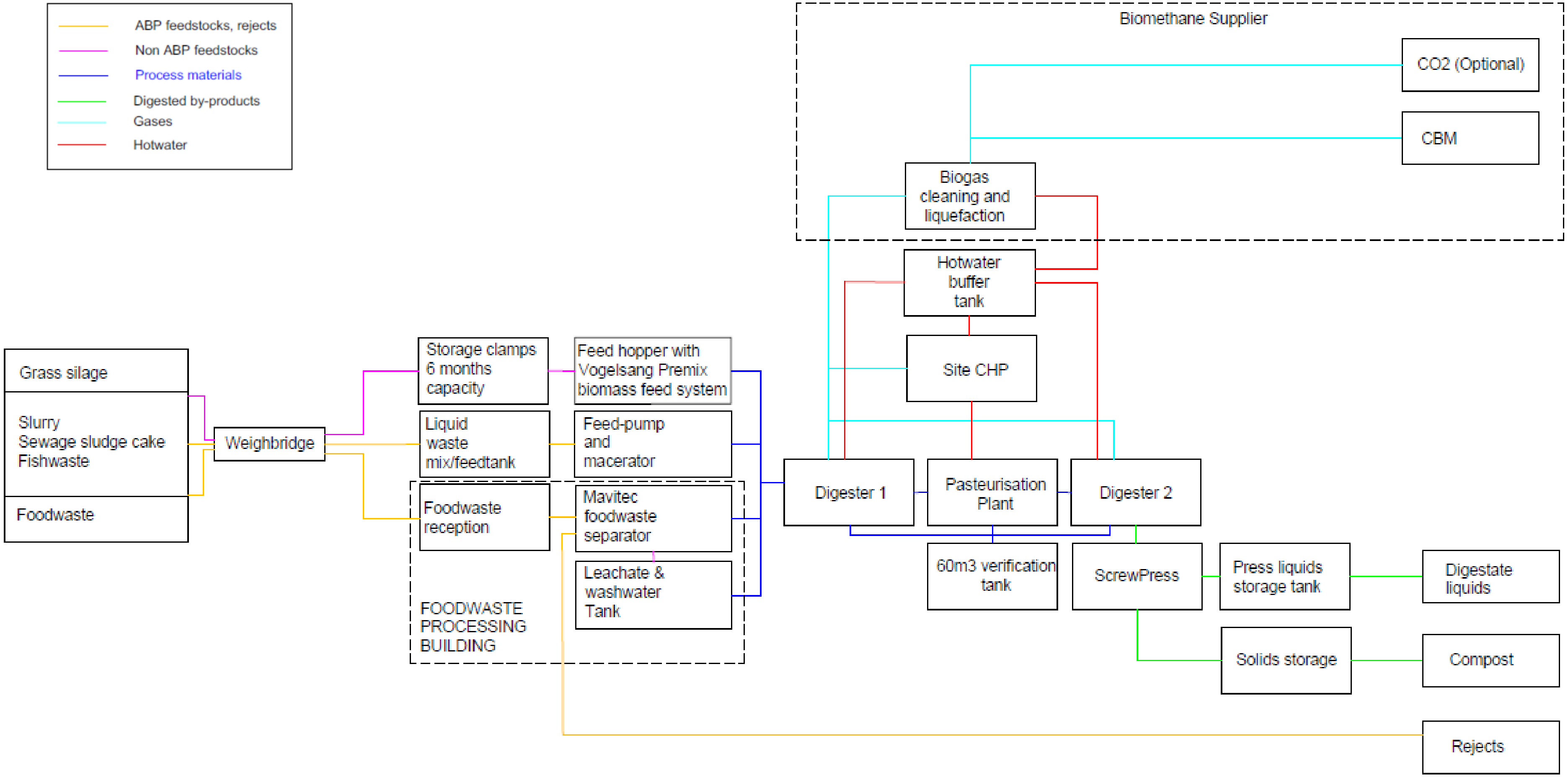


Figure 18: Process flow diagram of AD ABP CBM pathway. Source: WasteWorks, 2020.

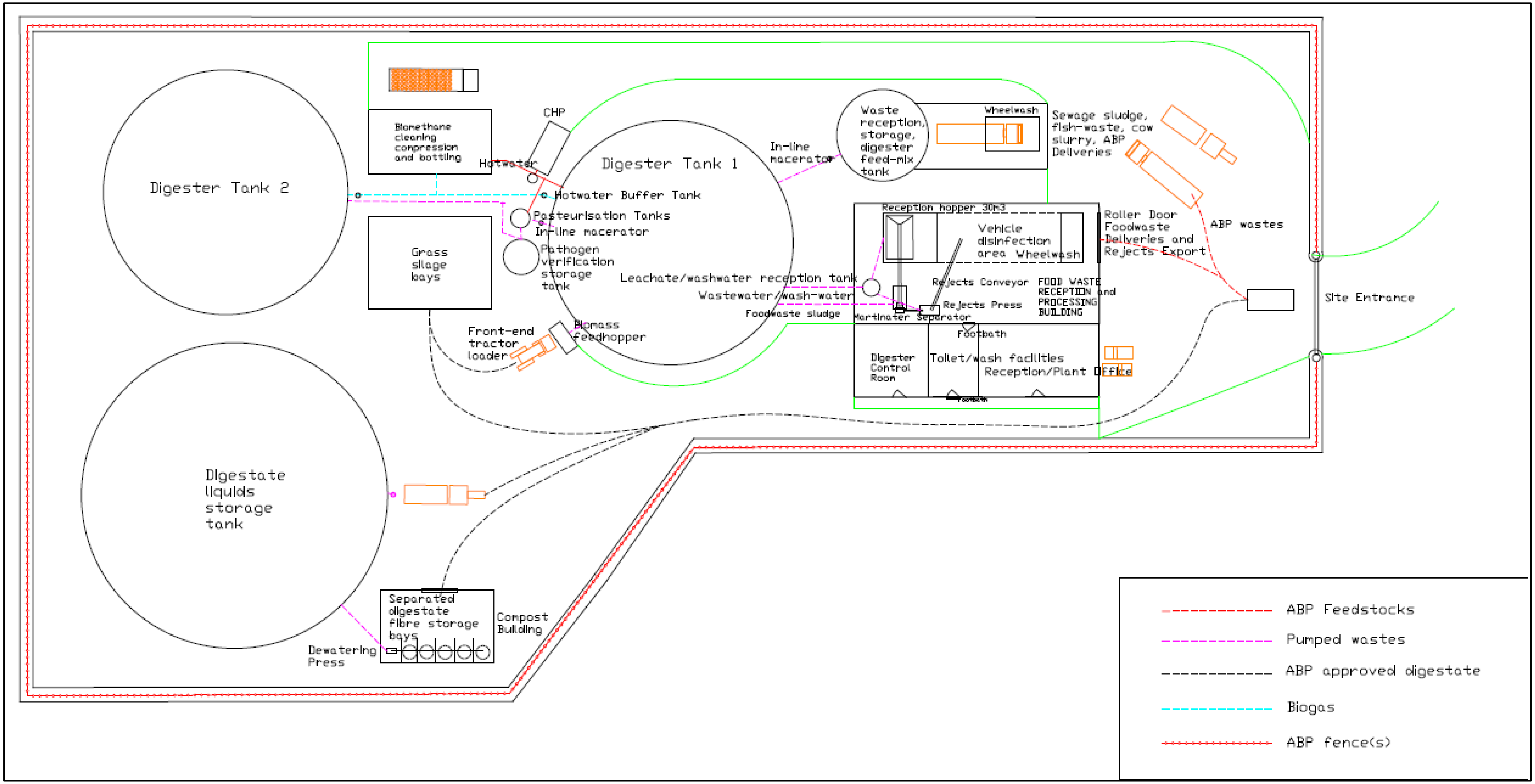


Figure 19: ABP CBM AD plant layout. Source: WasteWorks, 2020.

3. Carbon dioxide production

High purity carbon dioxide is produced by the upgrading facility. This can be released to atmosphere (as part of the natural carbon cycle), or compressed and stored for sale as a by-product. The compression of carbon dioxide also produces heat which can be recovered for use by the digester and pasteurisation processes. The techno-economic analysis performed in the previous chapter is based on a CO_2 liquefaction plant proposed by Bright Biomethane, a Dutch company.

B. Life Cycle Cost Analysis

A lifecycle cost analysis has been undertaken on the two AD systems described above:

1. Non ABP feedstocks AD plant, CBM for for grid injection, no CO_2
2. Mixed ABP & agri feedstocks AD plant, producing CBM for local vehicle use, with CO_2 liquefaction.

The life cycle cost analysis uses the data and assumptions applied in the AD pathways cost/benefit analysis to determine the cash flow of each project over a 20-year lifetime. The annual cash flows are discounted with a rate of 8%, assumed to be the weighted average cost of capital cost for such a project (Ricardo Energy & Environment, 2017). A general inflation rate of 2% has been applied.

The following key performance indicators of financial performance are used for the lifecycle cost analysis:

- **Net Present Value (NPV):** Difference between the present value of cash inflows and the present value of cash outflows over a period of time. It applies the discount rate to account for the time value of money.
- **Internal Rate of Return (IRR):** A discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. It measures the rate return on the investment made.

The NPV and IRR are calculated for the project cash flows before and after corporation tax. The full value of the initial capital investment has been applied as a negative cash flow on year 0 (no loan repayment and finance costs) so that the IRR values obtained indicate the potential return on investment from the perspective of the equity investor or institutional lender. The results of the discounted cash flow analysis for projects are presented here after. The discounted cash flow analysis over a 20 year period, takes into account replacement of machinery on year 15 and end-of-life value for the plant.

The analysis shows that in both scenarios, the project generates a healthy return on investment with IRRs after tax of 10.6% and 17.7% respectively. The Net Present Value of the project is €0.5 million and €3.3 million respectively, so the second scenario is much more profitable. While the roadmap proposed in Chapter 5.D is based on an evolutive plant with a step approach to investment in technology and revenue streams, the resulting cash flow and projection in terms of return on investment will likely fall within these two scenarios. This merits further consideration and a detailed analysis during the development of a business plan for the proposed project.

Table 14: Discounted Cash Flow Analysis of AD system using non-ABP feedstocks to produce CBM (no CO_2 scenario)

