Sustainability of Biomethane Production in Ireland

Exploring how Ireland can deliver a sustainable, agriculture-led biomethane industry

October 2021

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The core aim of this report is to assess whether Ireland can develop an environmentally sustainable biomethane industry without creating unintended negative consequences

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INTRODUCTION

The Dowth Farm & Research Facility in Meath, a Global Lighthouse facility ("Dowth"), supported by KPMG Sustainable Futures, has been commissioned by Gas Networks Ireland ("GNI") to produce an independent report assessing the environmental sustainability of a proposed national agricultural led biomethane industry in Ireland. The proposed national biomethane industry consists of a network of rural-based farm-scale anaerobic digestion ("AD") plants producing biomethane for injection into the natural gas network as well as a network of food-waste AD plants.

While biomethane industries have been rolled-out across Europe, Great Britain and Northern Ireland at significant scale over recent decades, its deployment in Ireland has been very limited to date, with only a handful of commercial scale AD plants developed. Although AD is considered a proven technology, there have been a number of environmental and economic concerns cited which have hampered its development and policy support in Ireland.

This report seeks to provide scientific analysis and real-world data on the key questions and knowledge gaps concerning the sustainability of an Irish agricultural led biomethane industry. The core aim of this report is to assess whether Ireland can develop an environmentally sustainable biomethane industry without creating unintended negative consequences.

The research and evidence utilised in this report has been drawn from existing local and international scientific data and research into biomethane production and supplemented with new research, primarily from academic researchers within Dowth, as well as through consultation with relevant experts within Teagasc, the state agency focused on research, advisory and education in agriculture, horticulture, food and rural development in Ireland.

This report provides evidence that the development of a sustainable biomethane industry in Ireland is technically feasible and so long as it is developed in a co-ordinated manner, can avoid any negative unintended consequences. As such, a number of proven methodologies have been provided to drive the rollout of a biomethane industry whilst ensuring continued agricultural productivity and improved environmental sustainability.

MARKET CONTEXT

The base case volume of biomethane deployment has been developed in line with the objectives of the Government's National Energy and Climate Plan 2021-2030 ("NECP") which sets an indicative target for indigenous biomethane at 1.6 TWh by 2030, which is to be reviewed again in 2023.[1] To provide further granularity of biomethane deployment over time, we have then referred to a deployment model through a scheme known as Project Clover ("deployment model"), which is an industry-led collaboration between a number of leading Irish agri-food companies seeking to establish a national biomethane industry.

It is worth noting that the Government's Renewable Heat Obligation consultation, published in August 2021, contemplates a range of renewable heat energy targets up to 5.5TWh, which are significantly more ambitious than the current NECP level. As outlined on page 35 of this report, we conclude that there is sufficient capacity from improved efficiency across land already in agricultural production to produce up to 9.5TWh of biomethane, meaning these higher levels of ambition remain feasible.

[1] The Department of the Environment, Climate and Communications recently opened a consultation on the potential introduction of a new Renewable Heat Obligation ("RHO") which includes three different levels of ambition of 3% (equating to c.1.6TWh renewable heat by 2030), 5% and 10%

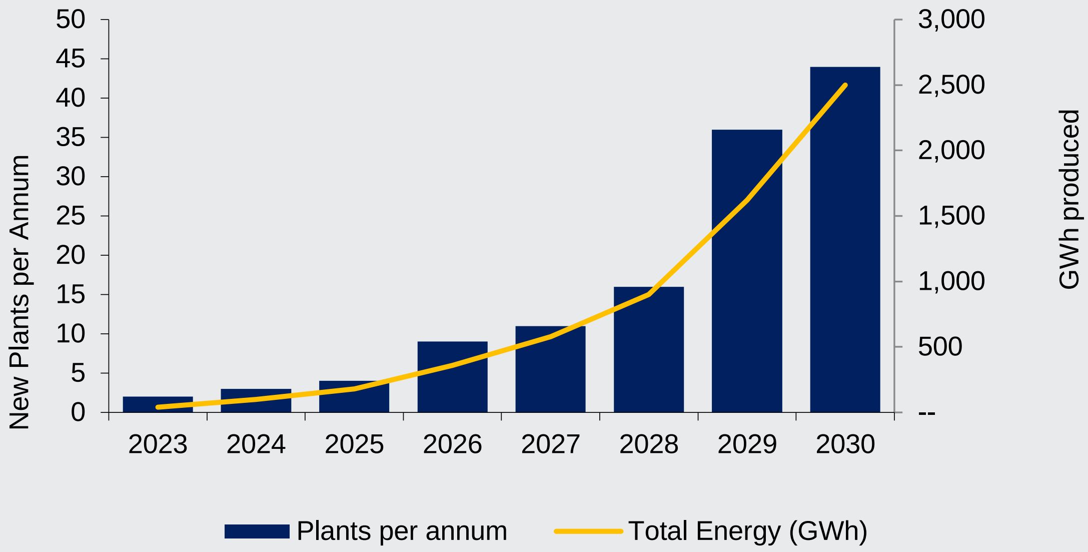

FIGURE 1 POTENTIAL GENERATION CAPACITY ROLL-OUT MODEL AS OUTLINED BY PROJECT CLOVER

The deployment model assumes the roll-out of 125 x 20 GWh farm-scale biomethane AD plants by 2030, fed primarily on agricultural materials and farm wastes in line with current government targets

The deployment model assumes an agricultural-led approach, utilising a mixture of plant-based feedstock and animal wastes. Under the above deployment model, 2.5TWh biomethane would be produced by 2030 requiring c.125,000 acres of agricultural land (1.1% of Ireland's agricultural land base) to produce the required 2.6 m (wet) tns of plant-based feedstock (equivalent to 5% of the current volume of grass silage produced annually in Ireland), alongside 1.75 m tns of slurry (equivalent to 4% of the slurry currently captured in Ireland). The volume of biomethane gas produced under this model would be sufficient to displace 15% of current commercial and industrial natural gas consumption.

The deployment model assumes the AD plants are deployed nationally, with plants primarily connected through a remote virtual pipeline of compressed gas tankers transporting biomethane from rural AD locations to centralised grid injection points, although there is scope for larger plants (40 GWh and larger) to have direct connection to the gas network for direct biomethane injection into the grid.

The following section provides a summary of the report's key findings, articulated through responses to key questions and challenges which have been raised by stakeholders:

- **Does the development of an Irish agricultural-led biomethane industry align with current and emerging policy direction?**

Our review has found that the development of an indigenous agricultural-led biomethane industry demonstrates strong alignment with key European and national environmental and energy policies.

Europe aims to be net zero by 2050 - enshrined in the first ever EU Climate Law. The development of a biomethane industry can contribute to this target as it displaces emissions from natural gas, slurry and chemical fertiliser production. Integrating slurry as feedstock to AD plants avoids the emissions from slurry storage and spreading and instead captures for use in energy production – simultaneously supporting farmers in complying with the Nitrates Directive. In addition, digestate (which is a by-product of the AD process) can be a key ingredient for the production of organic fertilisers, which have the ability to displace chemical fertiliser. This can avoid emissions associated with chemical fertiliser production, which can be up to 5.3 $kgCO_2e/kg$ N[2] depending on the fertiliser type. The analysis of the different farming scenarios shows with the adaption of multispecies swards ("MSS"), multiple sustainability actions can be improved on farm, such as increased grass output, while decreasing absolute emissions and improving biodiversity.

Furthermore, as outlined in **section 2**, a sustainable biomethane industry would directly contribute to the aims of the EU Methane Strategy. In addition, the uptake of improved management practices incorporating MSS and the displacement of chemical fertiliser with digestate biofertiliser each contributes to a number of the key goals set out in the EU Farm to Fork Strategy, the EU Circular Economy Action Plan and the EU Biodiversity Strategy.

At a national level, a biomethane industry could support the targets set out in the Climate Action and Low Carbon (Amendment) Bill which aims to put Ireland on a trajectory towards net zero emissions by 2050 and to achieve a 51% reduction in emissions by 2030. Finally, the development of biofertiliser as a by-product of the AD process could contribute to a number of the Ag-Climatise Actions (particularly Actions 1,9,12 and 20) and key ambitions set out in the Programme for Government.

