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Feasibility Study on Anaerobic Digestion for the Dingle Peninsula

Draft Report #1: Vision & Feedstock Analysis

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This study is funded by:

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List of Acronyms

AD: Anaerobic Digestion

CH4: Methane (Biomethane)

EMP: Energy Master Plan

GWh: Gigawatt-hour or a million kWh

GWh: Gigawatt-hours

kWh: kilowatt-hour or a thousand Wh of energy

MWh: megawatt-hour or a thousand kWh

Nm3: normalised cubic meter

RE: Renewable energy

RES-e: electricity produced from renewable energy sources

RES-heat: Heat produced from renewable energy sources

tCO2: tonne of CO2

tDM: tonne of dry matter

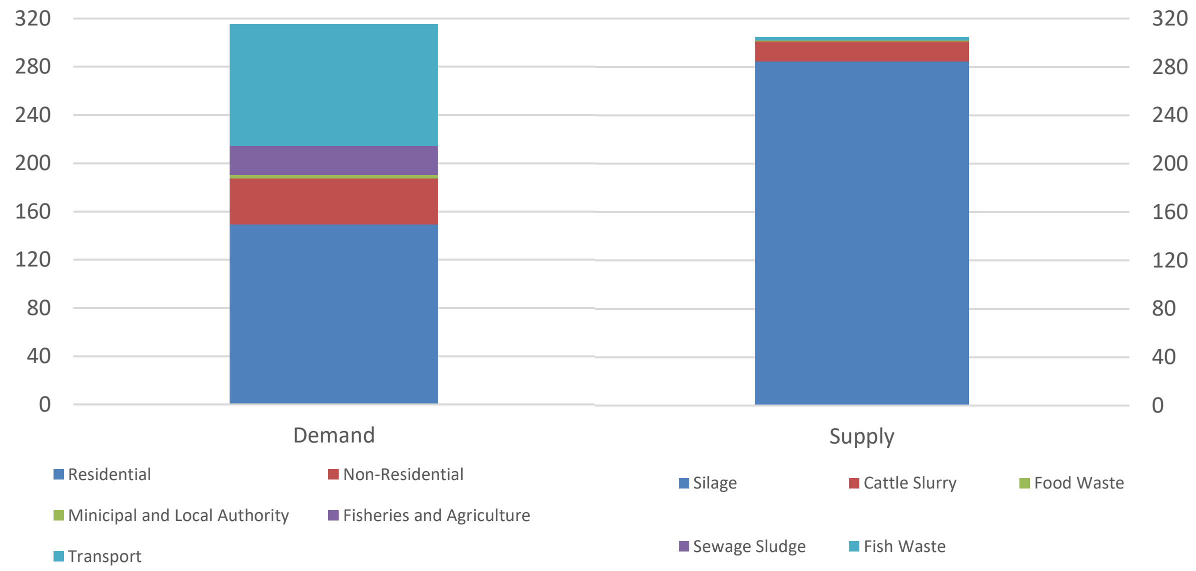
tVDS: tonne of volatile solid

TWh: Terawatt-hour, or a billion kWh

tWM: tonne of wet matter

Executive Summary

This feasibility study will assess the viability of an anaerobic digestion plant on the Dingle Peninsula. The Dingle Energy Master Plan commissioned by the Dingle Hub determined that the Dingle Peninsula consumes around 315 GWh per year. Initial feedstock analysis indicates that silage, cattle slurry, food waste, sewage sludge and fish waste could provide 305 GWh of energy to the region.



The energy available from agricultural feedstocks dwarfs that of the non-agricultural feedstocks, with 93% of the available practical energy coming from grass silage alone. The silage resource assumes an improved yield of silage from land that is currently used for silage in the Dingle Peninsula, as well as a switch of land currently used for pasture to silage production, and utilisation of unused land.

I. Introducing the Feasibility Study

A. Aims

The Dingle Sustainable Energy Community, led by the Dingle Hub/Molteic, has commissioned a feasibility study on the Development of Anaerobic Digestion in the Dingle Peninsula with the aim to become one of the leaders in the development of the rural bioeconomy in Ireland. The study, funded by the LECO project and Gas Network 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.

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. Our objective 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. The study will apply circular economy thinking, considering organic wastes as a valuable resource which when combined with agricultural by-products and feedstocks, can be turned into a high-quality fuel – enabling new economic opportunities locally.

B. Current Status

The study started in May 2019 with a comprehensive assessment of the biomass resource available in the peninsula to determine their practical potential for biogas, their spatial distribution and cost. This report presents the results of the feedstock analysis in Chapter IV. A workshop was organised on 3rd July with key stakeholders, with a view to discuss the biogas potential on the Dingle Peninsula and to define a shared vision for anaerobic digestion in the framework of the Dingle Peninsula's transition to a low carbon and sustainable energy community. It also helped identify the core principles which should govern its development. This shared vision and core principles are discussed in Chapter III.