Year in lifetime	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital expenditure	€ 2,715,500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ 915,500	€ -	€ -	€ -	€ -	-€ 306,550
Income																					
Heat	€ -	€ 68,845	€ 70,222	€ 71,626	€ 73,059	€ 74,520	€ 76,010	€ 77,531	€ 79,081	€ 80,663	€ 82,276	€ 83,922	€ 85,600	€ 87,312	€ 89,058	€ 90,840	€ 92,656	€ 94,509	€ 96,400	€ 98,328	€ 100,294
CBM	€ -	€ 1,047,816	€ 1,068,772	€ 1,090,148	€ 1,111,951	€ 1,134,190	€ 1,156,874	€ 1,180,011	€ 1,203,611	€ 1,227,683	€ 1,252,237	€ 1,277,282	€ 1,302,827	€ 1,328,884	€ 1,355,462	€ 1,382,571	€ 1,410,222	€ 1,438,427	€ 1,467,195	€ 1,496,539	€ 1,526,470
CO2	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Compost	€ -	€ 55,891	€ 57,008	€ 58,149	€ 59,312	€ 60,498	€ 61,708	€ 62,942	€ 64,201	€ 65,485	€ 66,794	€ 68,130	€ 69,493	€ 70,883	€ 72,300	€ 73,746	€ 75,221	€ 76,726	€ 78,260	€ 79,826	€ 81,422
Other	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Revenues	€ -	**€ 1,172,552**	**€ 1,196,003**	**€ 1,219,923**	**€ 1,244,321**	**€ 1,269,208**	**€ 1,294,592**	**€ 1,320,484**	**€ 1,346,893**	**€ 1,373,831**	**€ 1,401,308**	**€ 1,429,334**	**€ 1,457,921**	**€ 1,487,079**	**€ 1,516,821**	**€ 1,547,157**	**€ 1,578,100**	**€ 1,609,662**	**€ 1,641,855**	**€ 1,674,692**	**€ 1,708,186**
Costs																					
Feedstocks	€ -	€ 383,250	€ 390,915	€ 398,733	€ 406,708	€ 414,842	€ 423,139	€ 431,602	€ 440,234	€ 449,038	€ 458,019	€ 467,180	€ 476,523	€ 486,054	€ 495,775	€ 505,690	€ 515,804	€ 526,120	€ 536,643	€ 547,375	€ 558,323
Digestate	€ -	€ 25,550	€ 26,061	€ 26,582	€ 27,114	€ 27,656	€ 28,209	€ 28,773	€ 29,349	€ 29,936	€ 30,535	€ 31,145	€ 31,768	€ 32,404	€ 33,052	€ 33,713	€ 34,387	€ 35,075	€ 35,776	€ 36,492	€ 37,222
Heating	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Electricity	€ 9,321	€ 223,695	€ 228,169	€ 232,733	€ 237,387	€ 242,135	€ 246,978	€ 251,917	€ 256,956	€ 262,095	€ 267,337	€ 272,683	€ 278,137	€ 283,700	€ 289,374	€ 295,161	€ 301,065	€ 307,086	€ 313,228	€ 319,492	€ 325,882
Labour, overheads, insurance	€ 50,000	€ 113,700	€ 115,974	€ 118,293	€ 120,659	€ 123,073	€ 125,534	€ 128,045	€ 130,606	€ 133,218	€ 135,882	€ 138,600	€ 141,372	€ 144,199	€ 147,083	€ 150,025	€ 153,025	€ 156,086	€ 159,207	€ 162,392	€ 165,639
Maintenance and Repairs	€ -	€ 51,965	€ 53,004	€ 54,064	€ 55,146	€ 56,249	€ 57,374	€ 58,521	€ 59,691	€ 60,885	€ 62,103	€ 63,345	€ 64,612	€ 65,904	€ 67,222	€ 68,567	€ 69,938	€ 71,337	€ 72,764	€ 74,219	€ 75,703
Cost of CBM haulage & grid injection		€ 48,298	€ 49,264	€ 50,250	€ 51,255	€ 52,280	€ 53,325	€ 54,392	€ 55,480	€ 56,589	€ 57,721	€ 58,875	€ 60,053	€ 61,254	€ 62,479	€ 63,729	€ 65,003	€ 66,303	€ 67,629	€ 68,982	€ 70,362
Loan repayment	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Trading Costs	**€ 59,321**	**€ 846,459**	**€ 863,388**	**€ 880,656**	**€ 898,269**	**€ 916,234**	**€ 934,559**	**€ 953,250**	**€ 972,315**	**€ 991,761**	**€ 1,011,596**	**€ 1,031,828**	**€ 1,052,465**	**€ 1,073,514**	**€ 1,094,985**	**€ 1,116,884**	**€ 1,139,222**	**€ 1,162,006**	**€ 1,185,246**	**€ 1,208,951**	**€ 1,233,130**
Cash Flow before tax	-€ 2,774,821	€ 326,093	€ 332,615	€ 339,267	€ 346,052	€ 352,974	€ 360,033	€ 367,234	€ 374,578	€ 382,070	€ 389,711	€ 397,506	€ 405,456	€ 413,565	€ 421,836	-€ 485,227	€ 438,878	€ 447,656	€ 456,609	€ 465,741	€ 781,606
Cumulative CF before tax	-€ 2,774,821	-€ 2,448,728	-€ 2,116,113	-€ 1,776,846	-€ 1,430,793	-€ 1,077,820	-€ 717,787	-€ 350,553	€ 24,025	€ 406,095	€ 795,806	€ 1,193,312	€ 1,598,767	€ 2,012,332	€ 2,434,168	€ 1,948,941	€ 2,387,819	€ 2,835,475	€ 3,292,084	€ 3,757,825	€ 4,539,431
Depreciation	€ -	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 143,533	€ 61,033	€ 61,033	€ 61,033	€ 61,033	€ 61,033
Corporate tax	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	-€ 31,191	-€ 32,202	-€ 33,234	-€ 34,286	-€ 35,360	-€ 36,454	-€ 37,571	€ -	-€ 51,009	-€ 52,194	-€ 53,403	-€ 54,636	-€ 97,277
CF after tax:	-€ 2,774,821	€ 326,093	€ 332,615	€ 339,267	€ 346,052	€ 352,974	€ 360,033	€ 367,234	€ 343,387	€ 349,867	€ 356,477	€ 363,219	€ 370,096	€ 377,110	€ 384,265	-€ 485,227	€ 387,869	€ 395,462	€ 403,206	€ 411,106	€ 684,329

	Before Tax	After Tax
IRR	11.1%	10.5%
NPV	€ 497,088	€ 486,445

Table 15: Discounted Cash Flow analysis of AD systems using ABP feedstocks to produce CBM, with site CHP and CO_2 liquefaction.

Year in lifetime	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Capital expenditure	€ 4,335,500	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ 1,805,500	€ -	€ -	€ -	€ -	-€ 463,050
Income																					
Heat	€ -	€ 118,409	€ 120,777	€ 123,193	€ 125,657	€ 128,170	€ 130,733	€ 133,348	€ 136,015	€ 138,735	€ 141,510	€ 144,340	€ 147,227	€ 150,171	€ 153,175	€ 156,238	€ 159,363	€ 162,550	€ 165,801	€ 169,117	€ 172,500
CBM	€ -	€ 1,206,557	€ 1,230,689	€ 1,255,302	€ 1,280,408	€ 1,306,017	€ 1,332,137	€ 1,358,780	€ 1,385,955	€ 1,413,674	€ 1,441,948	€ 1,470,787	€ 1,500,202	€ 1,530,207	€ 1,560,811	€ 1,592,027	€ 1,623,867	€ 1,656,345	€ 1,689,472	€ 1,723,261	€ 1,757,726
CO2	€ -	€ 204,908	€ 209,007	€ 213,187	€ 217,450	€ 221,799	€ 226,235	€ 230,760	€ 235,375	€ 240,083	€ 244,885	€ 249,782	€ 254,778	€ 259,873	€ 265,071	€ 270,372	€ 275,780	€ 281,295	€ 286,921	€ 292,660	€ 298,513
Compost	€ -	€ 114,304	€ 116,590	€ 118,922	€ 121,300	€ 123,726	€ 126,201	€ 128,725	€ 131,299	€ 133,925	€ 136,604	€ 139,336	€ 142,122	€ 144,965	€ 147,864	€ 150,821	€ 153,838	€ 156,915	€ 160,053	€ 163,254	€ 166,519
Other	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Revenues	€ -	**€ 1,644,179**	**€ 1,677,062**	**€ 1,710,604**	**€ 1,744,816**	**€ 1,779,712**	**€ 1,815,306**	**€ 1,851,612**	**€ 1,888,645**	**€ 1,926,418**	**€ 1,964,946**	**€ 2,004,245**	**€ 2,044,330**	**€ 2,085,216**	**€ 2,126,921**	**€ 2,169,459**	**€ 2,212,848**	**€ 2,257,105**	**€ 2,302,247**	**€ 2,348,292**	**€ 2,395,258**
Costs																					
Feedstocks	€ -	€ 458,920	€ 468,098	€ 477,460	€ 487,009	€ 496,749	€ 506,684	€ 516,818	€ 527,154	€ 537,698	€ 548,452	€ 559,421	€ 570,609	€ 582,021	€ 593,662	€ 605,535	€ 617,646	€ 629,998	€ 642,598	€ 655,450	€ 668,559
Digestate	€ -	€ 52,253	€ 53,298	€ 54,364	€ 55,451	€ 56,561	€ 57,692	€ 58,846	€ 60,022	€ 61,223	€ 62,447	€ 63,696	€ 64,970	€ 66,270	€ 67,595	€ 68,947	€ 70,326	€ 71,732	€ 73,167	€ 74,630	€ 76,123
Heating	€ 17,960	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Electricity	€ 19,062	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -	€ -
Labour, overheads, insurance	€ 50,000	€ 121,500	€ 123,930	€ 126,409	€ 128,937	€ 131,516	€ 134,146	€ 136,829	€ 139,565	€ 142,357	€ 145,204	€ 148,108	€ 151,070	€ 154,091	€ 157,173	€ 160,317	€ 163,523	€ 166,793	€ 170,129	€ 173,532	€ 177,003
Maintenance and Repairs	€ -	€ 100,372	€ 102,379	€ 104,427	€ 106,516	€ 108,646	€ 110,819	€ 113,035	€ 115,296	€ 117,602	€ 119,954	€ 122,353	€ 124,800	€ 127,296	€ 129,842	€ 132,439	€ 135,087	€ 137,789	€ 140,545	€ 143,356	€ 146,223
Cost of CBM for local vehicle fuel distribution		€ 118,041	€ 120,402	€ 122,810	€ 125,266	€ 127,771	€ 130,327	€ 132,933	€ 135,592	€ 138,304	€ 141,070	€ 143,891	€ 146,769	€ 149,705	€ 152,699	€ 155,753	€ 158,868	€ 162,045	€ 165,286	€ 168,592	€ 171,963
Trading Costs	**€ 87,022**	**€ 851,086**	**€ 868,108**	**€ 885,470**	**€ 903,179**	**€ 921,243**	**€ 939,668**	**€ 958,461**	**€ 977,630**	**€ 997,183**	**€ 1,017,126**	**€ 1,037,469**	**€ 1,058,218**	**€ 1,079,383**	**€ 1,100,970**	**€ 1,122,990**	**€ 1,145,449**	**€ 1,168,358**	**€ 1,191,726**	**€ 1,215,560**	**€ 1,239,871**
Cash Flow before tax	-€ 4,422,522	€ 793,093	€ 808,955	€ 825,134	€ 841,637	€ 858,469	€ 875,639	€ 893,152	€ 911,015	€ 929,235	€ 947,820	€ 966,776	€ 986,111	€ 1,005,834	€ 1,025,950	-€ 759,031	€ 1,067,399	€ 1,088,747	€ 1,110,522	€ 1,132,732	€ 1,618,437
Cumulative CF before tax	-€ 4,422,522	-€ 3,629,429	-€ 2,820,474	-€ 1,995,340	-€ 1,153,703	-€ 295,234	€ 580,405	€ 1,473,556	€ 2,384,571	€ 3,313,805	€ 4,261,625	€ 5,228,401	€ 6,214,512	€ 7,220,346	€ 8,246,296	€ 7,487,266	€ 8,554,664	€ 9,643,411	€ 10,753,933	€ 11,886,665	€ 13,505,102
Depreciation	€ -	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 271,200	€ 157,500	€ 157,500	€ 157,500	€ 157,500	€ 157,500
Corporate tax	€ -	€ -	€ -	€ -	€ -	€ -	-€ 81,599	-€ 83,963	-€ 86,375	-€ 88,835	-€ 91,344	-€ 93,903	-€ 96,513	-€ 99,176	-€ 101,891	€ -	-€ 122,836	-€ 125,718	-€ 128,658	-€ 131,656	-€ 197,226
CF after tax:	-€ 4,422,522	€ 793,093	€ 808,955	€ 825,134	€ 841,637	€ 858,469	€ 794,040	€ 809,188	€ 824,640	€ 840,400	€ 856,476	€ 872,873	€ 889,598	€ 906,658	€ 924,059	-€ 759,031	€ 944,562	€ 963,028	€ 981,864	€ 1,001,076	€ 1,421,210

	Before Tax	After Tax
IRR	18.6%	17.7%
NPV	€3,485,718	€3,290,160

By way of sensitivity analysis, key variables in the discounted cash flow analysis have been altered by 20% either way of their baseline value assumed above. The impact on the NPV and IRR are listed in the tables below.

Table 16: Sensitivity analysis results – Non ABP CBM, no CO_2.

	IRR before tax		NPV before tax	
Baseline values	11.10%		€ 497,088	
Change in variables below	-20%	20%	-20%	20%
Value of CBM	-2.00%	20.30%	-€ 1,645,240	€ 2,639,417
Cost of Silage	14.70%	7.20%	€ 128,668	-€ 286,491
Capital cost	14.60%	8.60%	€ 999,959	€ 5,782
Heat price	10.50%	11.80%	€ 356,330	€ 637,846

In this scenario, the project's profitability is very sensitive to the value of CBM injected into the grid and becomes negative with a 20% reduction (fuel price and subsidy included). The cost of silage has also a significant impact as it is the only feedstock involved and its purchase represents about 45% of the total operating costs. A 20% increase in the silage cost renders the project unprofitable. Equally, a 20% increase in capital cost brings the project close to becoming unprofitable. Overall, the project's financial viability is quite sensitive to changes in key variables. The risks associated with these will have to be analysed in detail as part of business planning for future projects, and a robust risk register will form an integral part of the due diligence process for financing.

Table 17: Sensitivity analysis results – ABP CBM & CHP + CO_2 scenario

	IRR before tax		NPV before tax	
Baseline values	18.60%		€ 3,485,718	
Change in variables below	-20%	20%	-20%	20%
Value of CBM	11.90%	24.70%	€ 1,018,832	€ 5,952,603
Cost of Silage	21.40%	15.70%	€ 4,605,117	€ 2,366,318
Capital cost	23.40%	15.20%	€ 4,288,588	€ 2,682,847
Heat price	18.00%	19.20%	€ 3,243,622	€ 3,727,813
CO2 price	17.00%	19.60%	€ 3,066,769	€ 3,904,666

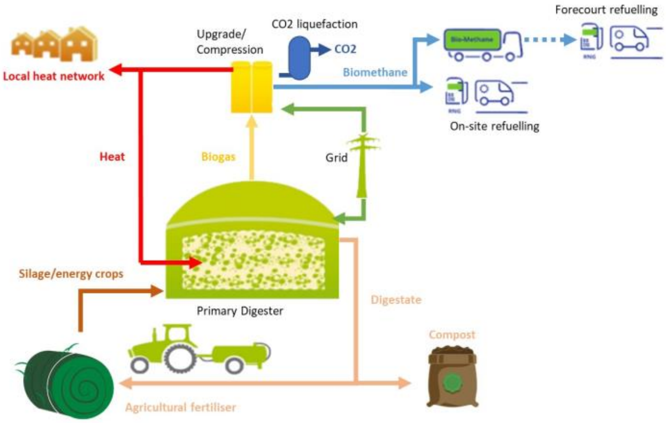
In this scenario, the project's profitability is much more robust. It is most sensitive to a reduction in the CBM value (fuel price and subsidy included) but the IRR remains well above the discount rate of 8%. As in the scenario above, the price of heat sold has little influence on the profitability of the project.