- **Can Ireland grow sufficient incremental feedstock to supply a biomethane industry without impacting current animal feed dynamics?**

In order to produce the annual volume of biomethane under the deployment model (2.5TWh), the AD plants would collectively need to source c.0.6m tnDM[3] of feedstock per annum. This could include grass silage, or alternative feedstocks such as MSS. At present Ireland produces c.31m tnDM of grass per annum (of which 12.5m tnDM is harvested as silage, and the balance grazed or unharvested). As such the annual requirement represents an increase of c.5% per annum of silage production, or 2% of overall grass production.

Our review of the available evidence strongly suggests that Ireland has both the technical capacity and capability to produce this additional 5% of feedstock to supply an indigenous biomethane industry. In total we have calculated that Ireland could produce an additional 3.1m tnDM of feedstock from improved efficiency across land already in agricultural production without impacting feedstock currently used for livestock or utilising biodiverse or high nature value ("HNV") farmland - which is extensively managed farmland that has high biodiversity, enhanced ecosystem services and societal value. This volume of feedstock would enable the production of c.9.5 TWh of biomethane per annum which we consider conservative since this doesn't include biomethane gas potential from food waste or tillage crop rotations.

This analysis suggests that the potential opportunity is in excess of the current NECP targets, and subject to successful roll-out of the technology, could allow increases in the NECP targets in the future.

As outlined in our case study, the Northern Ireland ("NI") AD sector, which has been operating for c.10 years, currently consumes an equivalent of 9% of historic NI annual silage production, which suggests an overall quantum of 5% in ROI is credible.

We note that our estimate of 3.1m tnDM is within the range identified by all key previous studies on this topic including O'Shea (2017), McEniry (2013), and the European Commission.

In calculating our figure of 3.1m tnDM, we have considered two key components - availability of suitable land to grow the incremental feedstock, and the technical feasibility to grow increased yields on this land:

[2] Timonen et al. (2019) LCA of anaerobic digestion: Emission allocation for energy and digestate

[3] Teagasc 2018 Report (assuming a 25% DM content of grass)

AVAILABILITY OF SUITABLE LAND

CSO data shows that there is approximately 4.5m ha of available grassland in Ireland, of which we have calculated that c.768k ha is available and suitable to grow incremental feedstock for a biomethane industry. This land bank is primarily land currently used for beef cattle grazing or beef sector silage production which has not been optimised for land fertility or crop yield. This figure is derived by subtracting areas of High Nature Value ("HNV") farmland and Special Areas of Conservation i.e. bogs and high organic soils, commonage and rough grazing areas and grassland devoted to dairy enterprises from the total grassland area. We have then sensitised down this resulting figure by 30% based on CSO data and the Teagasc National Farm Survey to exclude a portion of small holdings that may not be willing to change practices. Based on empirical and practical experience (including 6 years of real-world data) at Dowth, it is understood that sustainable growth and utilisation of pasture on a wide variety of farms that are below average production is possible with adequate measurement and management of soils (fertility and biology) and pasture (management and sward type).

Under the assumed model, this identified land would remain as grassland, however, be optimised such that each hectare produces on average 10tnDM/ha rather than the current 6tnDM/ha, with the incremental yield utilised as feedstock for AD plants. This increase is modest and readily achievable when the correct management techniques are implemented. The financial outlay per hectare to achieve this yield increase ranges from €449 / ha in Year 1 and 3 when lime application is required to €203/ ha in Year 2, 3 and €295/ ha in Year 5 when a smaller application of lime is required. From Year 5, maintenance levels of lime, phosphorus and potassium will be required. Digestate will be able to supply the phosphorus and potassium requirements. Lime will need to be applied at maintenance levels of approximately 5 tn/ha every 3 to 4 years - costing approximately €130/ha.

In order to deliver the volume of feedstock required under the deployment model, Ireland would need to see c.20% of this 768k ha landbank adopting land improvement techniques over the coming decade. The Teagasc National Farm Survey shows that 18% of farms in the cattle enterprises are deemed to be viable enterprises[4], we expect farmers would be generally receptive to considering alternative enterprises and implementing land improvements to increase profitability and improve the environmental performance of the farm. This expectation is supported by experience from Dowth, which has been working with a significant number of Irish farmers to implement similar land optimisations.

As a further example of market appetite, a 2020 tender exercise by Teagasc to source grass silage for its own AD plant in Grange, Co. Meath saw it 12 times oversubscribed, with farmers attracted by the long-term, price certain contracts available.

Although outside the scope of this report, it should be noted that there is 253,000 ha of tillage land in Ireland. This can provide extra forages for AD plants in localities through the use of temporary lays and growing energy rich crops such as maize or sugar beet for AD plants. Locally situated AD plants could provide an alternative market for tillage farmers and will allow them to vary their rotation of crops, which will have positive impacts on agronomy in terms of disease pressures and on soil carbon through the use of temporary lays and better rotations. This will impact on farm profitability through diversification. Energy crops will fit into a rotation of crops on a tillage farm, they are annual crops, so their volume and availability will vary from year to year.

We note the ongoing work by SEAI has indicated a lower level of land available for growing feedstock for AD, with a key difference being the assumed availability and desirability of permanent pastureland to deliver AD feedstock. While analysis from Dowth has successfully demonstrated that permanent pastureland can be utilised in an environmentally sustainable way to produce incremental volumes, we note that draft findings from the SEAI suggests that there is broadly sufficient feedstock available to deliver the 2.5 TWh envisaged under the deployment model.

IMPROVED CROP YIELD

Assuming there is a suitable quantity of land available to produce incremental feedstock, the next question is how feasible it is to increase the average yield per hectare.

4 Teagasc National Farm Survey 2019 Sustainability Report

Based on Teagasc surveys, the current average grass yields for the non-dairy sector is 6-7 tnDM/ha/yr. Teagasc launched Grass10 with a target of achieving 10 tnDM/ha/year grass utilised – equating to c.12-13 tnDM/ha/yr (assuming livestock consume and convert over 70% of this to meat and milk protein). In its Grass10 Report[5], Teagasc noted that the "701 grassland farmers that participated in the 42 Grass10 courses in 2019/20 increased grass production by 1.8 tonnes DM/h", proving that it is possible to increase grass yield simply through proven land management techniques.

This evidence is further supported by research at Dowth, which has showed that utilising MSS rather than just ryegrass can increase yields from 10 tnDM/ha/yr to 12-13 tnDM/ha/yr in addition to reducing the fertiliser requirement by approximately 58% (see **section 6**). Such increased yields can be achieved primarily by (1) correcting soil nutrition deficiencies; (2) installing or upgrading grazing infrastructure on the farm and (3) sowing MSS.

NORTHERN IRELAND CASE STUDY

While our research confirms the ability to produce the incremental feedstock required for an indigenous biomethane industry, stakeholders have raised concerns it could disrupt the current animal feed dynamics and pricing. In considering this issue, we have looked to the NI market which has already developed a mature AD sector of equivalent scale to that proposed in Ireland.

As outlined in the graph below, NI deployed c.90 AD plants between 2011 and 2017 - the vast majority of which were agricultural AD plants fed on a mixture of silage and slurry. Despite these plants consuming an incremental c.700,000 tns of grass silage annually (c.8% of historic silage production), over the same period the number of dairy cattle grew by c.12%, while overall cattle numbers increased by 4%. This would suggest that the AD sector did not lead to a constraint on cattle expansion.