C. Next Steps

The next step will be to investigate and compare suitable technical biogas pathways, from feedstock to energy end-use, considering their environmental, social and economic impacts. This will lead to conducting the preliminary design and a lifecycle cost analysis of anaerobic digestion projects, deemed as being most beneficial. In addition, a multi-criteria spatial analysis will be undertaken to identify optimal locations for anaerobic digestion plants.

The feasibility study, planned for completion by January 2020, will also recommend business and financing models appropriate for community participation, in consultation with key stakeholders. It will provide the community with a roadmap for the deployment of anaerobic digestion systems on the Peninsula and guide the next steps for project development.

II. The Study Area

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.

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

A. Introduction

In this chapter, 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.

B. 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 a EU RE Directive target of 16% by 2020. The biggest share of our 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.

C. 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. According to the analysis, the projected achievable out-turns for these targets by 2030 are 34.96% and 36.34% respectively (Kevin Curtin, 2019).

Table *1* shows the distribution of final energy usage within the study area in 2016, sector by sector, and Figure 2 shows the fuel mix. Overall, the energy expenditure in the peninsula was estimated at 38.5 million euro for 2016.

Table 1: Sectorial final energy usage for 2016.[1]

Sector/User Group	Final Energy Consumption (GWh)
Residential	149.32
Non-Residential	38.24
Municipal and Local Authority	2.95
Fisheries and Agriculture	23.68
Transport	101.33
TOTALS	**315.52**

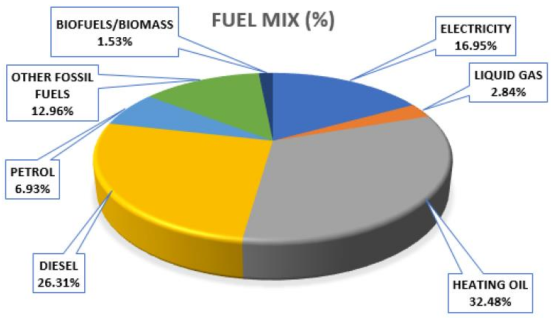


Figure 2: Final energy consumption by carrier in 2016.[2]

Figure 3 is a map showing the geographical distribution of final energy use within the study area.

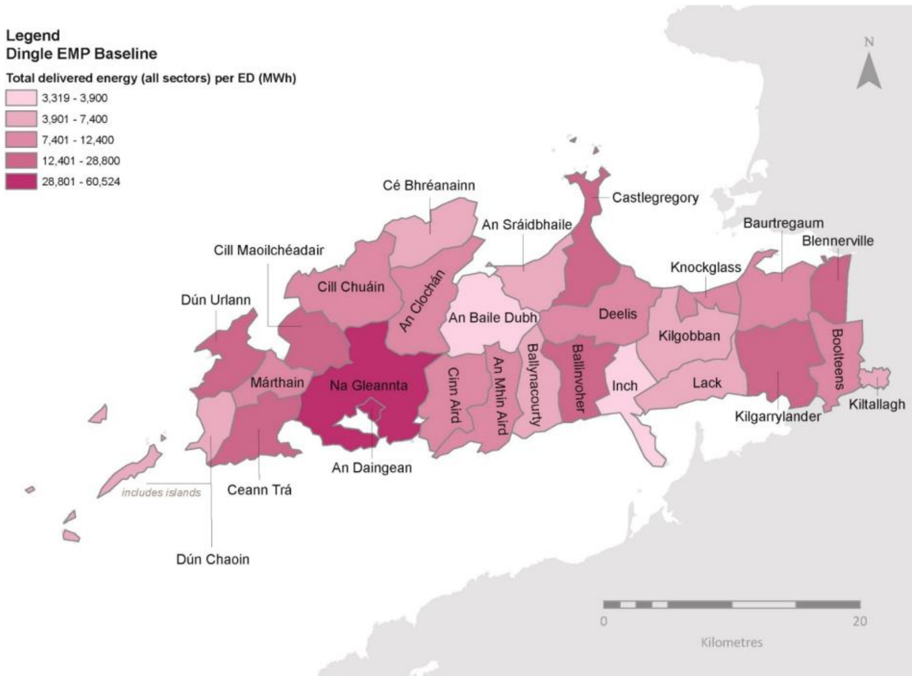


Figure 3: Map of total energy delivered per ED in Dingle.

[1] Seasonality-adjusted data.

[2] A seasonality-adjusted pie-chart of the Dingle Peninsula's fuel mix was not produced by the EMP. The non-seasonality-adjusted pie chart is displayed here.

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.

D. 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 CO2 emissions were 1.22 million tonnes of CO2 per year (tCO2/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/yr 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.