Chapter 5. Further discussion on biomethane market deployment

A. Biomethane grid injection or use as a local transport fuel

The use of biogas for producing heat and electricity at farm-scale has proven very challenging economically, even with the additional revenue provided by gate fees, in part because there is generally not sufficient demand in and around the farm. In Ireland as well as in many EU countries, the decommissioning of guaranteed, subsidised electricity tariffs (REFIT here) has virtually rendered the biogas-to-CHP pathway unfeasible. Support mechanisms for AD have moved to incentivise the production of biomethane, specifically for injection into the natural gas grid where it mixes with natural gas and is distributed to end-users for heating, electricity generation and fuelling compressed natural gas (CNG) vehicles.

The techno economic analysis conducted in section Chapter 3.D indicates that the economic viability of the CBM pathways depends most on the value of the biomethane produced, and requires heavy subsidies to compensate for the low price given to biomethane injected in the grid as a substitute to natural gas. It should be emphasized that the CBM pathways are also heavily dependant on non-primary energy revenues from the sale of CO_2, compost and heat. It is worth noting in this regard that if all non-CBM revenues were set to zero, most pathways would have a negative or marginally positive Return on Capital value - in any case well below the discount rate considered in the annualised capital cost calculation.



In this context, it is worth considering a different scenario in which the biomethane produced is used **locally as a vehicle fuel**, replacing diesel or petrol. Biomethane is particularly suitable for heavy goods vehicles, vans, buses and tractors. This would require the installation of a refuelling station with a dedicated CBM pump, either at the site of production or at one or several existing pumping station. The latter would require either piping the CBM from the AD plant to a nearby service station, or CBM storage rigs to be stationed at the station(s).

An initial cost/benefit analysis was conducted for such a scenario by using a biomethane price of c€9.1/kWh at the pump, based on equivalent price of LPG as vehicle fuel[13] at the pump excl. VAT. If we deduct the excise duty (c€0.94/kWh) and NORA biofuel levy (c€0.21/kWh) applied to natural gas for transport, the net value of biomethane at the pump could be c€7.9/kWh. If a margin of 5% for the retailer, and a cost of c€1.1/kWh for the compression and refuelling infrastructure (B. M. Smyth, 2010), this leaves a potential price of c€6.4/kWh paid to the biomethane producer. This is over 3 times the price of CBM we have assumed excl. subsidy for injection into the gas grid. When introduced to the pathways' cost benefit analysis conducted in the previous section, and using a more conservative subsidy c€6/kWh from Biofuels Obligation Scheme (BOS) certificates (L. Gil-Carrera, 2019), the potential return on capital values increases by an average of 5.5% (Figure 20 below), to between 10% and 17%, well above the discount rate of 8% utilised in the analysis. The EU RED also supports the concept of biomethane for transport by offering lower GHG emissions savings target (65%) as compared to biomethane to be used for heat (80% savings required). So from a sustainability viewpoint transport is also favourable.

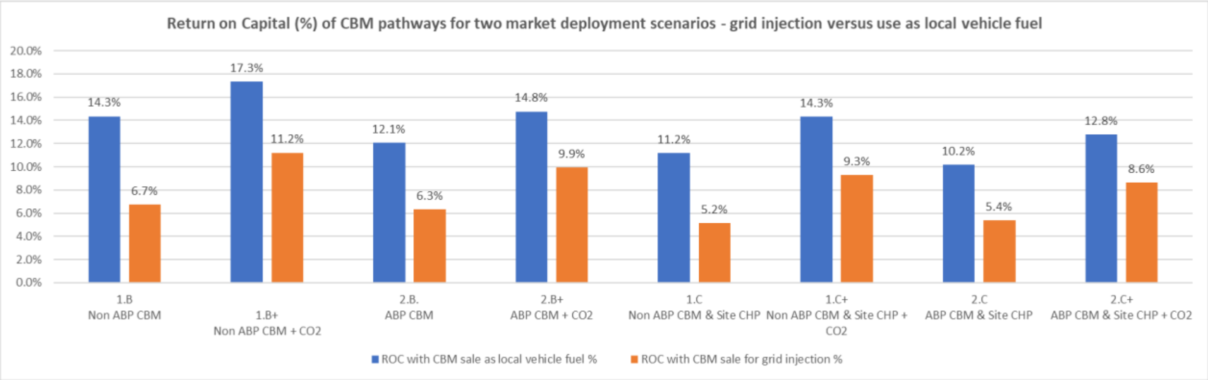


Figure 20: Return on Capital for CBM for grid injection versus local transport deployment scenarios

B. The case for lower CBM standards when used locally

Our projections are based on a AD pathways to produce CBM for gas network injection standard or use in dedicated CNG vehicles. However, diesel (and petrol) vehicles can operate efficiently using compressed biomethane with a lower percentage of methane[14] and gas purity than natural-gas injection standard. Apart from use as vehicle fuel, compressed biomethane (CBM) can be used in CHP powered by dual fuel CNG/CBM – where the CBM has a lower calorific value than natural gas. Dual fuel use CBM/LPG is also possible. There are several large potential users in Dingle (hotels, hospital etc). Vehicle-grade CBM could therefore be delivered to multiple users including garages (vehicle use) and operators of CHP. Multiple potential uses for biomethane provide flexibility and help to ensure continuous use of the gas.

The adoption of a lower CBM standard suitable for vehicle use, say at 90%+ methane content, has a number of advantages:

- The capital expenditure for the upgrading/compression plant could potentially be reduced by 40% since the technology is much less complex than grid standard and there is a wider range of potential suppliers.

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[13] LPG is taken as a reference due its positioning as an alternative vehicle fuel in Ireland, for which refuelling stations can be deployed outside of the natural gas grid.

[14] In Thailand, CBM at 92% concentration is widely used as a transport fuel (Tim Clarke, 2019).

- The operating costs could be reduced by 25% due to lower electricity usage for upgrading and maintenance costs (lower pressure across the membrane).
- Deploying a fleet of dedicated CNG only engine vehicles locally, without connection to the natural gas grid, would require significant storage capacity to guarantee security of supply for users. However, the filling stations dispensing gas could also store compressed CNG so that either CBM or CNG (or a mixture) would always be available for these vehicles
- The use of CBM in dual-fuel vehicles would assist gradual adoption of the fuel in Dingle area, as it provides flexible use of three fuels; CBM and/or CNG (or mixture of) OR petrol/diesel; without necessitating a large investment in a fleet of CNG engine vehicles.
- Local use by a more diverse range of vehicles and applications (CHP) would facilitate a better balance between biomethane production and demand, lowering the requirement for local CBM storage capacity.

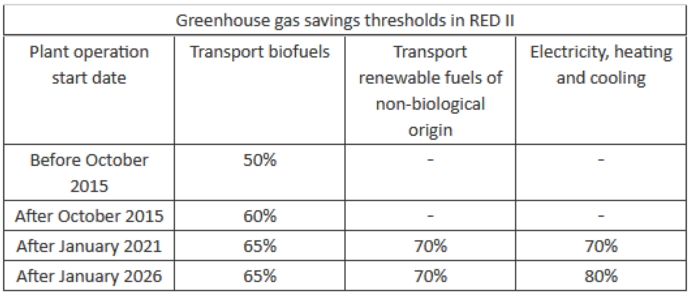
C. Implications of the Sustainable bioenergy and the Recast EU Renewable Energy Directive (REDII)

While biomass fuels are important in helping the EU meet its greenhouse gas reductions targets, biofuel production typically takes place on cropland that was previously used for other agriculture such as growing food or feed. Since this agricultural production is still necessary, it may lead to the extension of agriculture land into non-cropland, possibly including areas with high carbon stock such as forests, wetlands and peatlands. This process is known as indirect land use change (ILUC). As this may cause the release of CO2 stored in trees and soil, indirect land use change risks negating the greenhouse gas savings that result from increased biofuels.

Hence REDII Article 26 sets out the sustainability criteria to be applied for biomass fuels from 2021, including that biomass fuels produced from agricultural biomass shall not be made from raw material obtained from land:

a. with high biodiversity value, i.e. primary forests (those with no clearly visible human activity), specially protected areas, special areas of conservation and highly biodiverse grasslands;
b. with high carbon stock, i.e. wetlands, continuously forested areas;
c. that was peatland.

REDII also sets minimum GHG emissions savings to be achieved compared to their fossil fuel equivalent[15]:



Greenhouse gas savings thresholds in RED II			
Plant operation start date	Transport biofuels	Transport renewable fuels of non-biological origin	Electricity, heating and cooling
Before October 2015	50%	-	-
After October 2015	60%	-	-
After January 2021	65%	70%	70%
After January 2026	65%	70%	80%

The RED II methodology for calculating life cycle GHG emissions is contained in Annex VI: Rules for calculating greenhouse gas impact of biomass fuels and their fossil fuel comparators. The methodology accounts for different sources of GHG emissions along the supply chain of the biofuel in question.

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[15] Source: https://ec.europa.eu/jrc/en/jec/renewable-energy-recast-2030-red-ii

An analysis conducted for SEAI by Navigant & Byrne O'Cleirigh indicates that a feedstock mix of 60% grass silage and 40% slurry generally meets the 70% threshold for heat and power systems, but not the 80% to be in place for installations built after 2026. This directive states that when used for production of biomethane for transport, grass silage (or other biomass/crop feedstock) should comprise a maximum of 60% of the feedstock; and the other 40% should be waste. While similar calculations on GHG savings of biomethane as a transport fuels were not available at the time of the report, we assume that the same requirements will apply in terms of feedstock mix.

Considering the above, the sustainability criteria of REDII has very substantial implications regarding the proposed "non ABP" grass silage-based pathways (to CHP or CBM, CBM+CO2), which are outlined hereafter.

a) ABP regulations leading to the pasteurisation of slurry

The ABP regulations state that if any ABP waste is included in a digester feedstock, then ALL other feedstocks must also be pasteurised. However, the Department of Agriculture have agreed that if cow slurry is the only ABP category waste[16], then slurry can be imported and pasteurised separately; and that, in this case only, other non-ABP feedstocks need not be pasteurised.

b) Increased plant throughput and digester size/capacity

Because cow slurry has very low biogas production potential (typically 20m3/tonne) compared to grass silage (average 140m3/tonne), not only does the overall feed amount has to be increased substantially, but in order to preserve the longer retention time required for grass silage (minimum 40 days) compared to cow slurry (typical 25 days), the digester capacity must be increased substantially compared to silage only.

c) Pasteurisation plant and associated infrastructure

The biogas plant must include a pasteurisation plant for the slurry. The slurry must be received and processed completely separately from the other feedstocks before adding to the digester. This entails separate reception facilities. Other capital items typical of ABP biogas plant include appropriate fencing and access, and vehicle cleaning facilities.

d) Heat balance

One would expect that the requirement to pasteurise the cow slurry would require substantial extra heat input; but if the slurry is pasteurised (70'C) and added to the digester, this will raise the temperature of the digester contents considerably toward to the operational target of 40'C; so that less direct heat input to the digester is required. The overall impact on the heat balance is unlikely to be severe.

e) Capital and operational expenditure

The pasteurised slurry must be strictly monitored and recorded as discrete batches prior to adding to the digester and the other feedstocks. Samples must be regularly sent to a lab for testing. Recycling of digestate to participating farms will need to be recorded as batches of tested approved material; with a record of the batch, the receiving farm and the date. These measures increase operational expenses of the plant.

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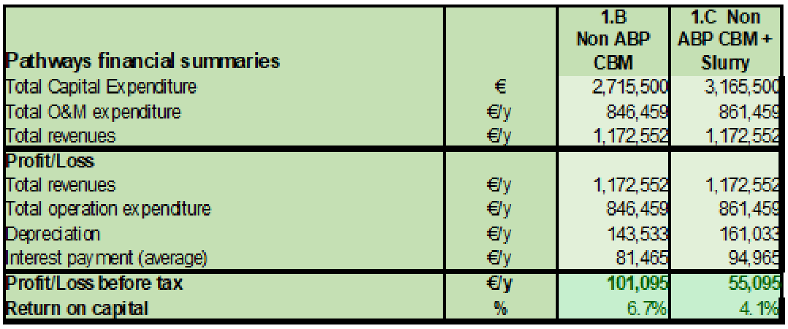
[16] In the case of a 60:40 grass silage/slurry mix, it is assumed that slurry would be sourced from several farms and would therefore have to be pasteurised.

The following table summarises the additional capital and operating costs and its effect on the profit and loss account, with a 2.6% decrease in return on capital.