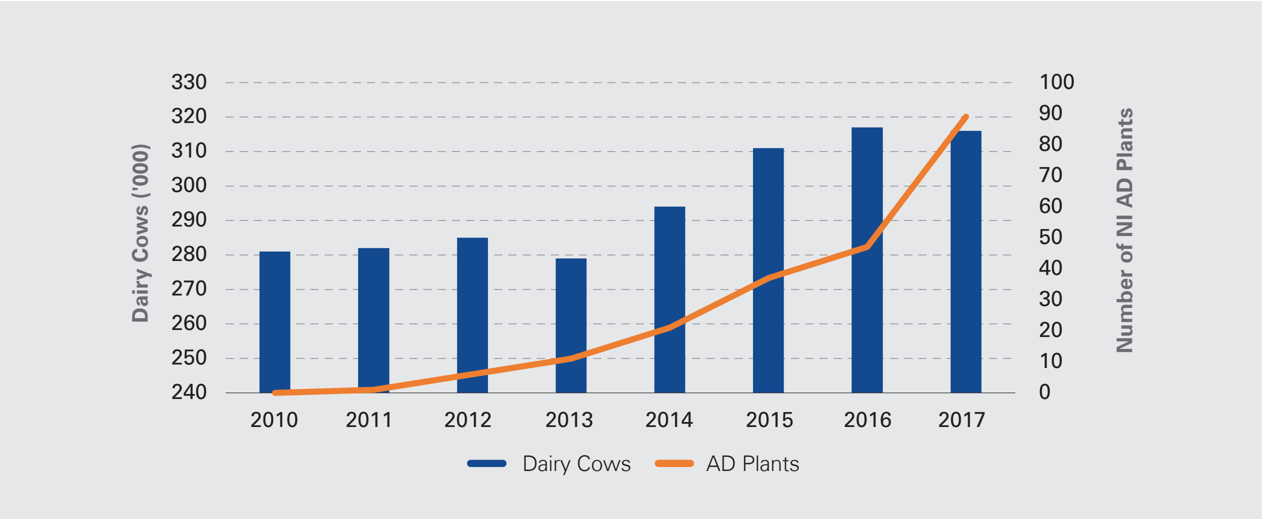

FIGURE 2 NORTHERN IRELAND AD SECTOR, SOURCE: DAERA STATISTICAL REVIEW OF AGRICULTURE IN NI

The Department for Agriculture, Environment and Rural Affairs (DAERA) statistics show that the amount of farmland dedicated to grass increased by over 25,000 ha over the same period, including an 18% increase in land with grass less than 5 years old. This suggests a material programme of reseeding and land optimisation, which is in line with anecdotal evidence of AD plant owners achieving increased grass yield through improved crop management.

We note that there was also an increase in cattle feed utilisation over the period, indicating that the increased cattle numbers were supported by a combination of increased grass production and grain feed.

5 Teagasc Grass10 Report 2017-2020

While there have been some examples of very localised competitive disruption, overall silage pricing doesn't appear to have been impacted by the development of the AD sector. We do note that average conacre prices have risen over the period, although this appears to have been driven primarily by an increase in demand for grazing land (presumably for the increased cattle numbers), since overall land utilised for grass silage production did not increase over the period.

- **Would the development of a biomethane industry result in an intensification of agricultural activities, including an increased use of chemical fertilisers and pesticides?**

Given that a key objective of developing an indigenous biomethane industry would be to assist in the decarbonisation of Ireland and increased environmental sustainability within the agricultural sector, it is vital that activities associated with producing AD plant feedstocks don't themselves lead to an increase in farm intensification such as increased use of chemical fertiliser.

Based on extensive research at Dowth, researchers have concluded that although there would be a short-term increase in fertiliser applications as landowners build and optimise soil fertility, once the initial fertility deficit is addressed, it is possible to operate the land with materially lower carbon inputs, while producing significantly enhanced yields, resulting in a reduced overall carbon lifecycle on the land. The soil fertility deficit is one of lime, phosphorus and potassium. With the use of MSS after Year 1 all nitrogen requirements (70- 90 kg/ha) are met with the digestate applications from the AD plant. Nitrogen applications will not need to increase on lands used to grow forage for AD plants. This ensures a very circular system for nitrogen applications.

In the short term (approximately 5 years), more fertiliser and lime inputs will be needed to build soil fertility. This requirement is not just to produce incremental forage for AD plants, but is necessary for any agri-based practice on land with sub-optimal fertility. Phosphorus and potassium fertilisers are required in the short term to increase soil nutrition. Research from Teagasc notes that just 21%[6] of Irish agricultural soils are at optimal fertility. This leaves a nutrition gap that must be filled by artificial fertiliser and lime to get the soil fertility to an optimum level (target index 3). In the short term, more fertiliser and liming will be required to get Irish soils to this optimal index in order to meet increased yield requirements. O'Donnell et al.(2021)[7] calculated that Irish soils currently require 95,500 tns of phosphorus per annum to optimise production. If imports and indigenous sources are added together, they total 70,956 tns of phosphorus applied annually. This represents an existing deficit of 24,544 tns of phosphorus that is required for optimal agricultural production in Ireland.

On average, transforming soil to an optimal fertility level requires between 35-50% more phosphorus and potassium fertiliser use. These are necessary agronomic inputs and cannot be avoided. However, there is an instant pay-off resulting from the higher yields achieved as a direct result of increased fertiliser application. Once soils have reached optimum fertility, only maintenance fertiliser will be required and forage yields will have stabilised at higher productivity rates - c.10.5 tnDM/ ha compared to the national average of 6 tnDM/ha for lower soil fertility rates. Digestate can be used as a biofertiliser to displace chemical fertiliser use and promote the aims of a circular bio-based economy. If the digestate has sufficient nutrient quality and nutrient availability it may be suitable as a maintenance fertiliser.

Following the introduction of MSS at Dowth, nitrogen use was reduced by 58% and phosphorus use declined by 42% when optimal conditions were reached (after approximately 5 years), whilst improving yields by 2-3 tnDM/ ha. The same effect was observed for lime applications – whereby corrective lime applications were applied on a whole farm basis in 2013 and 2015 but only partial applications were required in 2017 and 2019. No lime applications have been applied since and currently none are required in the near future. Once optimal conditions are met, the need for inputs is greatly reduced.

This report includes a partial life-cycle analysis ("LCA" or the "model") 'The Dowth Multispecies Swards Model' that captures emissions from livestock, animal manure storage and application, fertiliser use and carbon from electricity and diesel on farm. The model was created to assess and quantify the impacts of additional production on a typical beef farm. The model's fundamentals are that: (1) there is additional productive capacity on Irish beef farms; (2) the beef herd is maintained; (3) soil fertility is optimised; and (4) carbon sequestration is accounted for. The model assessed three scenarios: Scenario 1: Sowing a perennial ryegrass sward; Scenario 2: sowing an MSS system; and Scenario 3: Hybrid system – 50% MSS for grazing by the cattle and hybrid ryegrass/ red clover mix for sale to the AD facility. The model aims to increase the production of forages in excess of the national herd's requirement by correcting soil nutrition. Nitrogen and lime application are the predominate sources of emissions

6 Teagasc Soil Fertility Report 2020

7 O'Donnell et al. (2021) An overview on deficit and requirements of the Irish national soil phosphorus balance

in the scenarios. Digestate will be used as the primary nutrition source first and foremost in all cases which helps to lower emissions. In the three scenarios assessed in this report, Scenario 2 MSS decreases absolute emissions from a baseline of 122 $tnCO_2e$ to 111 $tnCO_2e$ in Year 5. Scenario 1 decreases absolute emissions by 2 $tnCO_2e$ to 120 $tnCO_2e$ in Year 5 and Scenario 3 increases absolute emissions by 15 tn CO_2e to 137 $tnCO_2e$ in Year 5, when compared against a baseline of 122 $tnCO_2e$. This analysis shows that Scenario 2 MSS delivers the yield required to establish a sustainable biomethane industry in Ireland.

Analysis from Ricardo Energy shows that even with higher levels of fertiliser application initially, the forages produced for AD plants comply with RED II sustainability criteria. The Dowth Systems Model (**section 6**) shows an increasing forage yield from 6 tnDM/ha to an average of 11.21 tnDM/ha across all scenarios - with a reduction in artificial fertiliser use by 3% in Scenario 1 and 11% in Scenario 2 and 2% in Scenario 3. The model shows that once soil fertility improves and increased yields are achieved, these higher yields are essentially locked in and maintained as the fertiliser inputs are reduced.

- **Can an agricultural-led biomethane industry produce green gas which is able to meet the EU Renewable Energy Directive II ("RED II") requirements, both now and in the future?**

In order for biomethane gas from AD plants to be classified as a zero carbon, renewable fuel, plants must be able to achieve increasingly strict sustainability criteria as outlined within the EU Renewable Energy Directive II ("RED II") and future RED III criteria.