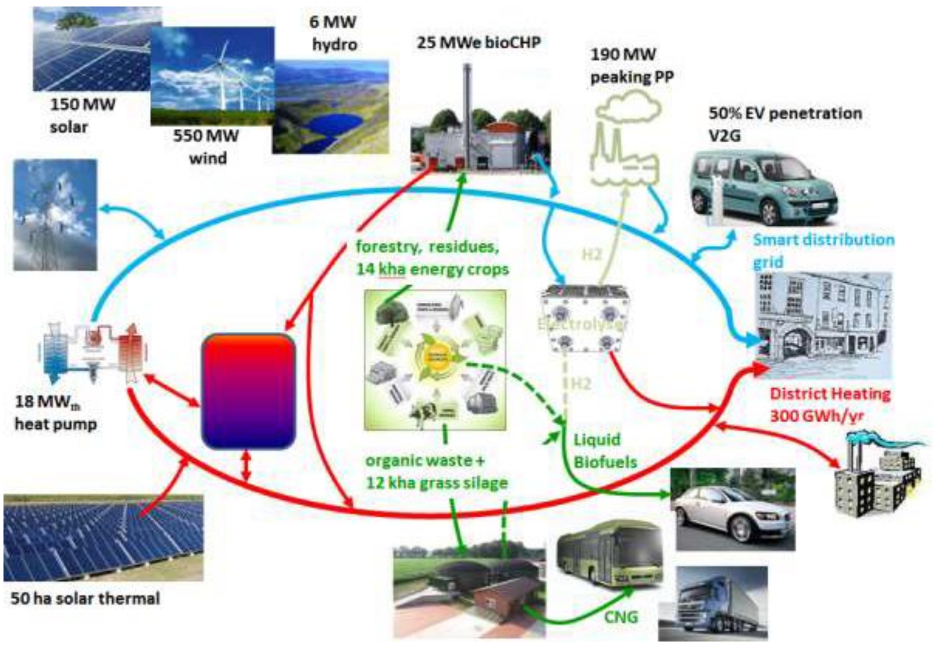


Figure 4: Kerry's Renewable Energy Roadmap - recommended energy system.

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 feedstock and create new sources with energy crop cultivation.

E. Vision & Key Principles for Biogas Development in Dingle

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 prospect 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 captured by 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.

IV. Anaerobic Digestion Feedstock 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 IV.C focuses on non-agricultural feedstocks in the peninsula – municipal wastes and industrial wastes. Section IV.D gives a brief summary of the key findings. Table 2 below shows the characteristics of feedstock used in this report. While LCH4/kgVS (litres of methane per kilogram of volatile solids) is the usual method of defining the biomethane potential of feedstock, LCH4/kgDS (dry solids), or the equivalent measurement of Nm3CH4/tDM (normal cubic metre of methane per tonne of dry matter) is used in this report for ease of understanding.

Table 2: Characteristics of feedstock.

Feedstock	DS	VS	VS/DS	Specific Methane Yield	Specific Methane Yield
	(%wwt)	(%wwt)	(%)	(LCH4/kgDS)	(LCH4/kgVS)
Grass Silage	23	20.93	91%	364	400
Cattle Slurry	7	5.25	75%	107	143
Food Waste	30.6	27.0504	88%	242	274
Sewage Sludge (Cake)	17			120	
Fish Waste	32.2	17.8	55%	216	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. There is a marginal amount of slurry captured from the milking parlour.

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

Agriculture is dominated by three farming enterprises in Dingle[3]: cattle rearing and finishing (47%), dairy farming (18%) and sheep farming (17%). The remaining 18% is comprised of land used for mixed grazing and mixed crops [9]. There were over 25,237 heads of cattle in 2010[5] 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.

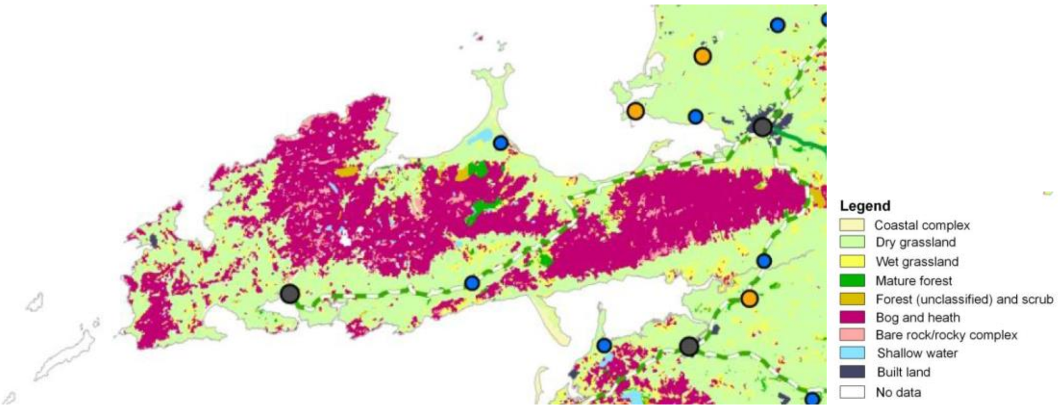


Figure 5: Vegetation type and land cover [9].