Pathways financial summaries		1.B Non ABP CBM	1.C Non ABP CBM + Slurry
Total Capital Expenditure	€	2,715,500	3,165,500
Total O&M expenditure	€/y	846,459	861,459
Total revenues	€/y	1,172,552	1,172,552
Profit/Loss			
Total revenues	€/y	1,172,552	1,172,552
Total operation expenditure	€/y	846,459	861,459
Depreciation	€/y	143,533	161,033
Interest payment (average)	€/y	81,465	94,965
Profit/Loss before tax	**€/y**	**101,095**	**55,095**
Return on capital	**%**	6.7%	4.1%

f) Other implications - seasonal availability of slurry

Most dairy cow slurry available for collection is produced during winter months from November to March. After this the animals are increasingly in the field; resulting in an average of only 15% of the full-rate slurry being available from each farm during the "summer" months. In order to obtain the same amount of slurry to maintain the maximum 60% silage ratio, this will involve a substantial increase in the number of participating farms during this period, which would increase pro-rata the collection area and transport distances involved – both to collect slurry and return digestate. For example assuming farms of the same herd size (136 units), we can say that if there are five farms supplying slurry during the winter months, the number of participating farms will need to be increased by a factor of 3.

On a national scale regarding the "Greengas" programme, this presents very obvious practical and logistic difficulties. Biogas plant must be spaced according to the summer distribution. This means that many farms will be only supplying slurry during the summer. The alternative - increasing the % of slurry relative to silage to a biogas plant during winter months - would further reduce the financial viability of the proposed AD plant.

Another pertinent factor is the process implication of co-digesting grass silage with slurry. UCC research indicates that mono-digestion of grass at VS loading rates of 3.5kgVS/m3/d is optimal and provides higher specific methane yield (SMY) than co-digestion of slurry at 20% slurry addition (Wall, 2014).

Given the potential negative impacts of the sustainability criteria of REDII discussed above, further research should be conducted on the matter to establish more precisely the GHG emission reduction potential of AD plants with grass silage as primary feedstock and adequate proportions of slurry in the agricultural feedstocks mix. This is a lot less of a concern in the ABP pathways were a substantial proportion (30-40%) of organic municipal and industrial wastes are being used as feedstocks, however compliance with the REDII GHG emissions savings thresholds should be verified.

D. Recommendations for the deployment of AD systems in the peninsula.

Considering the cost/benefit analysis of the different AD pathways undertaken above, our recommendation is to focus on a gradual deployment that reduces the risk of technical and financial failure based on the following steps:

- Installation of a digester capable of processing ABP feedstocks but, at least initially operating predominantly with agricultural feedstocks, for the production of CBM, initially for grid injection. Installing the AD system near a heat user is useful, but non-essential. However, selling the compost from the digestate is a welcome addition to the revenue stream, with minimal extra investment, and contributes to the local bioeconomy.

- When AD plant operational capability is well established, the introduction of ABP feedstocks in the mix entering the AD process will generate extra income due to gate fees, and reinforce the circular bioeconomy of Dingle.
- In parallel, establishing a local market for biomethane as a local transport fuel, by installing a dedicated refuelling station at the AD plant first, and eventually at one or several local forecourts, would increase the profitability of the project, maximise its local climate impact and establish it as a pillar of the local circular economy.
- The setup of the refuelling infrastructure should go hand in hand with kick-starting the local CBM market promoting duel-fuel conversion of existing petrol/diesel vehicles, including tractors. Dedicated compressed natural gas (CNG) vehicles can come into play later when the market is well established in Ireland and locally. The use of CBM in local combined heat and power plants installed at a large heat user (e.g. a local hotel with a swimming pool), can also help with the transition process. CNG imported in pressurised cylinders can be used as back-up gas for the refuelling infrastructure.
- When funds are available, investing in a food-grade CO_2 liquefication plant would generate substantial additional revenues and increase profitability significantly, with a readily available market locally and nationally.
- If electricity costs escalate, it might be worth considering to invest in a combined heat and power plant to meet the electrical requirements of the plant, in particular if there is a local outlet for the surplus heat produced by the biogas upgrading and compression system, and the CO_2 liquefication plant.

Chapter 6. Spatial Multi-Criteria Analysis (MCA)

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 including: heat demand, feedstock availability, land cover, zoning, designated sites, topography, and proximity to settlements, roads, and fuelling stations.
- Define scoring matrix for individual criteria in terms of suitability for AD development, and apply inter-criteria weighting to compile overall suitability score.
- Apply scoring system to GIS layers and produce overall map with scoring result (colour grading from least suitable to most suitable). Validate/verify the result.

The results of the spatial MCA will help identify the areas of the peninsula that have the highest degree of suitability, which can then be the focus of more detailed investigations. 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.

B. 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 18 Geographical layers included in the analysis.

Layer	Spatial Resolution	Source
Total Heat Density (2015)	100m x 100m (ha)	Pezzutto et al., (2018)
Practical Silage Potential	ED Level	WP3 Technological Pathways
Practical Slurry Potential	ED Level	WP3 Technological Pathways
Practical Municipal Waste Potential	ED Level	WP3 Technological Pathways
Land cover	100m x 100m (ha)	European Corine Land Cover (CLC) (Copernicus Land Monitoring Service , 2018)
Special areas of conservation (SACs) or special protected areas (SPAs)	Scale of base-mapping used = 1:5000 or 1:10,560, which corresponds to 6 inches to 1 mile	National Park and Wildlife Services (2019)
Zoned land	Not stated	Kerry County Council (2015)
Settlements	Ungeneralised boundary datasets (highest resolution available, <20m)	Central Statistics Office (2016)
Slope	90m x 90m	National Aeronautics & Space Administration (2012)
Fuelling Stations	n/a	Digitised from Google using local knowledge
Roads	n/a	OpenStreetMap contributors (2019)

C. Factors

1. Heat Density

Heat demand (or heat density) has been calculated for buildings in the EU28 + Switzerland, Norway and Iceland as part of the Hotmaps project (Pezzutto *et al.*, 2018). The data were extracted and clipped to the bounds of the study area (fig. 1). The total heat density ranges from 0 – 772.871 MWh/(ha*year). As expected, areas of high heat demand are clustered around settlements and along main roads.

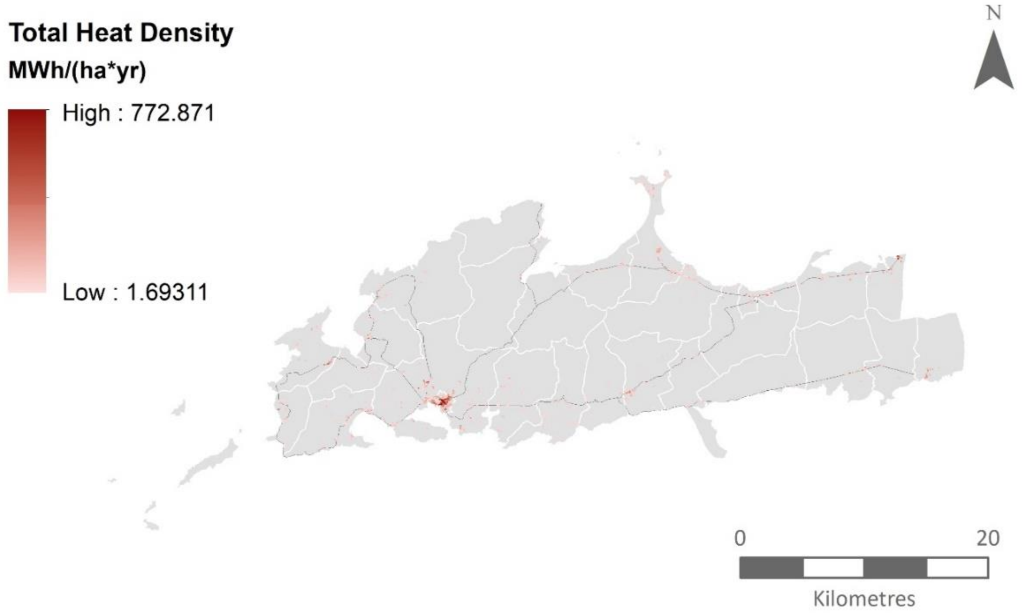


Figure 21 Heat demand on the Dingle Peninsula. Source: Pezzutto *et al.* (2018)

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.

2. Practical Silage Potential

The practical silage potential has been mapped at the ED level as part of the feedstock analysis section of the report. This factor represents the availability of silage as a potential feedstock. 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.

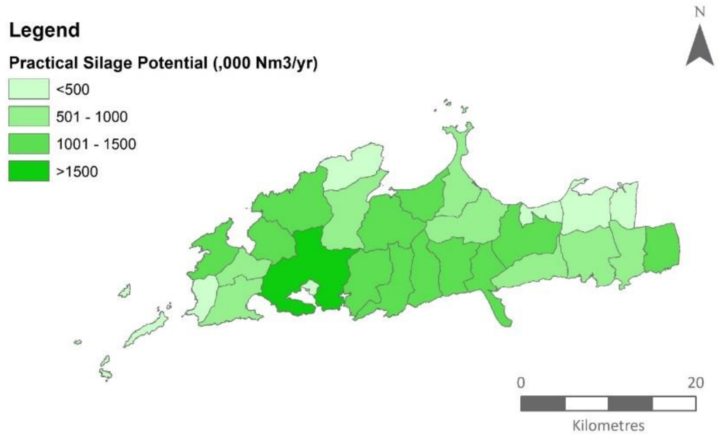
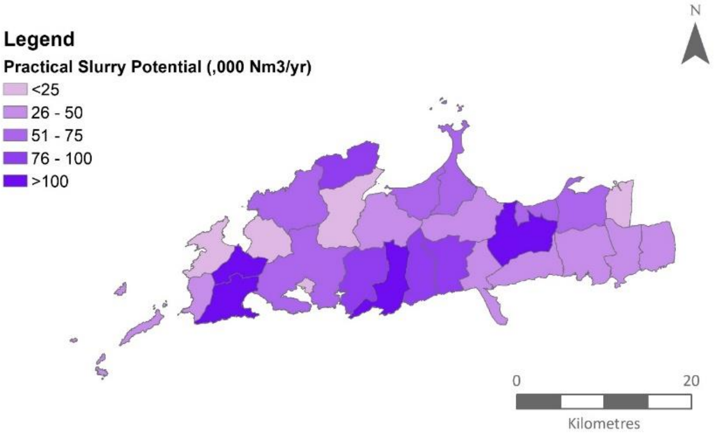


Figure 22 Practical silage potential per ED.

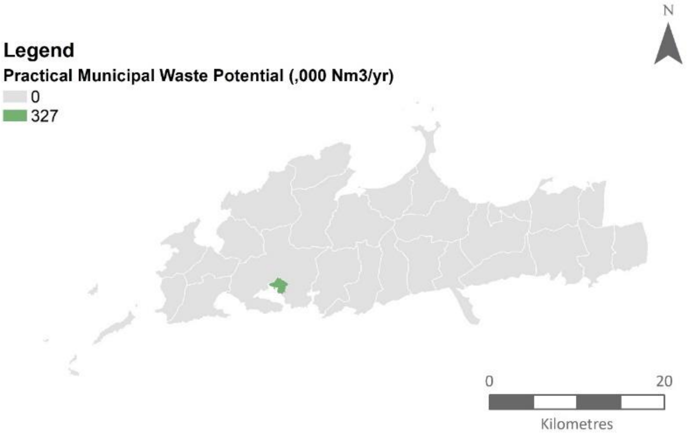
3. Practical Slurry Potential



The practical slurry potential has been mapped at the ED level as part the feedstock analysis. This factor represents the availability of slurry as a potential feedstock. The practical slurry 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 23 Practical slurry potential per ED.

4. Practical Municipal Waste Potential



The practical municipal waste potential was assessed at the ED level as part of the feedstock analysis. This factor represents the availability of organic municipal waste as a potential feedstock. Only one ED (Dingle) has any potential for municipal waste as a feedstock. The ED was assigned a score of 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.

Figure 24 Practical municipal waste potential.

5. Land cover

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 (fig. 5). Land cover types considered suitable for AD development included pastures, land **principally occupied by agriculture, with significant areas of natural vegetation, and natural grasslands**. 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)
- 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 or undesirable)

Some of the land cover types were considered as constraints – these are outlined later in this section of this report.

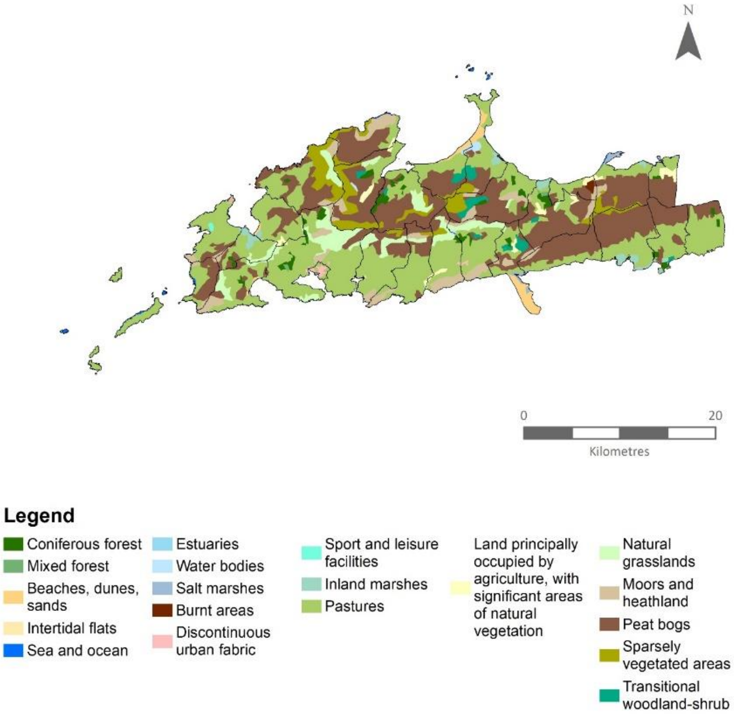


Figure 25: Land cover on the Dingle Peninsula. Data source: Copernicus Land Monitoring Service (2018)

6. Protected or zoned land

Designated sites, including special areas of conservation (SACs) and special protected areas (SPAs) were mapped from data obtained from the NPWS for 2019 (fig. 6). While development is not necessarily prohibited in these areas, it is more cumbersome. As such, the area *outside* of these areas may be considered more desirable for development. A data layer was produced representing the areas *outside* of designated sites. This was converted to a 100m x 100m raster and given a score of 255.