The RED II criteria stipulate that biomass fuels produced from agricultural biomass cannot be derived from raw material obtained from (1) land that was formerly peatland; (2) lands with a high biodiversity value; and (3) lands with a high carbon stock. In addition, RED II requires that all biomass fuels used for electricity, heating and cooling must achieve at least a 70% GHG emission saving, increasing to 80% for installations that start operating from 2026.

This report has assessed the ability of Irish agricultural AD plants to meet the RED II 2021 and 2026 criteria using different agricultural feedstock mixes (see **section 4** for further details). Three scenarios were run through the Ricardo/SEAI RED II calculator: (1) Perennial Rye-Grass; (2) MSS feedstock mix; and (3) Hybrid MSS feedstock mix. These scenarios were tested using variable rates of digestate as a replacement to chemical fertiliser.

Overall, the results demonstrated that it will be possible for Irish agricultural-led AD plants to produce biomethane which meets RED II sustainability criteria so long as an appropriate feedstock mix is used which includes a sufficient proportion of slurry.

Slurry would be required as co-feedstock to meet the RED II sustainability criteria for all scenarios. The inclusion of slurry is required because harvesting the methane from slurry prevents it from being released to the atmosphere, thereby having the effect of being carbon negative and improving the overall GHG savings of the AD facility. The proportion of slurry required ranges from 40-55% in order to meet the 2026 (80% GHG emission savings) RED II criteria. The difference in slurry requirements between scenarios is a result of the lower fertiliser requirements for MSS versus Perennial Rye-Grass.

- **Would the development of a biomethane industry have a negative impact on biodiversity?**

The Irish National Biodiversity Action Plan (2017 – 2021) has stated an objective to ensure that "biodiversity and ecosystems in Ireland are conserved and restored, delivering benefits essential for all sectors of society and that Ireland contributes to efforts to halt the loss of biodiversity and the degradation of ecosystems in the EU and globally", while the World Economic Forum has stated that "biodiversity loss and ecosystem collapse are one of the biggest threats facing humanity in the next decade".

Against this background, and given that the EU biodiversity strategy 2030 highlights "changes in land use" and "overexploitation of land" as two of the five key biodiversity threats, it is vital to ensure an Irish biomethane industry is developed in such a way to ensure it doesn't have any negative biodiversity impact.

In addressing biodiversity concerns, we have considered two core approaches – the use of MSS instead of existing monoculture grasses, and enhanced rules, building on existing EU RED II requirements, to ensure biodiverse land is not utilised for AD feedstock production.

MULTI-SPECIES SWARDS (MSS)

This report shows that the use of MSS can be a viable pathway to grow incremental forages to act as a feedstock for AD plants, rather than mono-culture ryegrass which has historically been considered. While mono-culture ryegrass remains a co-feedstock option for biomethane production, the use of MSS offers a number of additional benefits such as enabling more forage to be produced using less nitrogen fertiliser whilst improving biodiversity and drought resistance. MSS, due to their clover content, allow for the reduction of artificial nitrogen ~ circa 100 kg N/ ha.

Diversity in MSS plants species can be increased up to six-fold based on research at Dowth. Studies from the 'Smartgrass' project in University College Dublin show that both beetle and wasp numbers increased with MSS compared to ryegrass swards[8]. Additional work from Dowth shows an increase in 300% of the earthworm population (an indicator species for soil health and biodiversity) under MSS compared to monoculture ryegrass, while MSS requires less pesticide and fertiliser than ryegrass. Work is currently underway by Teagasc which has shown positive increases in biomethane volumes from MSS further supporting their use within a national biomethane industry.

LAND RESTRICTIONS

The development of an Irish biomethane industry must not have a negative impact on biodiverse lands or areas of high ecological value. While this concept is already an integral aspect of the RED II sustainability criteria, which AD plants established in Ireland will be required to adhere to, we believe further protections may be beneficial.

This report has considered areas of HNV farmland. These farms occur most frequently in areas that are mountainous, or areas where natural constraints prevent intensification. There is approximately 1.5 million ha of HNV farmland in Ireland. This report recommends that where an area of land is identified as a potential AD feedstock source within a high HNV zone, enhanced screening is conducted to ensure that it would comply with the RED II protocol to ensure local biodiversity integrity is maintained when developing a biomethane industry.

- **What impact would anaerobic digestion have on agricultural emissions, particularly ammonia and nitrogen oxide (NO_x)?**

Agriculture is the largest contributor to Ireland's emissions, but is also an important area for climate mitigation through increased efficiencies as outlined in the Teagasc Marginal Cost Abatement Curve[9] and enhancing the potential of its soils to act as carbon sinks. The climate impact of AD plants is multifaceted and greatly affected by the management of the plant and its value chain. Although AD plants can significantly reduce emissions from slurry and chemical fertiliser production, in addition to the fossil energy source biomethane displaces, there are concerns relating to the potential increase in ammonia and NO_x emissions.

The roll-out of AD plants is likely to increase the ammonia emissions from digestate compared to animal slurries. This is because the AD process increases the pH of digestate, which allows more ammonia to be present. However, this impact is well understood and as such, the industry has developed appropriate mitigation strategies, such as covered storage, trailing hoses/shoes, direct injection into soils and ammonia harvesting technologies which transform nitrogen into a valuable fertiliser. We would recommend those involved in handling digestate are provided with appropriate training to ensure these best practice techniques are used and enforced. Appropriate training could be included as part of the Biomethane Charter discussed in **section 7**.

Nitrous oxide (N_2O) is a naturally occurring GHG released from soils. Excess N_2O is released when nitrogen fertilisers are added to soils. Digestate from AD has been shown to reduce N_2O emissions by 37%[10]. This report also advocates that MSS are implemented for AD feedstock, which achieve nitrogen savings of 100 - 120 kg N/ ha compared to traditional grass swards.

As noted, this report includes a partial LCA to assess and quantify the impacts of additional production on a

8 personal communication

9 Lanigan et al. (2019) An Analysis of Abatement Potential of Greenhouse Gas Emissions in Irish Agriculture 2021-2030

10 Nkoa (2014)

typical beef farm. In Scenario 3 absolute emissions rise and in Scenario 1 and 2 absolute emissions decrease. In Scenario 1, intensity emissions per tnDM of forage output drops from 0.09 tnCO_2e/ tnDM to 0.05 tnCO_2e/ tnDM. The intensity emissions per tnDM of forage sold in Scenario 2 decreases from 0.08 tnCO_2e/tnDM in Year 1 to 0.04 tnCO_2e/ tnDM in Year 5, a drop in carbon intensity of 50%. In Scenario 3 the intensity emissions decrease from 0.07 tnCO_2e/ tnDM in Year 1 to 0.04 tnCO_2e/ tnDM in Year 5, a decrease in carbon intensity of 43%. The extra increase in productivity is driven by extra inputs, however as offtake yield of silage is high, it doesn't build soil nutrition to reduce the artificial fertiliser inputs quickly enough for digestate to supply all the nutrients needed. The result is that nutrition has to be supplied from artificial fertiliser which keeps the emissions at a high level relative to production. The analysis of the models shows that Scenario 2 is the best model to increase the production of forage and beef while simultaneously decreasing the absolute carbon emissions and nitrogen fertiliser emissions to produce forage for AD.

- **Can anaerobic digestion improve soil quality and soil carbon sequestration potential?**

Soil carbon sequestration is noted as a crucial climate mitigation measure in the most recent IPCC report, as well as being highlighted in the EU Farm to Fork Strategy and Ag-Climatise. Irish grassland soils contain approximately 440 tnCO_2/ha (120 tnC/ha) equating to 30 years of Ireland's GHG emissions[11]. It is widely agreed that soil carbon does not increase without limit, but eventually reaches a saturated level. However, it is estimated that Irish grasslands maintain an average carbon saturation of 48% and cropland soils have an average saturation level of 38%[12] - highlighting the potential opportunity to increase carbon sequestration.

The Government recently announced the establishment of a National Soil Carbon Observatory to monitor carbon emissions and removals from Irish soils. This will be developed via the roll-out of up to 10 flux towers which can be used to measure carbon exchange between the atmosphere and soils. This work will be run by Teagasc and is expected to contribute to the achievement of carbon credits towards Ireland's obligations under the EU Effort Sharing Regulation. In addition, Devenish is currently running a long-term experiment to quantify carbon sequestration in an Irish context with interim results expected in two years.