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

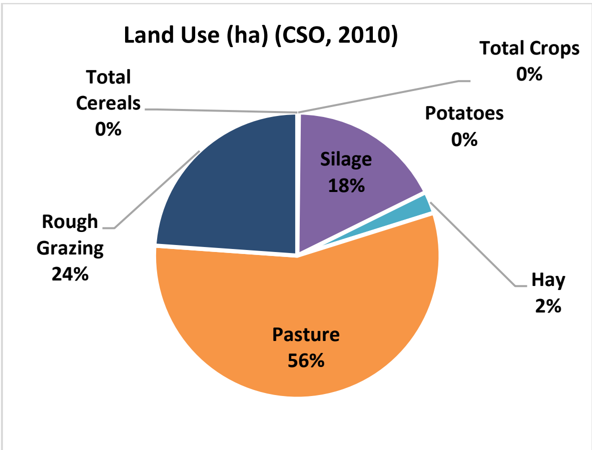


Figure 6: Distribution of land use in Dingle

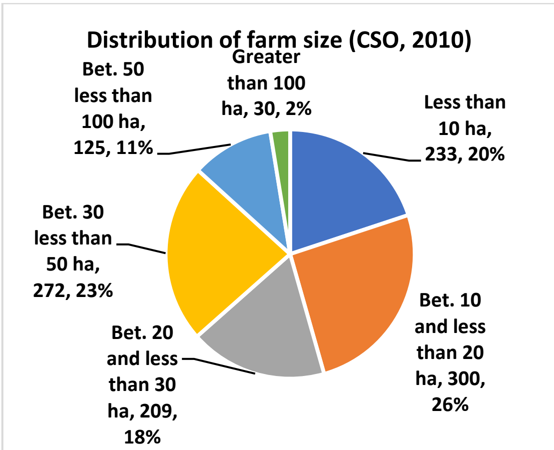


Figure 7: Distribution of farm size in Dingle

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:

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[3] 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.

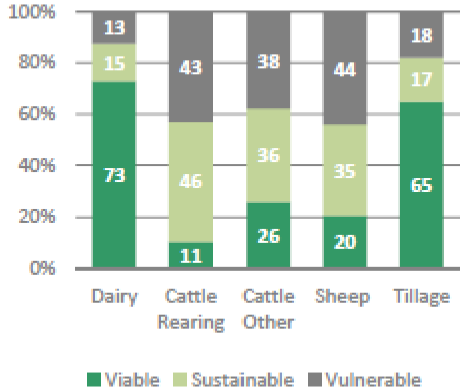
[5] While there are nationwide statistics available for livestock numbers, the latest data available for the Dingle Peninsula specifically is the 2010 CSO Agricultural Census.

a) Gross margin by farm enterprise and direct payment contributions to family farm income in the South Region[6] [11]:

Regional Farm Structure 2018 - South				
	Cattle Rearing	Cattle Other	Dairy	Sheep
UUA (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%

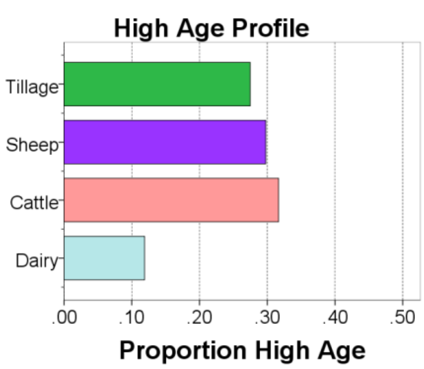
The table above indicates that, in the South Region, dry cattle farms are highly dependent on Direct Payments for their subsistence. Single Farm Payments constitute about 60% of the Direct Payments on dry cattle farms and 78% on dairy farms. At national level, the average suckler farm with a FFI of €8,318,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

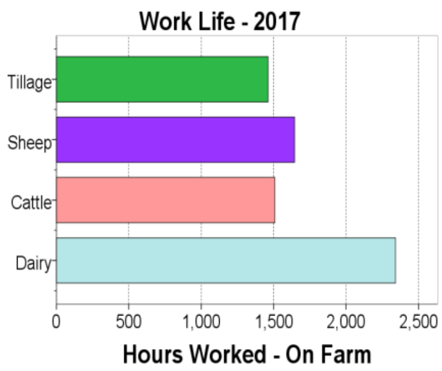
b) Proportion of farms viable, sustainable and vulnerable per enterprise type [11]:



In the 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]:

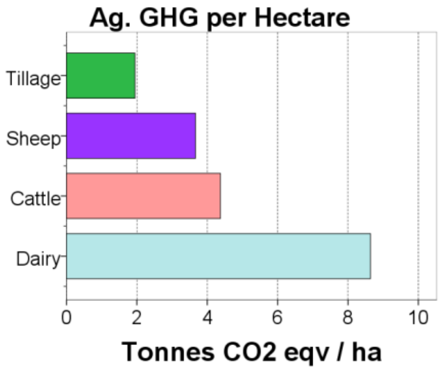


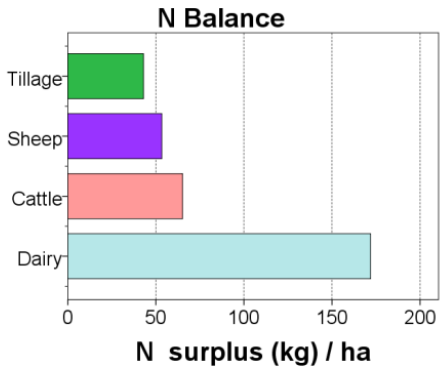


[6] The South Region is defined by the Nomenclature of Territorial Units for Statistics (NUTS) as a group of the following counties: Carlow, Clare, Cork, Kerry, Kilkenny, Limerick, Tipperary, Waterford and Wexford [28].

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.

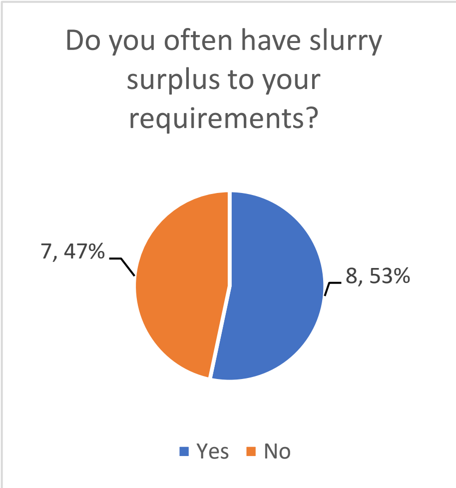
3. Field survey of farmers in the study area

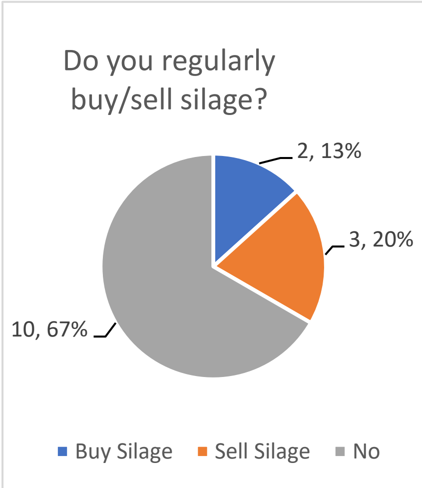
A semi-formal survey was designed by the team to ascertain the potential feedstock availability from the farming sector in the study area. The survey was specifically aimed at dairy farmers or dry cattle farmers, farming more than 50 hectares as this group of farmers was considered most likely to participate 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 3 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 3: 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 (m3)	*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	*658*	*450*	*850*
Estimated bale tonnage	*412*	*72*	*855*
Given tonnage	*600*	*600*	*600*
Estimated total tonnage	*684*	*180*	*1,010*
Estimated DM tonnage	*156*	*41*	*232*
t DM / ha / a	*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.

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 tDM/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 Nm3 CH4/tVS (tonne of volatile solid), at 91% VS per dry matter weight. This is equivalent to 364 Nm3 CH4/tDM.

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 tDM/ha
b) All land under pasture will yield 10 tDM/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 tDM/ha,yr as per the survey results in Table 3 to 10 tDM/ha,yr.
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 tDM/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 IV.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 tDM/ha (in line with survey results in Table 3).

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 4 below. The DM content of slurry was taken to be 7%. The biomethane potential of slurry was taken to be 107 Nm3 CH_4/tDM. The practical biogas potential from slurry considers that slurry loses (10%) of gases during storage. The figures in Table 4 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 4: 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 5: Analysis of potential agricultural feedstocks.

	Theoretical Silage Potential		Practical Silage Potential				Practical Slurry Potential
	(tDM/yr)		(tDM/yr)				(tDM/yr)
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 (tDM/yr)	**197,810**	**61,990**	**12,398**	**15,825**	**47,474**	**75,697**	**9,378**
Total (Nm3/yr)	**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 waste operator in the study area reported transport costs of €50 per tonne of food waste to treatment centres. If a biogas plant was in the region, this could reduce those costs to waste operators in the Dingle Peninsula.

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 [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]. The same food waste production per person factor as above was used. A DM content of 30.6%, and a biomethane potential of 242 Nm3/tDM 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 tDM/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 tDM/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 6: Food waste production in the Dingle Peninsula.

Food Waste Feedstock	Theoretical (tDM/yr)	Practical feedstock potential (tDM/yr)	Practical biogas potential (Nm3/yr)
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 7.

Table 7: Wastewater treatment plant sludge production in Dingle.