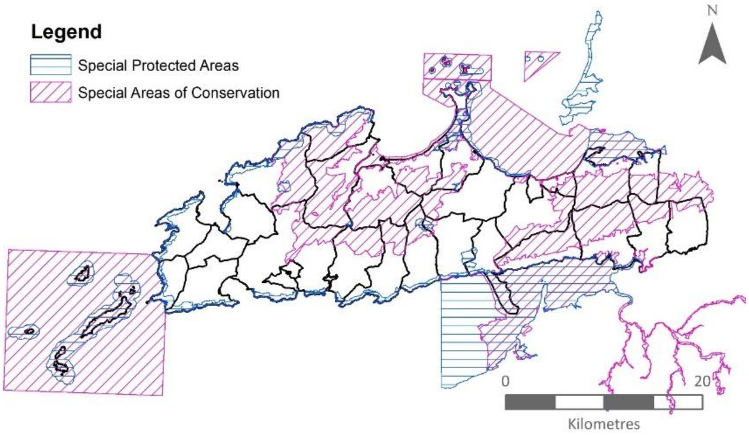


Figure 26: Designated sites on the Dingle Peninsula. Data source: NPWS (2019)

The zoned land data layer was mapped as per the Kerry County Development Plan 2015-2021 (fig. 7). 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

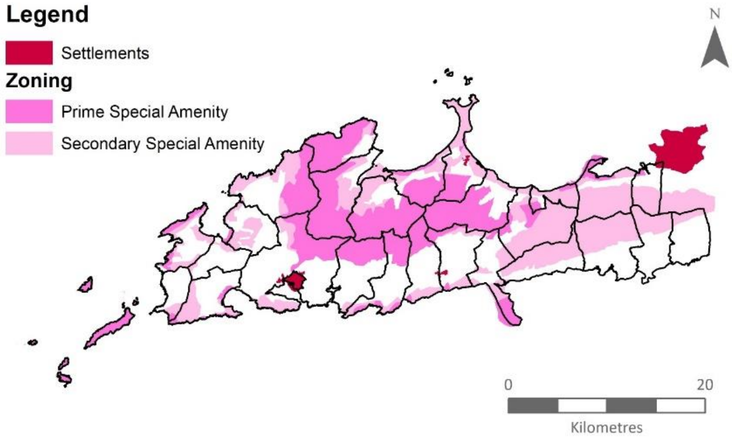


Figure 27: Zoned land on the Dingle Peninsula. Data sources: Kerry County Council (2015) and CSO (2016)

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 are discussed later in this report.

7. Proximity to roads and fuelling stations

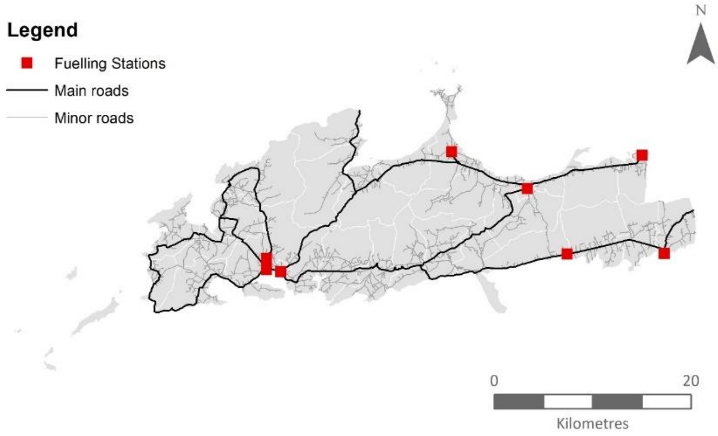


Figure 28: Figure 8 Roads and fuelling stations on the Dingle Peninsula.

Proximity to roads and fuelling stations (fig. 8) was also considered in the analysis. A raster cost path layer was produced using the fuelling stations and elevation data as inputs (fig. 9). This represents the proximity of the fuelling stations, taking into account topography, to all locations on the peninsula. 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 (fig. 10).

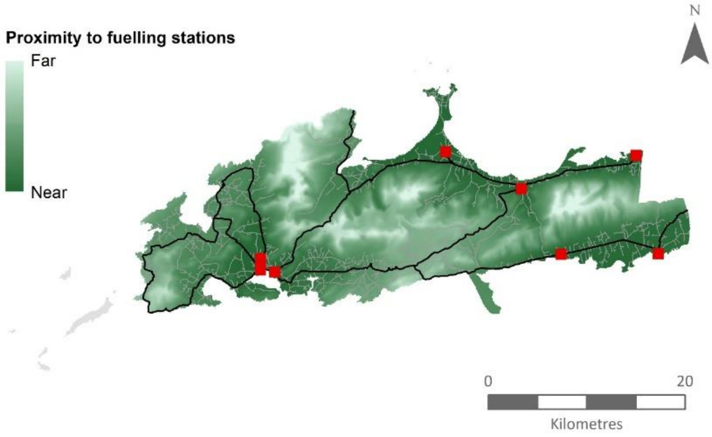


Figure 29: Raster cost path layer illustrating proximity to fuelling stations, taking into account topography.

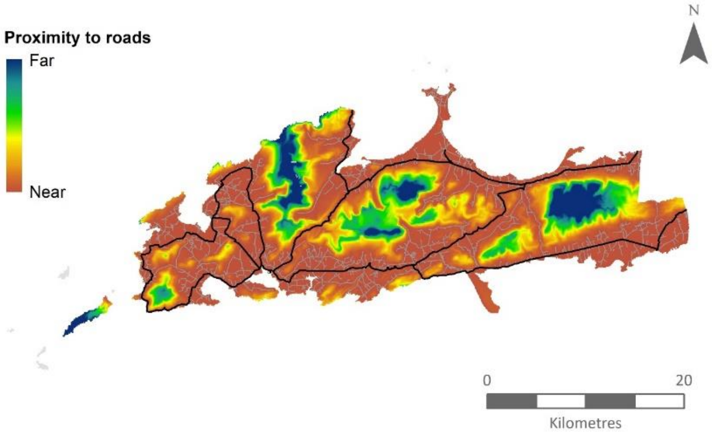


Figure 30 Raster cost path layer illustrating proximity to roads, taking into account topography

D. Constraints

A constraints layer was produced to eliminate categorically unsuitable areas from the spatial MCA. This layer included the features shown in Table 19. A map of the overall constraint areas is shown in Figure 31: Constraint areas (areas excluded from spatial MCA)..

Table 19 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

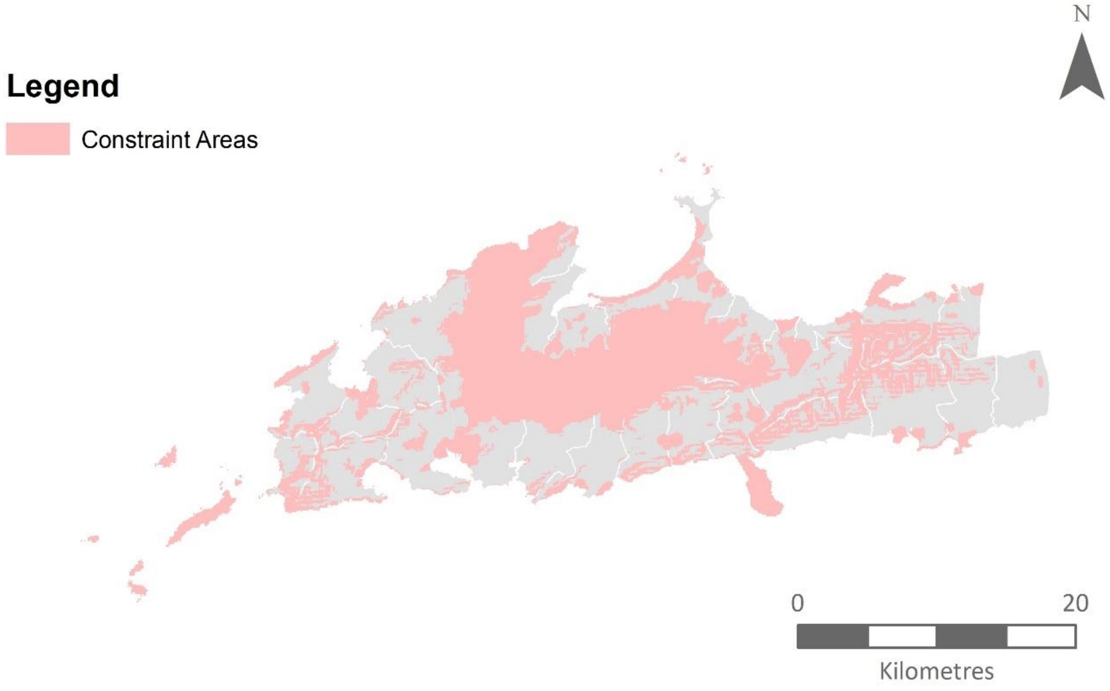


Figure 31: Constraint areas (areas excluded from spatial MCA).

E. 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 20).

Table 20 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 21.

Table 21 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

Weights were multiplied by the scaled values of each of the factor layers described previously in this report.

F. Performing 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

Figure 32 shows the output of the analysis. The composite suitability score is unitless, with the highest values representing highest levels of desirability.

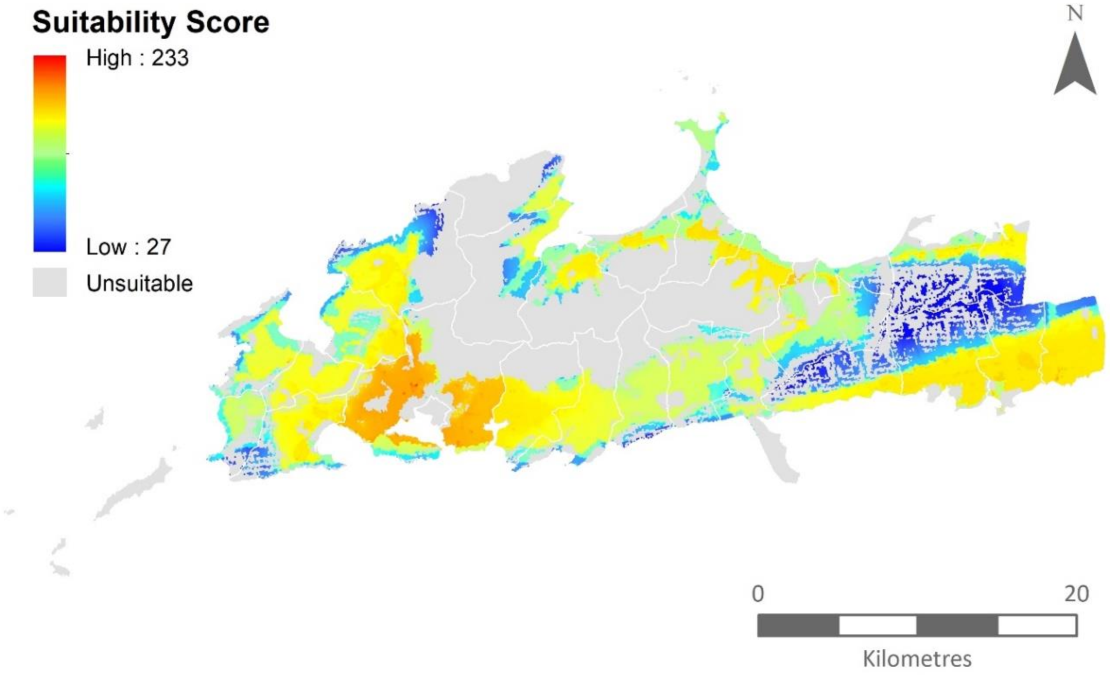


Figure 32: Site suitability map for an AD development on the Dingle Peninsula

Dingle town is the epicentre for all main feedstocks including grass silage, and would suggests that in order to minimise transport distance, the biogas plant should be located within a reasonable radius of the town. In addition, proximity to energy users is another key factor in terms of preferable location of the AD plant, notably in terms of servicing potential refuelling station (piping gas would be much less costly than transporting it with cylinders) and heat users. The logistics of transporting and distributing CO_2 and compost should also be considered.

All spatial analysis data and figures must be considered in the light of the geography and access. All feedstocks north of the Connor Pass are unavailable due to the limited road access (light vehicle traffic only). Thus any feedstocks arising in the area from Brandon to Camp would require transport to any plant located in the Dingle area (for instance) via Camp. The feedstocks concerned are sewage sludge and food wastes, since the other resource – fish waste is only available in the vicinity of Dingle itself. Due to the low population of this area however, the impact on the availability of sewage sludge and food waste on the total resource is minor; hence the relatively large % of the total resource that we have considered is available to the plant.