In this report, carbon sequestration is included in the partial LCA in **section 6**. Figures have been taken from literature to represent Irish soils and climate. The model uses a range of 0.3-0.5 tnC/ha for carbon sequestration. By integrating carbon sequestration into farm level GHG accounting, this report demonstrates that a farm's net emissions can be reduced between 47% for Scenario 3 and up to 64% for Scenario 2. Further research must be done to understand the expected sequestration improvements and permanence from improved land management practices – as it varies with climate, management and soil type.

Soil nutrition and quality is an integral part of the LCA completed in **section 6**. Soil fertility drives forage yield and as such, achieving optimal soil fertility is essential. Optimal soil fertility can reduce emissions, increase yields and reduce nitrogen fertiliser use. In terms of soil carbon sequestration, research shows that as soil pH and nutrition increases, the soil's ability to sequester carbon also increases. In this report, the model looks at using animal slurries and digestate as the fertiliser source in the first instance. When more nutrition is needed, artificial fertilisers are integrated. As farmers begin their journey of improving soil quality, there is a very fine balance between building soil nutrition and maximising yield. It is recommended that potential suppliers of forage for AD plants are identified as early as possible and put on a soil nutrition build programme before sales of forages commence – see the Devenish Soil Improvement Programme in **section 5** as an example of such as scheme.

11 Teagasc (2020)
12 EPA (2017)

- **How would digestate from the anaerobic digestion plants be managed and utilised?**

Digestate has typically been viewed as a waste product and burden for AD plants, with operators commonly paying farmers to act as off-takers. However, transforming digestate into a more usable and valuable fertiliser can shift this 'waste' material into a potential revenue stream for plant operators. The use of digestate as a key ingredient for the production of organic fertiliser which can replace chemical fertilisers aligns with the aims of a circular bio-based economy, EU Farm to Fork Targets, and avoids the emissions associated with chemical fertiliser production. However, the fertiliser value of digestate depends on its nutrient content and the availability of those nutrients. These characteristics vary with feedstock type, processing technology implemented and soil quality of the land where it is applied.

The chemical fertiliser replacement value of digestate varies in the literature and can range between 15-100%[13] with nutrient availability increasing with simple processing techniques such as solid-liquid separation[14]. Anecdotal evidence suggests that over time, with repeated applications and improved soil quality, digestate can displace up to 80-90% of chemical fertiliser use[15] and can enhance soil biological activity. However, digestate has a lag time compared to the quick impact of chemical fertilisers and is expected to release nutrients more slowly over a period of time. The scenarios assessed in the LCA in **section 6** each utilise a portion of digestate as a source of fertiliser. Research has demonstrated that the use of digestate can reduce N_2O emissions to 0.25 g N_2O per kg N applied as slurry and digestate - compared with 1.49 g of N_2O per kg Calcium Ammonium Nitrate ("CAN") applied currently[16].

Nutrient recovery technologies aim to increase the availability of nutrients in digestate and process it into a more concentrated form. The nutrients harvested from these processes can help to reduce the overall cost of biomethane and provide valuable renewable nutrients for use on-farm. This report outlines a number of nutrient recovery technologies to transform digestate into a more usable product, such as biorefining, ammonia harvesting and slurry dewatering - discussed in **section 4.**

- **How could one ensure a biomethane industry is developed according to best practice and not produce unintended negative consequences?**

While this report has demonstrated that an Irish biomethane industry can be developed in a sustainable manner to produce positive environmental outcomes, this requires the industry and its stakeholders to adopt best practice across a wide variety of areas including plant construction, feedstock production/management, digestate management and plant operation. Given that there remains risk of unintended consequences if developed in an uncoordinated or unconstrained manner, we recommend the introduction of formal guidelines, potentially in the form of a "Biomethane Charter" which would prescribe key requirements that participants in the industry must adhere to.

The Charter could apply to all participants in the industry e.g. famers suppling feedstock and acting as off-takers for the digestate as well as plant operators.

While the development of such a Charter and its adoption / enforcement would need multi-stakeholder support and consultation, we have produced a potential high-level scope for the areas and topics which could be considered, including two potential levels of compliance (i) Tier 1 (compulsory compliance) and (ii) Tier 2 (optional best practice). **Section 7** provides an outline of areas for consideration in the Charter, including RED II and future RED III compliance and the achievement of the EU Farm to Fork objectives as well as aligning with the Good Agricultural and Environmental Condition ("GAEC") standards.

It is envisaged that the specific requirements would be developed with key stakeholders, including representatives from the farming community to ensure that the Charter is not overly burdensome but effective in avoiding unintended negative consequences to both the environment and dynamics of Ireland's agricultural sector. The Charter is likely to have a strong emphasis on measurement, reporting and verification ("MRV") to ensure the impacts and performance of the industry are monitored to ensure best practice and optimal environmental outcomes.

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13 McCabe et al., (2019); SYSTEMIC (2020) Mineral Concentrate; Agriculture and Horticulture Development Board Nutrient Management Guide (RB209) Organic Materials

14 European Biogas Association (2014)

15 Anecdotal evidence suggests that a small portion of chemical fertiliser is likely to be needed to start the growing seasons, however there is significant variability in the fertiliser replacement value of digestate.

16 Nkoa., (2014)

1 Basis for this report

Ireland aims to achieve net zero emissions by 2050 and has a draft interim target of a 51% emission reduction by 2030 – included in the recent draft of the Climate Action and Low Carbon Development (Amendment) Bill 2021 ("Climate Bill"). In order to achieve net zero emissions, there is a strong obligation for sector-wide decarbonisation. As the largest contributor to Ireland's total greenhouse gas ("GHG") emissions, agriculture is primed as a crucial sector to decarbonise and improve its wider sustainability, particularly in relation to biodiversity and water quality.

Agricultural-based anaerobic digestion ("AD") for the production of biomethane is often positioned as a key technology to decarbonise both industry and the broader agricultural sector, whilst providing a number of potential ancillary benefits in terms of sustainability and wider rural development. These potential benefits are increasingly valuable against a backdrop of stringent climate and environmental policy, rising carbon prices and wider corporate decarbonisation commitments.

KPMG Sustainable Futures ("KPMG") and Devenish have been commissioned by Gas Networks Ireland ("GNI") to draw on existing academic research, as well as primary empirical data and on-farm experience from Dowth to assess whether a scalable, agri-based biomethane industry can be established sustainably in Ireland without causing negative, unintended consequences. The key areas of focus within this report include:

- Assess whether Ireland can produce incremental feedstock volumes without disrupting human food production and the national herd
- Assess the potential role of digestate in improving soil quality when used appropriately
- Assess the role of AD in reducing direct application of raw slurry to land
- Assess the potential for displacement of chemical fertilisers and pesticides
- Assess the potential to reduce ammonia / NOx emissions
- Provide an overview of best practice approaches across Europe
- Explore the benefits from MSS on yields, biodiversity and climate resilience
- Assess the potential to increase soil carbon sequestration

While we have received input and support from a wide range of stakeholders, we would like to particularly thank Teagasc for its expertise, analysis and advice as we prepared this report, which has helped ensure the outputs and recommendations are consistent with Teagasc's own research.

After carbon dioxide, methane is the second biggest contributor to climate change

2 Policy context

The adoption of the first ever, global and legally binding climate change agreement, the Paris Agreement, signals what is to be a landmark shift in global climate policy. In order to meet the 1.5°C goal, a suite of robust, innovative and effective measures is required across sectors. Europe intends to contribute to this goal by enshrining in legislation a target to of net zero emissions by 2050 via the Climate Law. The development of an agri-led biomethane industry is remarkable in its alignment with key policy developments at a European and national level, as demonstrated below.