Plant Location	Sludge Production (tDS/yr)
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 Nm3/tDM.

b) *Results*

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

Table 8: Sewage sludge production in the Dingle Peninsula.

Sewage Sludge Feedstock	Theoretical (tDM/yr)	Practical feedstock potential (tDM/yr)	Practical biogas potential (Nm3/yr)
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. Using fish waste would also provide the digestate produced from grass and slurry with nutrients that are not present in the land. 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. Further research is being conducted in Dingle on this topic. A DM content of 32%, and a biomethane potential of 216 Nm3/tDM was used [22].

b) *Results*

Table 9: Fish waste in Dingle harbour.

Feedstock	Quantity	Quantity	Biomethane
	(t)	(tDM)	(Nm3 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 10 below shows the estimated slaughter number of cattle and sheep on the Dingle Peninsula.

Table 10: 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 11 below shows the estimated weight of inedible material from livestock slaughtered.

Table 11: 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. Offal will be further considered as AD feedstock in the pathway analysis as part of Work Package 3 of this Feasibility Study.

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/tDM [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 the bacterial process which happens 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 unviable, seaweed was not quantified as a feedstock for an AD plant in the Dingle Peninsula. More can be read on marine algae for AD plants in **Appendix C – Potential for Algae**.

D. Summary of biogas feedstock analysis

Table 12: Summary of biogas feedstock analysis.

Feedstock	Theoretical Resource		Practical Resource	
	tDM/yr	Nm3 CH4	tDM/yr	Nm3 CH4
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	255,192	1,176	255,192
Total	**272,109**	**97,213,788**	**86,587**	**29,639,819**
Total (MJ)		**3,596,910,156**		**1,096,673,288**
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 tDM/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.

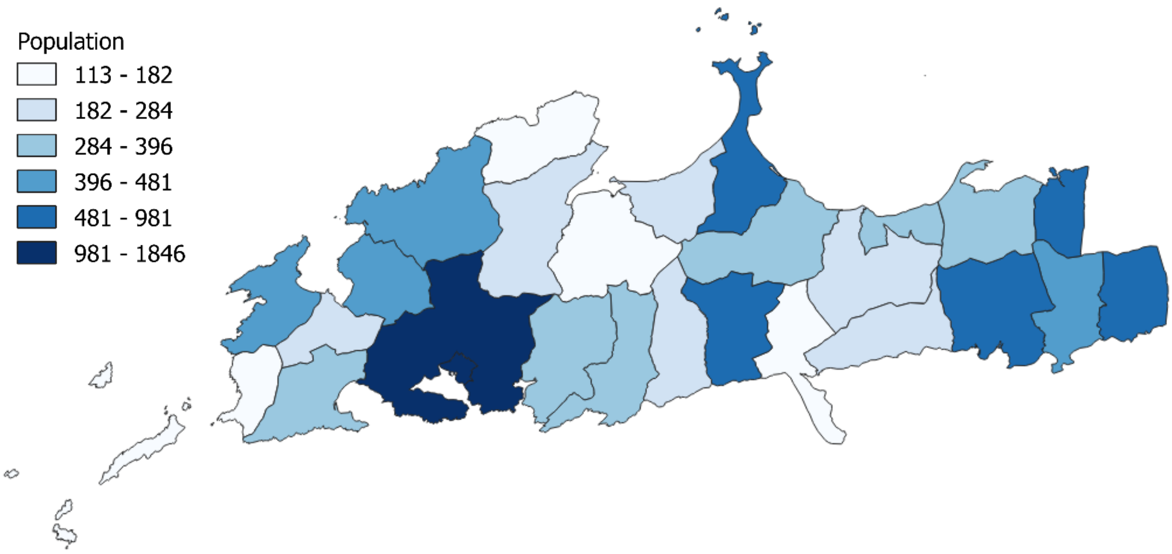
Generally, it is clear from the above analysis that agricultural feedstocks will play an important role in the production of biogas on the peninsula. While with a much smaller potential (1% of total potential), municipal and industrial feedstocks in the region would also play a part, as they typically 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.