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

Chapter 7. 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 on the Dingle peninsula, 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.

A. Ownership & Organisational Model

The 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 organisation 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.

1. 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.

2. 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.

3. 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 22: 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

4. 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.

B. 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.

1. 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.

2. 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:

a) 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.

b) 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’, ie, 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.

c) 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.

d) 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.

e) 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.

3. 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.

Chapter 8. Roadmap for community anaerobic digestion project in Dingle

Anaerobic digestion projects, along with any type of energy project development, require careful planning and tapping all available support at each stage. Below is a description of the main stages that a project will typically go through.

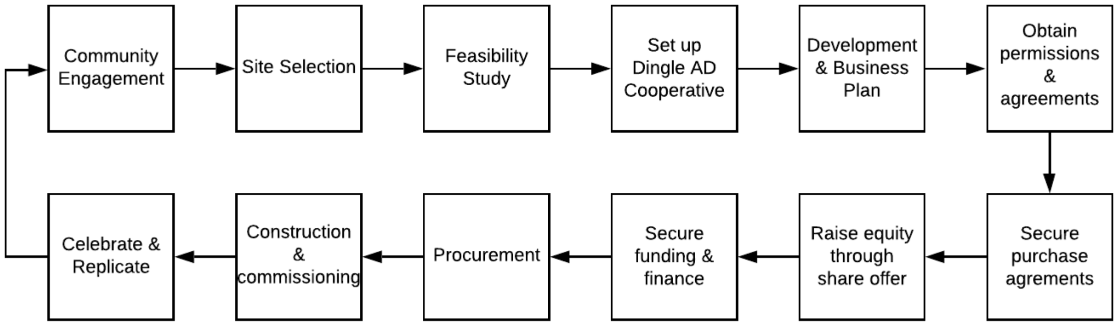


Figure 33: Roadmap for community anaerobic digestion in Dingle.

Some of these can overlap and most stages can be further broken down into sub-stages or parallel streams of work. This overview is to provide a framework for considering project development. For simplicity, it assumes a coop model with community shares providing some if not all of the capital.

A. Community engagement

This component threads through all of the work and is particularly evident early on when the ideas are discussed and crystallised into a particular project to pursue. The type of engagement will change from open discussions to focussed consultation to information dissemination to requesting support to celebration and reporting as the project progresses through the various stages.

B. Site Selection & Feasibility study

Using the multi-criteria spatial analysis results presented in section Chapter 6, conduct a detailed review of areas with most potential and shortlist promising site locations. Approach landowners of sites shortlisted with a view to obtain an exclusivity agreement which gives the right to the developer (the coop or a representative) to apply for permitting in their name. This legally binding document often called an 'option agreement' allows the developer onto the owner's lands to carry out investigations and to apply for a permissions including planning, grid connection, waste management licences, etc. The option is typically for a period of 2 years which can be extended by a further 2 or 3 years. On the basis that the option is viable, the developer and the landowner then normally enter into a long-term lease which is typically 25 years in length.

A detailed feasibility study specific to the site and proposed anaerobic digestion development must be undertaken, informed by the findings of this report in relation to feedstocks, technical pathways and lifecycle cost assessment, as well as planning and environmental constraints explored in the spatial analysis. A preliminary design and layout of the AD plant and associated civil and electrical works, in line with those presented in section Chapter 4, will support the permitting process, as well as preparations for the financing of the project.

C. Establish project organisation

Once a viable project has been identified and garnered community support, a suitable organisation should be set up to be responsible for the development and ultimate ownership of the anaerobic digestion plant and other asset such as biomethane storage & distribution system. This is often a co-op (I&Ps), Energy Cooperatives Ireland (ECI) and ICOS can help in setting up such an organisation.

D. Develop a plan

The feasibility study will have outlined a way forward and this will need to be developed into a set of specific steps needed to achieve the desired outcome. This is not a rigid document and may need to be adjusted as other aspects become evident but it will guide the next steps. There may be important time constraints that must be considered in terms of achieving milestones. This stage can also involve detailed technical specifications and layouts for the development. A specific element of the Plan will be to develop a business plan that will cover all aspects of the AD project from a business development and operation perspective, including a detailed financial plan that will support the bankability of the project.

E. Obtain Permissions

This is the heart of the development work and will involve various contracts or agreements that need to be signed to enable the project to happen. This will include land agreements as discussed above, planning permission, grid connections, purchase agreements for energy and other products from the plant (CO_2, compost, etc.), access agreements and usage rights of various kinds. Details on the roadmap for planning, ABP application and Waste Facility licensing are detailed in the Composting & Anaerobic Digestion Association of Ireland's guidelines.

F. Secure the long-term energy purchase agreements

As mentioned previously, there is no support scheme in place that will subsidise the production of biomethane and enable the development of anaerobic digestion projects at scale, yet. Currently, the Renewable Energy Support Scheme (RESS) and the Support Scheme for Renewable Heat (SSRH) offer potential long-term revenue streams where for AD projects with CHP. However, as the AD pathways analysis as shown in section Chapter 3.D, the viability of such projects is questionable. The project team will keep a watch on policy development in that regard.

In addition, the sale of biomethane for injection into the natural gas grid will be subject to an energy purchase agreement governing the quality and quantity of biomethane supplied, as well as the purchase price. The sale of biomethane as a transport fuel locally is unlikely to be subject to long-term supply contracts but securing supply agreements with 'anchor' buyers, such as captive fleets, can play an important role in establishing a baseline revenue stream.

G. Share offer

Once all of the necessary permissions and agreements are in place, the equity finance for the project can be raised. The offer will be based on the business model that has been developed through the earlier stages and will explain clearly, in simple, understandable terms what is being asked for and what return will be offered. It will be open about the risks involved and who is behind the scheme. ECI and ICOS can support the development of this document and possibly the administrative services associated

H. Financing & Funding

As loan finance is likely to be needed, discussions with banks or other financial institutions will have to be progressed. Risk finance maybe required to support the initial stages of the project, including costs for grid connection application, planning permission application, feasibility study, etc. The requirements to secure bank finance are stringent, they need to be identified in detail during feasibility study stage and all the evidence required must be carefully documented. This will be subject to a rigorous due diligence process.

A community-owned anaerobic digestion project has the potential to attract public funding from local and national sources, in particular for the project development phase, including from:

- the SEAI's Sustainable Energy Community programme;
- the DCCAE's Climate Action Fund;
- the DRCD's Rural Regeneration & Development Fund;
- the NEKD's Leader Funding Programme.

The Gas Innovation Fund should be approached to identify further funding opportunities for the project development.

I. Contract, Build, Commission

Once the finances are in place, the equipment and construction work can be procured. Reliable technical and contract management support for this phase will be essential from trusted advisors acting on behalf of the developer. Expertise from within the community that can be used and possibly reduce costs. The construction can now go ahead and a project manager will be needed to ensure that the various contractors work together effectively and the equipment is installed, tested and commissioned according to the various requirements. The start-up phase of the digester is critical for the health and good operation of the AD and must be conducted by an experienced specialist.

J. Celebrate, Operate & Replicate

A grand launch at commissioning is in order and a celebration of a huge amount of work and a significant achievement for the community. There will be a long list of people to thank; from the board of directors to the contractors, consultants and support agencies. The following years will involve management of the operations and the finances for the co-operative. There will be loans to repay, maintenance to carry out, bills to pay, receipts to record, interest to distribute, members to communicate with and community projects to support. Hopefully, this will produce the desired effects and improve the resiliency of the local community. The experience and learnings of the project should be leveraged to develop other projects and help other communities replicate what the cooperative has achieved.

References

[1] UN, "TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT UNITED NATIONS UNITED NATIONS TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT." [Online]. Available: https://sustainabledevelopment.un.org/content/documents/21252030 Agenda for Sustainable Development web.pdf. [Accessed: 31-Jul-2019].

[2] UN, "Paris Agreement," 2015. [Online]. Available: https://unfccc.int/sites/default/files/english_paris_agreement.pdf. [Accessed: 31-Jul-2019].

[3] C. A. & E. Department of Communications, "Climate Action Plan." [Online]. Available: https://www.dccae.gov.ie/en-ie/climate-action/Pages/default.aspx. [Accessed: 31-Jul-2019].

[4] Kerry County Council, "Chapter 13: Development Management - Standards & Guidelines," *2015*. [Online]. Available: http://cdp.kerrycoco.ie/wordpress/wp-content/uploads/2015/12/chptr_13.pdf. [Accessed: 31-Jul-2019].

[5] Kerry County Council, "Renewable Energy Strategy 2012," 2012. [Online]. Available: http://www.kerrycoco.ie/home3/planning/planning-policy/renewable-energy-strategy-2012/. [Accessed: 31-Jul-2019].

[6] XD Sustainable Energy Consulting Ltd., "Transition Kerry's Sustainable Energy Community Roadmap." [Online]. Available: http://www.transitionkerry.org/wp-content/uploads/2014/12/TransitionKerrySECRoadmap_FinalReport.pdf. [Accessed: 31-Jul-2019].

[7] EPA, "Public Access to Licensing Files," *Environmental Protection Agency (EPA)*. [Online]. Available: https://www.epa.ie/licensing/info/files/. [Accessed: 06-Aug-2019].

[8] R. O'Shea, I. Kilgallon, D. Wall, and J. D. Murphy, "Quantification and location of a renewable gas industry based on digestion of wastes in Ireland," *Applied Energy*, 2016. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0306261916305931.

[9] Kerry County Council, "Focus on agriculture In County Kerry." [Online]. Available: http://atomik.kerrycoco.ie/ebooks/agri.pdf. [Accessed: 06-Aug-2019].

[10] "Grass10 - Teagasc | Agriculture and Food Development Authority." [Online]. Available: https://www.teagasc.ie/crops/grassland/grass10/. [Accessed: 19-Jul-2019].

[11] E. Dillon, B. Moran, J. Lennon, and T. Donnellan, "Teagasc National Farm Survey 2018 Preliminary Results." [Online]. Available: https://www.teagasc.ie/media/website/publications/2019/National-Farm-Survey-Preliminary-Results-2018.pdf. [Accessed: 12-Jul-2019].

[12] C. Buckley *et al.*, "Teagasc National Farm Survey 2017 Sustainability Report," 2019. [Online]. Available: https://www.teagasc.ie/media/website/publications/2019/2017-sustainability-report-250319.pdf. [Accessed: 12-Jul-2019].

[13] T. Hennessy, C. Buckley, M. Cushion, A. Kinsella, and B. Moran, "National Farm Survey of Manure Application and Storage Practices on Irish Farms," 2011. [Online]. Available: https://www.teagasc.ie/media/website/publications/2011/TeagascNationalFarmSurveyOfManureApplication.pdf. [Accessed: 01-Apr-2019].

[14] F. Amlinger, E. Favoino, M. Prasad, and P. Foster, "The Collectable Source Separated Food and Garden Waste Arising from Households in Ireland," 2010. [Online]. Available: http://www.cre.ie/web/wp-content/uploads/2010/12/Collectable-Household-Food-and-Garden-Waste-in-Ireland1.pdf. [Accessed: 01-Apr-2019].

[15] Kerry County Council, "Tourism Strategy and Action Plan 2016 - 2022," *2016*. [Online]. Available: http://docstore.kerrycoco.ie/KCCWebsite/Tourism/TourismStrategy.pdf. [Accessed: 31-Jul-2019].

[16] J. D. Browne, E. Allen, and J. D. Murphy, "Assessing the variability in biomethane production from the organic fraction of municipal solid waste in batch and continuous operation," *Applied Energy*, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0306261914004607.

[17] A. Kelessidis and A. S. Stasinakis, “Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries,” *Waste Management*, 01-Jun-2012. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0956053X12000268. [Accessed: 14-Jan-2019].

[18] E. P. A. (EPA), “What you can do to improve your treatment system,” *Environmental Protection Agency (EPA)*. [Online]. Available: https://www.epa.ie/water/wastewater/legislation/youdo/. [Accessed: 06-Aug-2019].

[19] European Commission, “Dingle Waste Water Treatment Plant.” [Online]. Available: https://uwwtd.eu/Ireland/treatment-plant/ietp_172/2012. [Accessed: 02-Apr-2019].

[20] BIM, “The Business of Seafood 2016 - A Snapshot of Ireland’s Seafood Sector,” 2016. [Online]. Available: http://www.bim.ie/media/bim/content/publications/corporate-other-publications/BIM-the-business-of-seafood-2016.pdf. [Accessed: 25-Mar-2019].

[21] M. Archer, “Fish Waste Production in the United Kingdom - The Quantities Produced and Opportunities for Better Utilisation,” 2001. [Online]. Available: https://www.seafish.org/media/Publications/SR537.pdf. [Accessed: 02-Apr-2019].

[22] A. Mshandete, A. Kivaisi, M. Rubindamayugi, and B. Mattiasson, “Anaerobic batch co-digestion of sisal pulp and fish wastes,” *Bioresource Technology*, 01-Oct-2004. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0960852404000331. [Accessed: 02-Apr-2019].