EU GREEN DEAL FARM TO FORK

In 2019, the EU Farm to Fork Strategy was published which includes a number of ambitious proposals to transform agriculture and position it as a key sector for climate mitigation and adaptation. The development of an agri-led biomethane industry is strongly aligned with a number of the headline Farm to Fork goals, including:

- Ensure food production has a neutral or positive environmental impact.
- EU Carbon Farming Initiative - implement new green business models that sequester carbon
- Promote a circular bio-based economy
- Reduce pesticide use and excess nutrients in the environment by 2030.
- Achieve a 50% reduction in nutrient losses without reducing soil fertility leading to a 20% reduction in fertiliser use
- Increase the proportion of organic farming to 25% by 2030
- Implement a sustainable food labelling framework

METHANE STRATEGY

After carbon dioxide, methane is the second biggest contributor to climate change. To address this, the Commission released the EU strategy to reduce methane emissions (the "Strategy"). The Strategy points to the benefits of biogas derived from agricultural wastes to reduce methane emissions, generate new revenue streams for farmers and contribute to wider rural development. The use of digestate is also called out as a soil improver and mechanism to displace fossil-based fertilisers. It is noted that sequential cropping can be used with manure as feedstock for sustainable biogas production, while contributing to sustainable farming practices, and as such could also be further incentivised. It is estimated that by 2050, the EU's annual consumption of biogas and biomethane will increase to between 54 and 72 Mtoe (up from c.17 Mtoe in 2017). Ultimately, the Strategy plans to:

- Provide targeted support to accelerate the development of the market for biogas from sustainable sources such as manure or organic waste and residues via upcoming policy initiatives.

CIRCULAR ECONOMY ACTION PLAN

In tandem with the release of the EU Farm to Fork strategy, the EU Circular Economy Action Plan was published, building on the 2015 Action Plan which aims to transition Europe away from traditional linear value chains to circular models which promote resource longevity, optimal (re)use and recycling. Two actions of note in relation to agricultural led biomethane production are:

- Support a sustainable and circular bio-based sector through the implementation of the Bioeconomy Action Plan
- Explore the development of a regulatory framework for certification of carbon removals based on robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals.

BIODIVERSITY STRATEGY

Biodiversity is crucial to safeguard food security and underpins the sustainability of the agri-food industry. The EU Biodiversity Strategy for 2030 aims to restore and enhance biodiversity out to 2030. The roll-out of a biomethane industry based on sustainable and productive agriculture has the potential to positively contribute to biodiversity via the replacement of chemical fertilisers and integration of MSS - which have been proven to enhance biodiversity (see **section 4**) – thus contributing to the following targets:

- At least 10% of agricultural area is under high-diversity landscape features
- At least 25% of agricultural land is under organic farming management

PROGRAMME FOR GOVERNMENT

The Government published its Programme for Government ("PfG") document with climate mitigation and adaptation policies featuring extensively. The key measures of relevance to a sustainable agri-led biomethane industry are:

- Explore opportunities for farmers from anaerobic digestion
- Deliver an incremental and ambitious reduction in the use of inorganic nitrogen fertiliser through to 2030
- Seek reforms to the Common Agricultural Policy ("CAP") to reward farmers for sequestering carbon, restoring biodiversity, improving water and air quality and producing clean energy
- Continue to support farmers to embrace farming practices that are beneficial environmentally, have a lower carbon footprint and better utilise and protect natural resources
- Encourage investment in renewable infrastructure on farms

AG-CLIMATISE

In response to European and national climate targets, the Government published Ag-Climatise which contains a number of ambitious goals to improve the sustainability performance of agriculture. The development of a biomethane industry and its co-benefits are aligned with some of the key targets:

- Action 1: Reduce chemical nitrogen use to 325,000 tns (annually) by 2030
- Action 9: Increase the current area under organic production to 350,000 ha by 2030
- Action 12: Promote a sustainable bio-economy in the agri-food sector
- Action 17: Develop a pilot scheme in relation to on-farm carbon trading
- Action 20: Engage with stakeholders to maximise the potential opportunities from Anaerobic Digestion for the agricultural sector

CLIMATE ACTION AND LOW CARBON DEVELOPMENT (AMENDMENT) BILL 2021

The Government recently published a draft of the Climate Action and Low Carbon Development (Amendment) Bill to achieve net zero emissions by 2050 and a 51% reduction in emissions by 2030 (base year 2018). The Government is yet to decide how to apply the carbon budget across relevant sectors. The actions for each sector are expected to be detailed in the Climate Action Plan (updated annually). The roll-out of a biomethane industry can decarbonise both industry and agriculture, contributing to the goals set out in the Climate Bill.

The Government's Interim Climate Actions 2021 include a number of actions which are relevant to the potential roll-out of a biomethane industry in Ireland, including:

- 54d Develop biomethane grid injection infrastructure (subject to suitable policies and measures being put in place to support renewable gas production and use)

- 54e Review the indicative target set for the level of biomethane in the gas grid by 2030
- 55a Ensure investment in the gas grid is in keeping with Ireland's target for net zero emissions by 2050
- 55b Establish an official scheme for renewable gas in the gas grid
- 57b Consider introducing a renewable energy obligation in the heat sector
- 229b Continue to support the delivery of the GRAZE (Green Renewable Agricultural Zero Emissions Gas) Project
  DECC recently opened a consultation on the potential introduction of a new Renewable Heat Obligation as part of Action 57(b) listed above. If implemented, this obligation would require the suppliers of energy used in the heat sector in Ireland to ensure a proportion of energy supplied is renewable – the consultation document quotes 3%, 5% and 10% as different levels of ambition. No decisions have yet been made in relation to whether an obligation should be put in place and, if so, how it would be structured.

COMMON AGRICULTURAL POLICY

For 2021-22 a transitional regulation is in place until the new CAP enters into force for the period 2023-2027. There are nine specific actions for the forthcoming CAP, which are summarised below.[17]

FIGURE 3 CAP OBJECTIVES, SOURCE EUROPEAN COMMISSION

Reforms to the CAP have been agreed with 25% of the new CAP Reform budget to be allocated to the new ECO-Scheme Farm Payments which will include incentives/rewards on some topics that would assist the development of a Biomethane and Organic Fertiliser industry. These include:

- Climate change mitigation, including reduction of GHG emissions from agricultural practices, as well as maintenance of existing carbon stores and enhancement of carbon sequestration.
- Prevention of soil degradation, soil restoration, improvement of soil fertility and of nutrient management.
- Agro-ecology practices including crop rotation with leguminous crops, use of crops/plant varieties more resilient to climate change such as mixed species/diverse sward of permanent grassland for biodiversity purpose (pollination, birds, game feedstocks).
- Carbon farming practices including appropriate management of residues, extensive use of permanent grassland.
- Precision farming practices including nutrients management planning, use of innovative approaches to minimise nutrient release, optimal soil pH for nutrient uptake, circular agriculture, precision crop farming to reduce inputs (fertilisers, water, plant protection products).
- Improved nutrient management including implementation of nitrates-related measures that go beyond the conditionality obligations, and improved manure management and storage.

17 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en

RENEWABLE ENERGY DIRECTIVE II ("RED II")

For a biofuel or bioliquid to be considered "sustainable" in Europe it must meet the criteria established in the Renewable Energy Directive ("RED"). In 2018 RED was revised and the recast Directive 2018/2001/EU ("RED II") came into effect to cover the period 2021-2030. RED II includes a renewable energy target for 2030 of at least 32%. RED II sets out the requirements governing the production of sustainable solid and gaseous biomass which apply to installations with a fuel capacity >=20 MW of solid biomass and 2 MW of gaseous biomass. For a biofuel to be eligible to count towards national renewable energy targets it must meet the sustainability criteria set out in RED II. As per RED II, the following sustainability criteria is set out for biomass fuels produced from agricultural biomass from 2021[18]:

- Biomass fuels produced from agricultural biomass shall not be made from raw material obtained from
  - Land that was formerly peatland
  - Lands with a high biodiversity value (primary forests, specially protected areas, special areas of conservation and highly biodiverse grasslands)
  - Lands with a high carbon stock (e.g. wetlands, continually forested areas).
- All biomass fuels used for electricity, heating and cooling shall achieve at least a 70% GHG emission saving, increasing to 80% for installations that start operating from 2026.