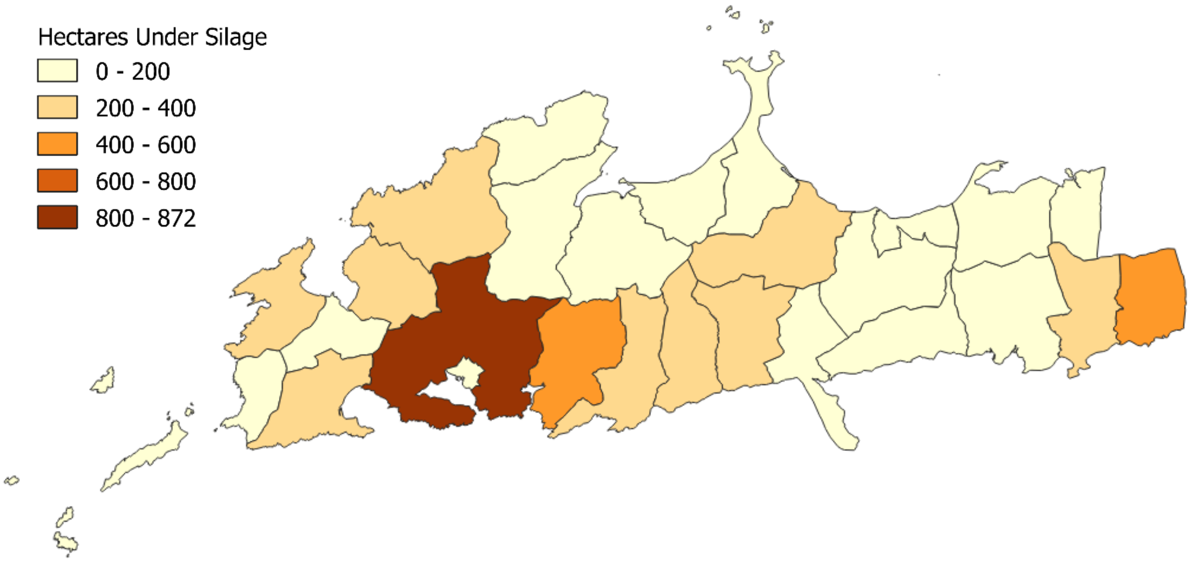
The seasonality of feedstocks must also be taken into consideration. Food waste and sewage sludge production on the peninsula are significantly seasonal due to the large influx of tourists in the summer months. Equally, the seasonality of slurry and silage harvesting and storage will impact the potential material flows into AD plant(s) in the study area. This will be researched further as part of Work Package 3.

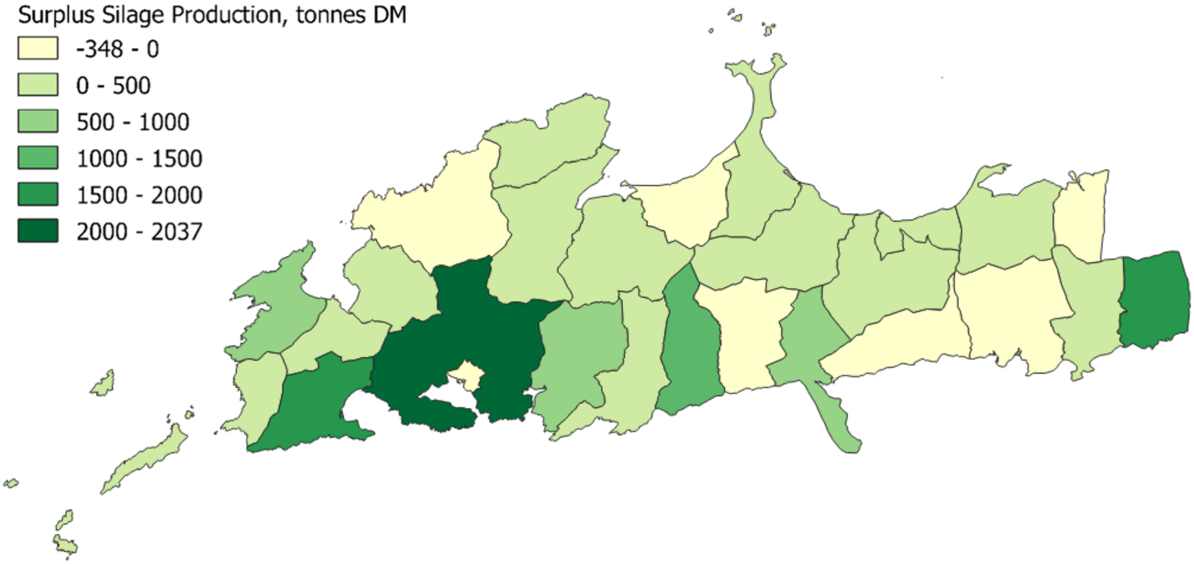
Finally, it is worth noting that the practical AD feedstock potential in the study area estimated at 32.6 million Nm3 of methane (CH_4) in above has an energy content of 304.6 GWh, compared to 315.5 GWh of final energy usage in the study area according to Dingle's EMP. This is promising in terms of the 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.