[23] S. Moskowitz, “Anaerobic Digestion of Slaughterhouse Waste.” [Online]. Available: https://pdfs.semanticscholar.org/7e5a/a7891694d6bee2a2cb86107940c881621202.pdf. [Accessed: 19-Jul-2019].

[24] EPA, “Anaerobic Digestion: Decision Support Software,” *Environmental Protection Agency (EPA)*, 2005. [Online]. Available: http://erc.epa.ie/safer/iso19115/displayISO19115.jsp?isoID=38. [Accessed: 19-Jul-2019].

[25] C. Walsh, “The use of Animal By-products The improving opportunities to add value to the beef and sheep slaughtering sectors,” 2014. [Online]. Available: https://beefandlamb.ahdb.org.uk/wp-content/uploads/2016/07/74318-5th-Quarter-Use-and-Flow-Final-Report-130514.pdf. [Accessed: 20-Jul-2019].

[26] M. R. Tabassum, A. Xia, and J. D. Murphy, “Potential of seaweed as a feedstock for renewable gaseous fuel production in Ireland,” *Renewable and Sustainable Energy Reviews*, 2017. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1364032116305962.

[27] T. Bruton, “A Review of the Potential of Marine Algae as a Source of Biofuel in Ireland.” [Online]. Available: http://www.fao.org/uploads/media/0902_SEI_-_A_Review_of_the_Potential_of_Marine_Algae.pdf. [Accessed: 16-Jul-2019].

[28] CSO, “Information Note for Data Users: revision to the Irish NUTS 2 and NUTS 3 Regions - CSO - Central Statistics Office.” [Online]. Available: https://www.cso.ie/en/methods/revnuts23/. [Accessed: 31-Jul-2019].

Wall, David & Allen, Eoin & Straccialini, Barbara & O'Kiely, Padraig & Murphy, Jerry. (2014). Optimisation of digester performance with increasing organic loading rate for mono- and co-digestion of grass silage and dairy slurry. Bioresource technology. 173. 422-8. 10.1016/j.biortech.2014.09.126.

Copernicus Land Monitoring Service, 2018. *CORINE Land Cover (CLC)*. [Database] Retrieved from: https://land.copernicus.eu/news/corine-land-cover-now-updated-for-the-2018-reference-year

CSO, 2016. *Census 2016 Boundary Files.* [Dataset] Retrieved from: https://www.cso.ie/en/census/census2016reports/census2016smallareapopulationstatistics/

Kerry County Council, 2015. *Kerry County Development Plan 2015- 2021, Volume 3: Maps.* http://cdp.kerrycoco.ie/wordpress/?page_id=81

NASA, 2012. *Digital Elevation Model of Ireland, from NASA's Shuttle Radar Topography Mission (SRTM).* [Dataset] Retrieved from: https://data.gov.ie/dataset/digital-elevation-model-of-ireland-from-nasas-shuttle-radar-topography-mission-srtm

NPWS, 2019. *Designated site boundary data.* [Database] Retrieved from: https://www.npws.ie/maps-and-data/designated-site-data/download-boundary-data

OpenStreet Map contributors, 2019. Planet dump [Data file from July 2019]. Retrieved from https://planet.openstreetmap.org

Simon Pezzutto, Stefano Zambotti, Silvia Croce, Pietro Zambelli, Giulia Garegnani, Chiara Scaramuzzino, Ramón Pascual Pascuas, Alyona Zubaryeva, Franziska Haas, Dagmar Exner (EURAC), Andreas Mueller (e-think), Michael Hartner (TUW), Tobias Fleiter, Anna-Lena Klingler, Matthias Ku¨hnbach, Pia Manz, Simon Marwitz, Matthias Rehfeldt, Jan Steinbach, Eftim Popovski (Fraunhofer ISI) Reviewed by Lukas Kranzl, Sara Fritz (TUW) Hotmaps Project, D2.3 WP2 Report – Open Data Set for the EU28, 2018 www.hotmaps-project.eu

Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. *Journal of mathematical psychology*, 15(3), pp.234-281.

Thompson, E., Wang, Q. and Li, M., 2013. Anaerobic digester systems (ADS) for multiple dairy farms: A GIS analysis for optimal site selection. *Energy policy*, 61, pp.114-124.

Allen, E., Wall, D.M., Herrmann, C., Murphy, J.D. 2014. Investigation of the optimal percentage of green seaweed that may be co-digested with dairy slurry to produce gaseous biofuel. *Bioresource Technology*, **170**, 436-444.

Czyrnek-Delêtre, M.M., Rocca, S., Agostini, A., Giuntoli, J., Murphy, J.D. 2017. Life cycle assessment of seaweed biomethane, generated from seaweed sourced from integrated multi-trophic aquaculture in temperate oceanic climates. *Applied Energy*, **196**, 34-50.

Murphy, F., Devlin, G., Deverell, R., McDonnell, K. 2013. Biofuel Production in Ireland—An Approach to 2020 Targets with a Focus on Algal Biomass. *Energies*, **6**(12), 6391-6412.

Tabassum, M.R., Wall, D.M., Murphy, J.D. 2016a. Biogas production generated through continuous digestion of natural and cultivated seaweeds with dairy slurry. *Bioresource Technology*, **219**, 228-238.

Tabassum, M.R., Xia, A., Murphy, J.D. 2018. Biomethane production from various segments of brown seaweed. *Energy Conversion and Management*, **174**, 855-862.

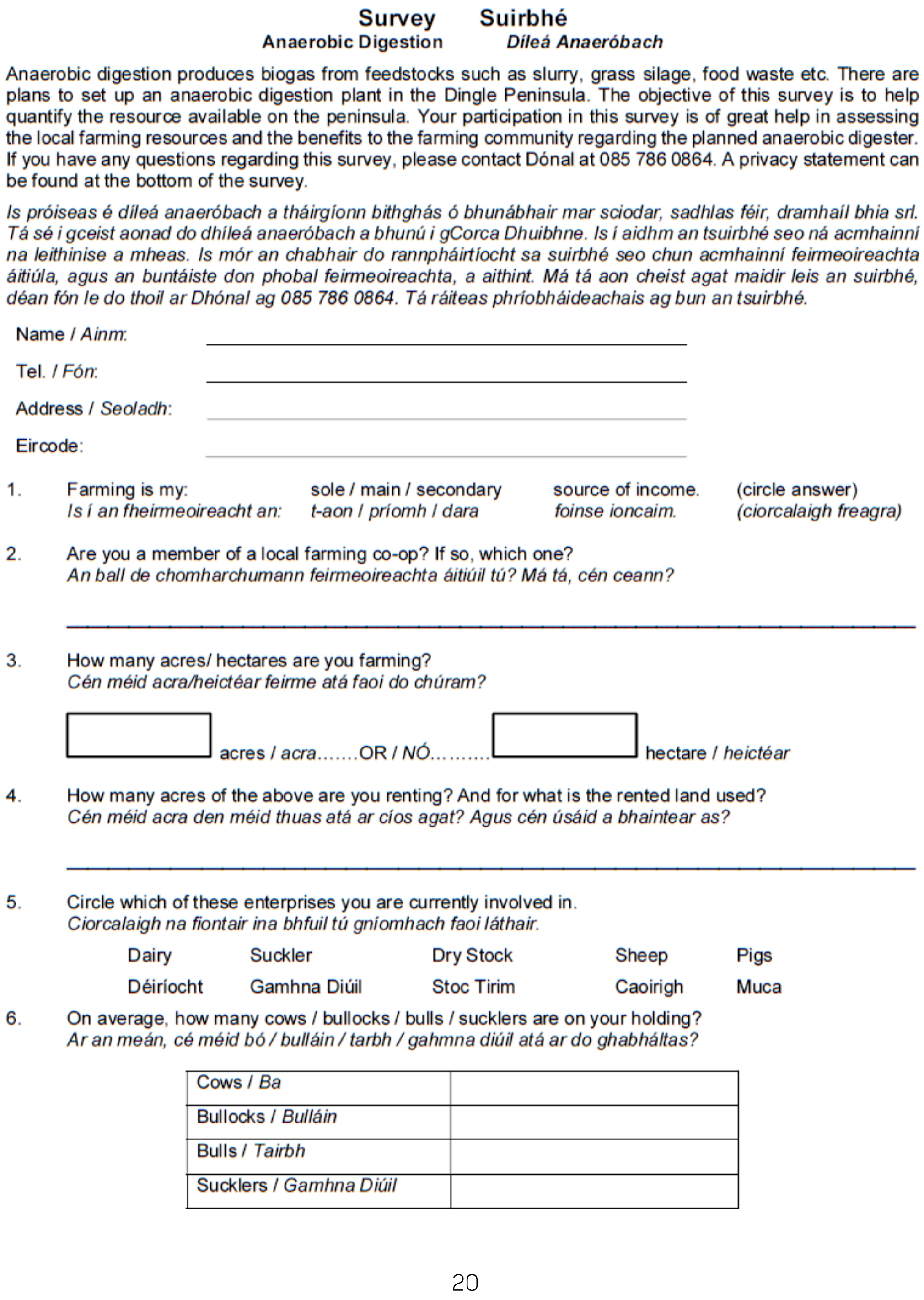
Tabassum, M.R., Xia, A., Murphy, J.D. 2017. Potential of seaweed as a feedstock for renewable gaseous fuel production in Ireland. *Renewable and Sustainable Energy Reviews*, **68**, 136-146.

Tabassum, M.R., Xia, A., Murphy, J.D. 2016b. Seasonal variation of chemical composition and biomethane production from the brown seaweed Ascophyllum nodosum. *Bioresource Technology*, **216**, 219-226.

Xia, A., Jacob, A., Herrmann, C., Tabassum, M.R., Murphy, J.D. 2015. Production of hydrogen, ethanol and volatile fatty acids from the seaweed carbohydrate mannitol. *Bioresource Technology*, **193**, 488-497.

Appendices

Appendix A – Survey



Survey **Suirbhé**
Anaerobic Digestion ***Díleá Anaeróbach***

Anaerobic digestion produces biogas from feedstocks such as slurry, grass silage, food waste etc. There are plans to set up an anaerobic digestion plant in the Dingle Peninsula. The objective of this survey is to help quantify the resource available on the peninsula. Your participation in this survey is of great help in assessing the local farming resources and the benefits to the farming community regarding the planned anaerobic digester. If you have any questions regarding this survey, please contact Dónal at 085 786 0864. A privacy statement can be found at the bottom of the survey.

Is próiseas é díleá anaeróbach a tháirgíonn bithghás ó bhunábhair mar sciodar, sadhlas féir, dramhaíl bhia srl. Tá sé i gceist aonad do dhíleá anaeróbach a bhunú i gCorca Dhuibhne. Is í aidhm an tsuirbhé seo ná acmhainní na leithinise a mheas. Is mór an chabhair do rannpháirtíocht sa suirbhé seo chun acmhainní feirmeoireachta áitiúla, agus an buntáiste don phobal feirmeoireachta, a aithint. Má tá aon cheist agat maidir leis an suirbhé, déan fón le do thoil ar Dhónal ag 085 786 0864. Tá ráiteas phríobháideachais ag bun an tsuirbhé.

Name / *Ainm*: ____________________

Tel. / *Fón*: ____________________

Address / *Seoladh*: ____________________

Eircode: ____________________

1. Farming is my: sole / main / secondary source of income. (circle answer)
Is í an fheirmeoireacht an: t-aon / príomh / dara foinse ioncaim. (ciorcalaigh freagra)

2. Are you a member of a local farming co-op? If so, which one?
An ball de chomharchumann feirmeoireachta áitiúil tú? Má tá, cén ceann?

____

3. How many acres/ hectares are you farming?
Cén méid acra/heictéar feirme atá faoi do chúram?

☐ acres / *acra*.......OR / *NÓ*.......... ☐ hectare / *heictéar*

4. How many acres of the above are you renting? And for what is the rented land used?
Cén méid acra den méid thuas atá ar cíos agat? Agus cén úsáid a bhaintear as?

____

5. Circle which of these enterprises you are currently involved in.
Ciorcalaigh na fiontair ina bhfuil tú gníomhach faoi láthair.

Dairy	Suckler	Dry Stock	Sheep	Pigs
Déiríocht	Gamhna Diúil	Stoc Tirim	Caoirigh	Muca

6. On average, how many cows / bullocks / bulls / sucklers are on your holding?
Ar an meán, cé méid bó / bulláin / tarbh / gamhna diúil atá ar do ghabháltas?

Cows / *Ba*	
Bullocks / *Bulláin*	
Bulls / *Tairbh*	
Sucklers / *Gamhna Diúil*	

20

7. For how many months of the year are your animals producing collectable slurry?
   Ar feadh cén méid mí sa bhliain a bhíonn d'ainmhithe ag táirgeadh sciodair a bailítear?

8. How much slurry (litres, gallons etc.) is collected from your animals annually?
   Cén méid sciodar (lítir, galúin, srl.) a bhailítear ó'd ainmhithe go bliantúil?

   litres / *lítear*…….OR / *NÓ*……… gallon / *galún*

9. How do you store slurry (slatted tank, open pit, lagoon, or other)?
   Conas a stórálann tú sciodar (dabhach lataí, carn oscailte, murlach, nó eile)?