The calculation of GHG emissions associated with the production and use of biofuels or bioliquids is summarised below:

$$E = eec + el + ep + etd + eu – esca – eccs – eccr,$$

where

- E = total emissions from the use of the fuel
- eec = emissions from the extraction or cultivation of raw materials
- el = annualised emissions from carbon stock changes caused by land use change
- ep = emissions from processing
- etd = emissions from transport and distribution
- eu = emissions from the fuel in use
- esca = emission savings from soil carbon accumulation via improved agricultural management
- ecc = emission savings from carbon capture and geological storage
- eccr = emission savings from carbon capture and replacement
- Emissions from the manufacture of machinery and equipment are not included

The establishment of an agri-based biomethane industry based on slurry and mixed swards has the potential to meet the RED II criteria as summarised in **section 4**.

An early draft of the EU's upcoming renewable energy directive confirms the bloc's objective of sourcing 38-40% of its energy from renewables by 2030. The draft includes the following:

- A boost for renewables used in heating and cooling, with a new binding target of 1.1 percentage point annual increase.
- An increase in the renewables target for transport, from 14% to 26%.
- And increase in the sub-target for advanced biofuels, from 3.5% to 5.5%, and the introduction of a dedicated supply obligation for aviation
- A certification system for renewable and low-carbon fuels.
- A targeted strengthening of bioenergy sustainability criteria, with possible national caps on the use of stem wood above a certain size for energy

18 SEAI Sustainability Criteria Options and Impacts for Irish Bioenergy Resources

EUROPEAN FERTILISER REGULATIONS

The European Commission has revised and extended the existing fertiliser regulations to support to use of fertilisers from organic / secondary raw materials, such as digestate. Regulation 2019/1009 will be binding from 2022 and will allow free trade across the internal market for more environmentally friendly fertilisers. Under the new Regulation, in order for fertilisers to bear the "CE" marking, they will have to satisfy a number of requirements broadly covered under quality, safety and labelling. It includes 7 Product Function Categories ("PFC") as summarised below.

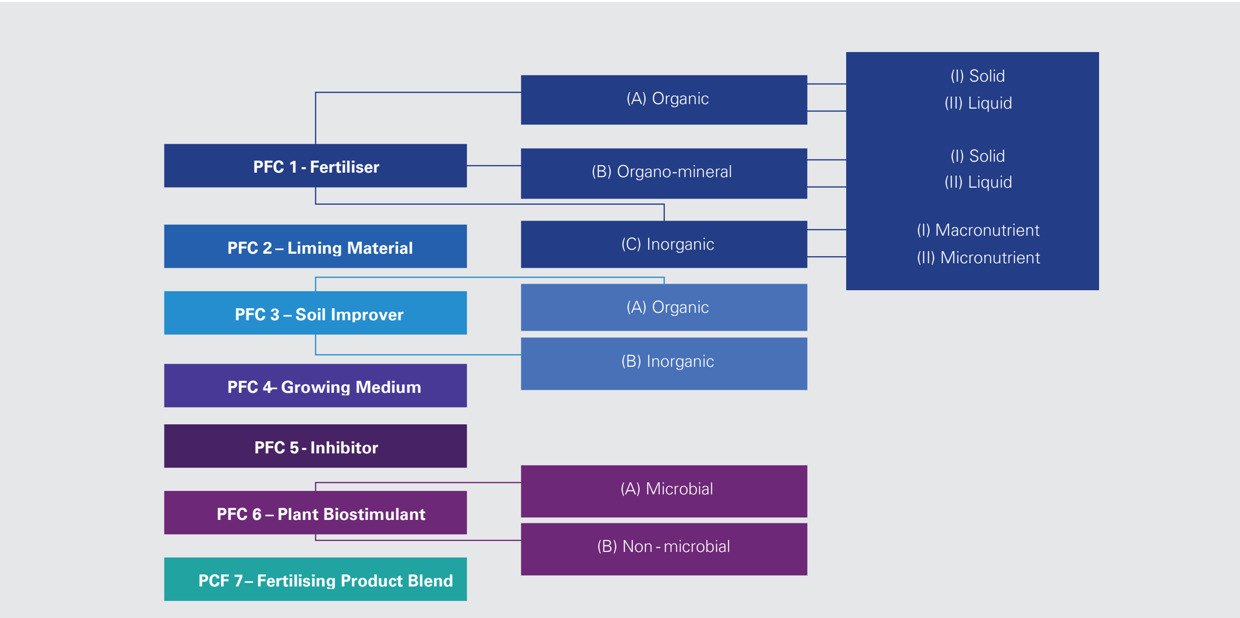


FIGURE 4 EU FERTILISER REGULATIONS BREAKDOWN

The Regulation allows for optional harmonisation, meaning that manufacturers can decide whether to produce a national or EU product. Ultimately, Regulation 2019//1009 is expected to create a level playing field for all fertiliser types across the EU.

NITRATES DIRECTIVE

The European Nitrate Directive 91/676/EEC limits the annual amount of nitrogen that can be applied to agricultural land in Member States to 170 kg N/ha/year from livestock manure in nitrate vulnerable zones ("NVZ"). Member States establish designated regions as NVZ for which Nitrates Action Programmes ("NAP") are developed. Ireland has adopted a whole territory approach, meaning the whole territory is designated as a vulnerable zone. The European Union (Good Agricultural Practice for Protection of Waters) Regulations commonly referred to as the "Nitrates Regulations" give legal effect to Ireland's Nitrates Action Programme. The most recent Regulations are: S.I. No. 605/2017, S.I. No. 65/2018.

In 2018, Ireland's derogation was renewed to allow intensive farmers a higher stocking rate of livestock manure (250 kg N/ha), subject to compliance with strict rules overseen by DAFM. The current derogation will run to the end of 2021, when the fourth programme concludes. The existing derogation went under review in response to concerns relating to water quality and the expansion of the dairy herd. A key change resulting from the review is the mandatory use of low emission slurry spreading equipment. A full review of the derogation and NAP is due in 2021 and could include changes to slurry storage time and facility requirements as well as reduced chemical fertiliser allowances.

The use of slurry as co-feedstock for biomethane and its processing for use as an organic fertiliser could displace some Nitrates Directive issues for farmers, such as storage requirements and nutrient management planning. By using slurry as a co-feedstock, the management of NPK can be more selective through digestate processing and is expected to improve the management of nutrients added to land. Typically, farmers look to export excess slurry to neighbouring farms, therefore work on behavioural change is expected to be important to promote an alternative offtake with AD plants.

ANIMAL BY-PRODUCTS REGULATIONS

The European Animal By-Product Regulation (ABP) 1069/2009 controls the use, recycling and disposal of animal by-products which are declared as unsuitable for human consumption[19]. The ABP Regulation stipulates which categories of ABP and in which conditions they are allowed to be treated in biogas plants. The Regulations classify ABP into three categories:

- Category 1: Very high risk e.g. carcasses (for disposal only)
- Category 2: High risk e.g. manures
- Category 3: Low risk e.g. catering waste

Plants approved by DAFM may handle ABP and non-ABP materials. However, the quantities may be restricted in plants that are not (fully) pasteurising feedstocks. This restriction will be detailed in the conditions attached to the plant's approval.

19 IEA Bioenergy (2012) Quality management of digestate from biogas plants used as fertiliser

3 Overview of agriculture

Agriculture has a clear obligation to decarbonise and improve its wider sustainability in response to increasingly stringent climate policy and downstream corporate climate commitments. Agriculture is a key enabler in the provision of valuable ecosystem services such as reduced water pollution, enhanced biodiversity and the maintenance of nutrient cycles. The following section provides an overview of the current Irish agricultural system and highlights potential synergies with the establishment of an indigenous biomethane industry.

PRODUCTION

Agriculture accounts for approximately 67.6% of Ireland's land cover (0.1% reduction from 2012 estimates)[20]. In terms of agricultural land use, approximately 4.5 million hectares of land was utilised in 2020 – mainly devoted to pasture (52.5%) and silage production (24%), as illustrated below.