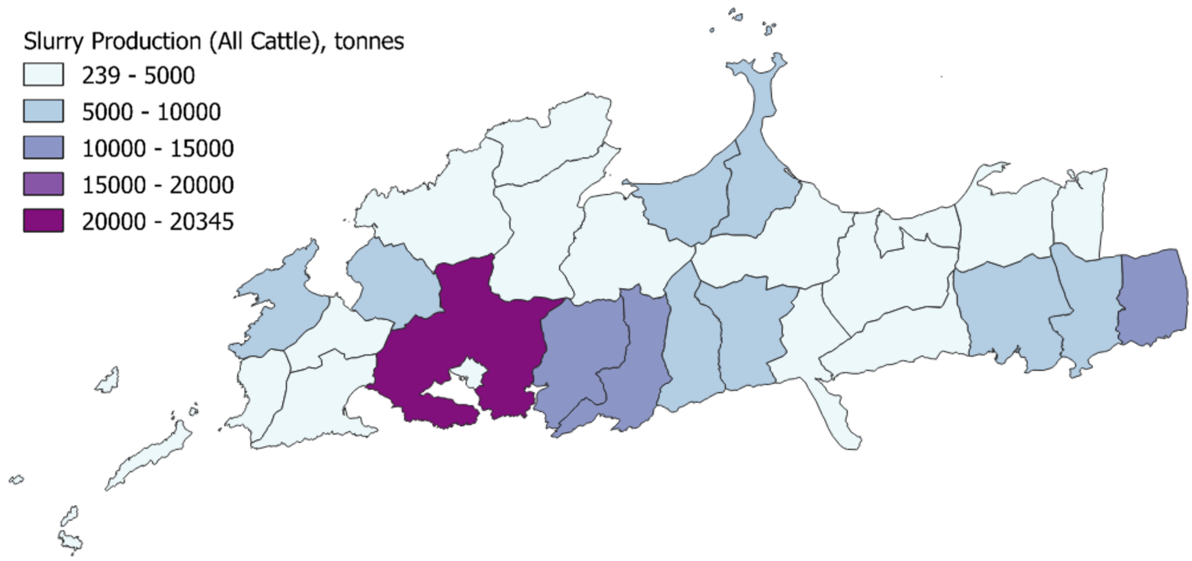
E. Spatial Analysis of Biogas Feedstock

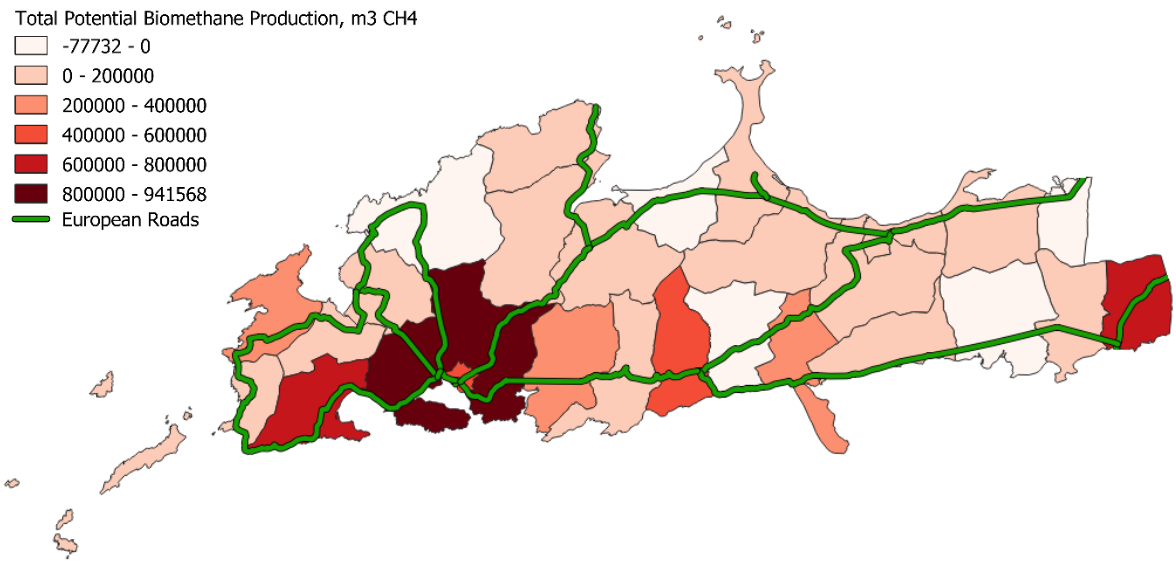
Census data acquired from the CSO gives information for every electoral division (ED) in Ireland for population (Population Census, 2016) and for hectares under silage and number of livestock (Agricultural Census, 2010). The CSO provide GIS data in conjunction with the census data. This data was mapped 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.




Hectares Under Silage
0 - 200
200 - 400
400 - 600
600 - 800
800 - 872


Surplus Silage Production, tonnes DM
-348 - 0
0 - 500
500 - 1000
1000 - 1500
1500 - 2000
2000 - 2037


Slurry Production (All Cattle), tonnes
239 - 5000
5000 - 10000
10000 - 15000
15000 - 20000
20000 - 20345


Total Potential Biomethane Production, m3 CH4
-77732 - 0
0 - 200000
200000 - 400000
400000 - 600000
600000 - 800000
800000 - 941568
European Roads

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VI. Appendix

A. 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 / gahmna diúil atá ar do ghabháltas?

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

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?

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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.

B. 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**

C. 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} yr^{-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} yr^{-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).

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