10. Do you often have slurry surplus to your requirements? Yes / No (circle)
    An mbíonn sciodar agat go rialta thar mar is gá duit? Bíonn / Ní bhíonn (ciorcalaigh)

11. On how many acres/hectares of your holding is silage harvested?
    Cén méid acra/heictéar ar do ghabháltas ar a mbaintear sadhlas?

    acres / *acra*…….OR / *NÓ*………. hectare / *heictéar*

12. How many times in the year do you harvest silage? 1 / 2 / 3 (circle)
    Cén méid uair sa bhliain a bhaineann tú sadhlas? 1 / 2 / 3 (ciorcalaigh)

13. How do you store silage? Bale / Pit / Both (circle)
    Conas a stórálann tú sadhlas? Burla / Carn / Dá rud (ciorclaigh)

14. If possible, give estimate of your total annual silage harvest (tonnage, size of pit, number of bales, etc.).
    Más féidir, tabhair tuairim ar d'fhómhar sadhlais bliantúil (tonnáiste, toirt cairn, uimhir burlaí, srl.).

15. Do you regularly buy/sell silage? Buy / Sell / No (circle)
    An gceannaíonn/díolann tú sadhlas go rialta? Ceannaíonn / Díolann / Ní (ciorclaigh)

16. If so, how many tons / bales etc.?
    Má sea, cén méid tonna / burla srl.?

    tonnes / *tonna*………..OR / *NÓ*……………. bales / *burla*

17. Will you harvest more/less silage in the future? More / Less / Same (circle)
    An mbainfidh tú breis/níos lú sadhlais sa todhchaí? Breis / Níos Lú / Méid céanna (ciorclaigh)

18. Have you full-time/part-time help with farming (family members included)? If yes, give average weekly hours.
An bhfuil cabhair lánaimseartha/páirtaimseartha agat ag feirmeoireacht (baill teaghlaigh san áireamh)? Má tá, tabhair meán uaireanta oibre sa tseachtain.

____

19. Do you think that farming in the Dingle Peninsula is currently viable? Will it become more or less viable in future?
An fiú a bheith ag feirmeoireacht i gCorca Dhuibhne faoi láthair? An i bhfeabhas nó in olcas a rachaidh seo sa todhchaí?

____

____

20. Do you envisage changes to your farming business in the future (retirement, diversification, change of farming enterprise, etc.)? If you do, what changes do you envisage?
An samhlaíonn tú go mbeidh aon athruithe i do chúram feirmeoireachta sa todhchaí (éirí as, éagsúlú, athrú go fiontar feirmeoireachta nua, srl.)? Más ea, cad iad?

____

____

We thank you very much for your participation in this survey. If you'd like further information on the Dingle Peninsula Anaerobic Digestion Feasibility Study, please contact Dónal at 085 786 0864, or email doc9011@gmail.com.

Ár mbuíochas as do rannpháirtíocht sa suirbhé seo. Más suim leat breis eolais a fháil ar an Staidéar Féidearthachta Dhíleá Anaeróbach Chorca Dhuibhne, déan teangmháil le do thoil le Dónal ag 085 786 0864, nó ar ríomhphost doc9011@gmail.com.

Privacy
In this survey, information is collected regarding the animals and feedstocks associated with your business or farm. This information will be used to help estimate the feedstocks available in the Dingle Peninsula for the feasibility study being conducted by XD Sustainable Energy Consulting Ltd, Clonakilty, Cork. The information is stored in a secure data centre. To exercise your right to be forgotten under EU GDPR law, email doc9011@gmail.com and ask to be removed.

Priobháideachas
Sa suirbhé seo bailítear eolas ar ainmhithe agus bunábhair bainteach le d'fheirm nó do ghnó. Úsáidfear an t-eolas seo chun na bunábhair i leithinis Chorca Dhuibhne a mheas don staidéar féidearthachta atá idir lámha ag XD Sustainable Energy Consulting Ltd, Cloich na Coillte, Corcaigh. Tá an teolas seo bailithe in ionad sonraí slán. Faoi dlí AE GDPR, más mian is féidir do cheart go ligfí i ndearmad a chur i bhfeidhm ach e-fost á údarú a sheoladh go doc9011@gmail.com.

Appendix B – Municipal Feedstock per Electoral Division

Electoral Division	Population	Food Waste Produced (t a^{-1})	Sewage Sludge Produced (t DS a^{-1})
An Baile Dubh	113	9.55	1.65
An Clochán	232	19.60	4.03
An Daingean	1,623	137.14	175.20
An Mhin Aird	368	31.10	5.37
An Sráidbhaile	239	20.20	3.49
Ballinvoher	560	47.32	9.26
Ballynacourty	284	24.00	4.15
Baurtregaum	375	31.69	5.47
Blennerville	658	55.60	9.61
Boolteens	482	40.73	7.04
Castlegregory	981	82.89	14.32
Cé Bhréanainn	153	12.93	2.92
Ceann Trá	396	33.46	5.78
Cill Chuáin	434	36.67	6.34
Cill Maoilchéadair	481	40.64	7.02
Cinn Aird	345	29.15	5.04
Deelis	349	29.49	5.10
Dún Chaoin	182	15.38	2.66
Dún Urlann	467	39.46	12.26
Inch	141	11.91	2.06
Kilgarrylander	643	54.33	9.39
Kilgobban	272	22.98	3.97
Kiltallagh	565	47.74	8.25
Knockglass	353	29.83	5.15
Lack	271	22.90	3.96
Márthain	260	21.97	3.80
Na Gleannta	1,846	155.99	26.95
Total	13,073	1,104.65	350.23

Appendix C – Potential for Algae

Written by David Wall

Dingle Peninsula Study: Potential for Algae

Seaweed biomass can potentially provide an attractive feedstock for anaerobic digestion (AD) in particular circumstances. Ireland has a significant potential with its considerable coastline (7500km) and temperate oceanic climate to accumulate a sizeable seaweed resource both naturally and through farm cultivation. Irish brown seaweeds include for *Ascophyllum nodosum*, *Laminaria digitata*, *Laminaria hyperborea*, *Saccharina latissima* and *Saccorhiza polyschides*. Of these, *Laminaria digitata* and *Saccharina latissima* have been identified as having most potential due to their rich organic composition (Tabassum et al., 2017). The estimated production of Irish seaweeds is 29,500 tonnes wet weight per annum, occurring naturally (Tabassum et al., 2018). This harvest is dominated by *Ascophyllum nodosum* which mainly accumulates in the north west of Ireland in Donegal and Galway (Murphy et al., 2013). At present, the natural seaweed resource in Ireland is used primarily for food and not biofuels (Tabassum et al., 2016a).

Seaweed (macro-algae) can be considered a third-generation biofuel source as it does not have any land or fresh water requirements as compared to traditional energy crops. It is also proposed as a feedstock that can achieve higher growth rates and higher rates of carbon fixation than land-based energy crops (Tabassum et al., 2017). Additionally, due to the absence of lignin (complex polymers) and hemicellulose, seaweed can be a more suitable biomass for digestion that allows for easier fermentation and minimal pre-treatment (Tabassum et al., 2018; Xia et al., 2015). However, the morphology of brown seaweed can vary substantially depending on the growth conditions at a given location; this includes for temperature, nutrients, sunlight and water flow. The body of the plant can be divided into different sections, namely the holdfast, stipe and frond, and the composition of each component can vary in terms of organic content. The frond has been identified as the most significant fraction in terms of contributing to biogas production (Tabassum et al., 2018). Despite the potential of natural seaweed stock for energy production, certain biodiversity issues must obviously be considered. Thus, a more favourable pathway proposed is the farm cultivation of seaweed, a concept known as integrated multi-trophic aquaculture (IMTA). Such a method combines seaweed cultivation with fish (salmon/mussel) farms. The benefit of this approach is that the nutrient waste from the fish can be sequestered by the seaweed and thereby cause increased plant growth as compared to pristine waters. The prospect of such a strategy will depend on the location of fish farm sites, however this is deemed the most economical method for seaweed farming (Tabassum et al., 2016a). Yields of 40-150 tonnes wet weight per hectare per annum have been indicated for seaweed farm cultivation.

The seasonal variation of seaweed is one of the main characteristics to be considered if it is to be used as a biomass resource for AD. The biochemical composition of seaweed will vary throughout the year as the seaweeds becomes 'ripe'. This will have inherent impact on the biogas production. For brown seaweed, the build-up of carbohydrates has typically been reported in the summer and autumn; in the winter, carbohydrates are used as an energy source in cellular activities (Tabassum et al., 2016b). Additionally, the ash content of seaweeds will vary throughout the year, for AD the feedstock should have as minimal ash as possible. Another concern is the build-up of polyphenols, inhibitory compounds for AD, which is dependent on the geographic location, harvest time light intensity and nutrient availability amongst other factors. Significant seasonal variation has been reported for brown seaweeds. Literature studies have previously shown that high polyphenol content in summer months adversely affected biogas production for *Ascophyllum nodosum*; two potential harvest dates were thus suggested, March and October. In October the SMY reported was 215 L CH_4 kg VS^{-1} (47 m^3 CH_4 t^{-1}) equivalent to a gross energy yield of 116 GJ ha^{-1} $year^{-1}$ (Tabassum et al., 2016b). For *Laminaria digitata*, significant seasonal variation in biochemical composition is evident. August was indicated as the optimal harvest time for this seaweed species with the SMY reported at 327 L CH_4 kg VS^{-1} (53 m^3 CH_4 t^{-1}) equivalent to a gross energy yield of 200 GJ ha^{-1} $year^{-1}$. The SMY was 40% higher than that for a December harvest indicating the impact of seasonal variation.

From a biogas production perspective, the potential for seaweed in Ireland is dependent on the availability of other feedstocks (in the vicinity) that can be used in co-digestion, for example, farm slurries and the organic fraction of municipal solid waste (OFMSW). This is deemed a more integrated approach. Indicative laboratory trials, co-digesting cultivated *Saccharina latissima* with dairy slurry at a ratio of 2:1 (on a volatile solids basis), have been shown to generate a specific methane yield (SMY) of 252 L CH_4 kg^{-1} VS at an organic loading rate (OLR) of 4 kg VS m^{-3} d^{-1} (Tabassum et al., 2016a). For natural stock *Laminaria digitata* co-digested with dairy slurry at a ratio of 2:1 (on a volatile solids basis), the SMY reported was 232 L CH_4 kg^{-1} VS at an OLR of 5 kg VS m^{-3} d^{-1} (Tabassum et al., 2016a). These can be considered quite high OLRs.

Seaweeds typically have much higher chloride content as compared with land-based biomass sources, due to their origin in the marine environment. A particular concern for the use of seaweed for AD is the accumulating salt concentrations, which can be deemed the inorganic, ash component of the plant. Ensuring that the inoculum (microorganisms) in the digester are acclimatised to tolerate higher salt concentrations is of importance to maximising the biogas production (Tabassum et al., 2016a). In the laboratory trials reported for cultivated *Saccharina latissima* and natural stock *Laminaria digitate*, chloride concentrations increased to high levels in digestion but were not found to be detrimental to operation. However, accumulation of salts was evident and accelerated at higher loading rates, thus, longer term operation of such digesters would require carefully monitoring (Tabassum et al., 2016a).

Beyond brown seaweed, *Ulva Lactuca* is a species of green seaweed, commonly referred to as sea lettuce, that appears along the Irish coastline in shallow estuaries and on beaches. Green seaweed accumulates due to over excessive agricultural practices and more specifically, eutrophication, whereby water sources become contaminated and overly enriched with nutrients. Such circumstances are referred to as "green tides" or "algal blooms" and are a common occurrence in Ireland and worldwide in countries such as France, Denmark and Japan. Algal blooms can result in the closure of beaches and dangerous conditions due to the build-up of toxic gases such as hydrogen sulphide (H_2S) as the high-sulphur containing seaweed rots. One example of this problem is in Timoleague in West Cork, where every year 10,000 tonnes of sea lettuce washes up on the strand as a result of eutrophication of the bay. The problematic sea lettuce is removed manually at a cost. However, *Ulva Lactuca* may present a potential resource if it can be utilised for AD. *Ulva Lactuca* could be combined with slurry and excess grass available from local farmers or food waste from local supermarkets to increase the biogas produced. Optimum conditions reported for *Ulva Lactuca* in digestion were reported at a mix of 25% fresh *Ulva lactuca* and 75% dairy slurry (on a volatile solids basis) which generated a SMY of 170 L CH_4 kg^{-1} VS at an OLR of 2.5 kg VS m^{-3} d^{-1} (Allen et al., 2014). Despite being a more difficult substrate to work with due to high sulphur levels and a low C:N ratio, utilising AD to treat *Ulva Lactuca* would not only provide a source of indigenous energy in Ireland but also a means of reducing the detrimental effects caused to the amenity of the Irish coastline.

The importance of seaweed in the future is its merit as a third generation (advanced) biofuel in transport. The latest recast of the EU Renewable Energy Directive (REDII) requires that 3.5% of transport energy must come from advanced biofuel sources by 2030. The target may be achievable by applying innovative technologies using seaweed as an alternative substrate for gaseous fuel production. The transport biofuel must also achieve 65% greenhouse gas emissions savings as compared to fossil fuels. Emissions savings from seaweed biomethane systems are varied depending on how they system is configured (22-70% savings have been suggested) (Czyrnek-Delêtre et al., 2017).