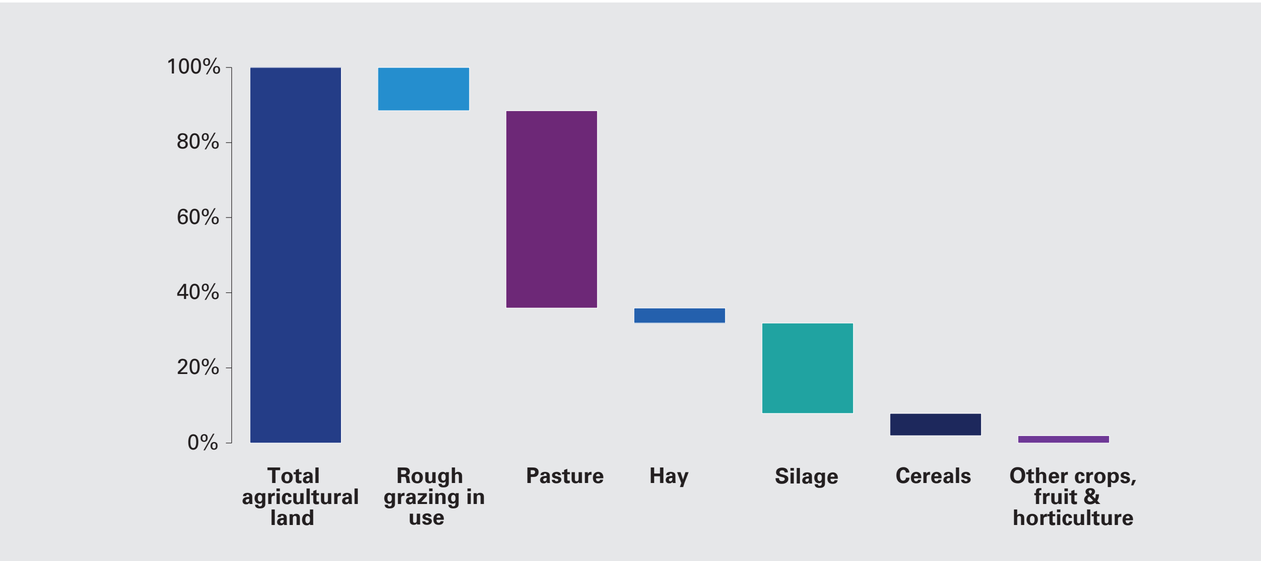


FIGURE 5 PROPORTION OF AREA UNDER VARIOUS CROP AND PASTURE PRODUCTION SYSTEMS COMPARED TO TOTAL AGRICULTURAL LAND USE AREA, SOURCE CSO

20 EPA (2020) Ireland's Environment An Integrated Assessment

Ireland has approximately 92,507 farms which are mainly devoted to Cattle and Dairy activities, as illustrated below, contributing to c.0.9% of GDP[22].

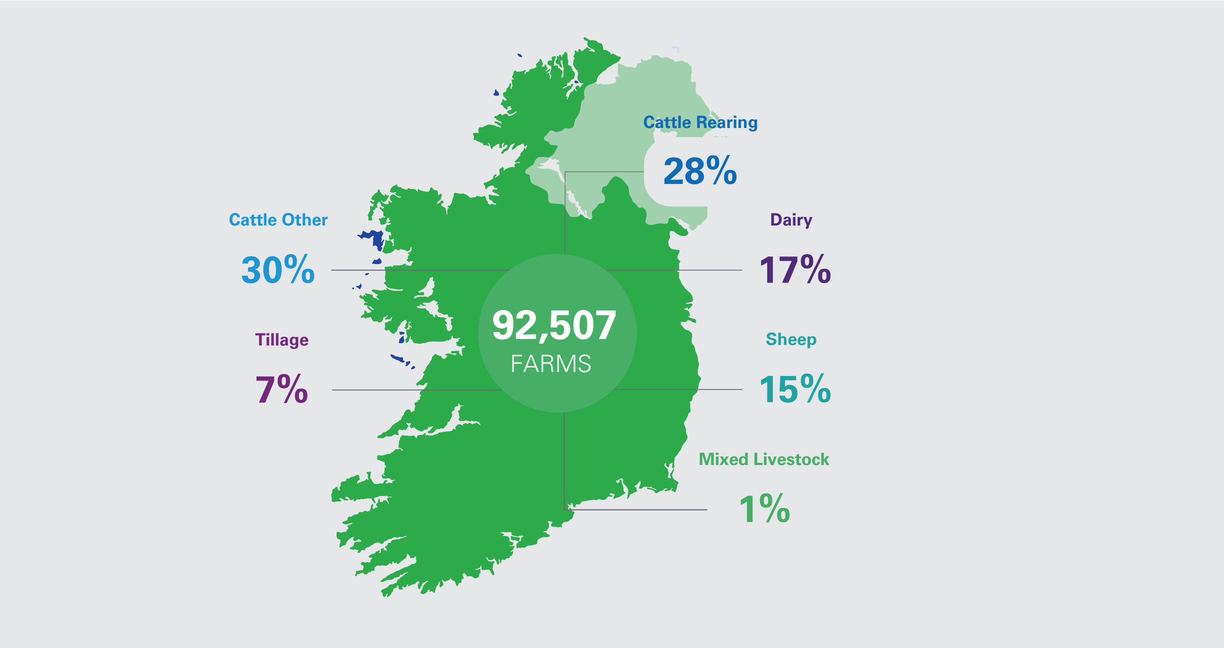


FIGURE 6 AGRI-SECTOR FARMING TYPE, SOURCE TEAGASC

ECONOMICS

The economic performance of family farms varies significantly with farming types. The Teagasc National Farm Survey (2019)[24] shows that just one third of family farms are considered viable, one third of Irish farms lose money and the remainder break even due to off-farm income streams. Furthermore, approximately 52% of Irish farm households have off-farm employment.

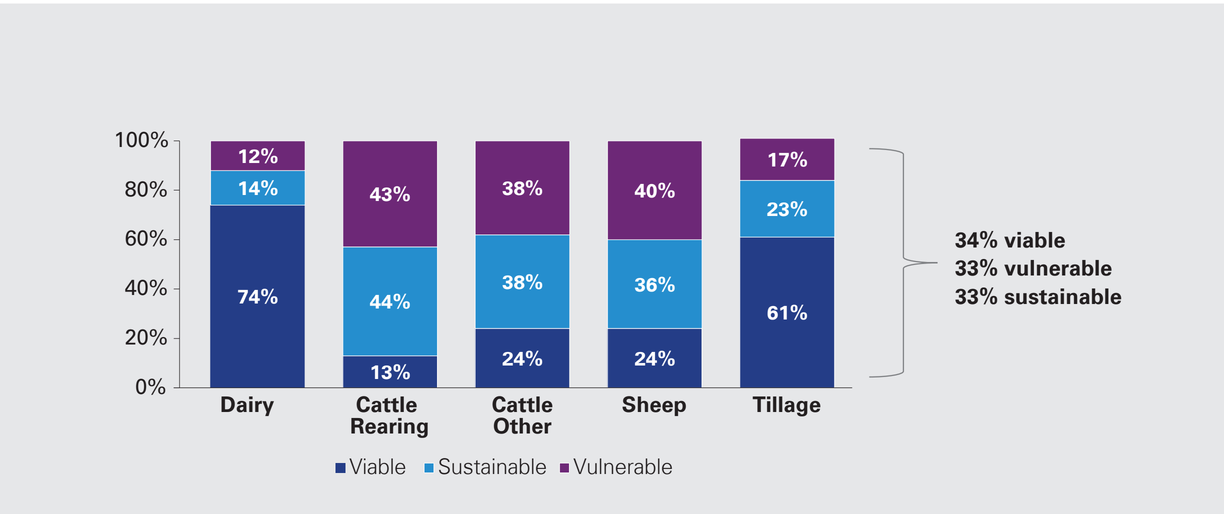


FIGURE 7 FINANCIAL PERFORMANCE OF IRISH FARMS, SOURCE TEAGASC

22 Statista (2019)

23 Teagasc National Farm Survey 2019

Average family farm incomes ("FFI") and net income excluding direct payments ("DP") are summarised below.

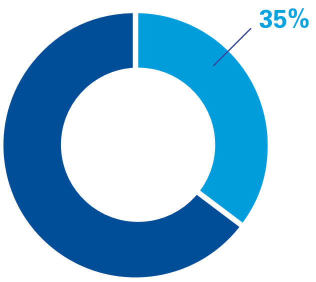
TABLE 1 AVERAGE FAMILY FARM INCOMES, SOURCE TEAGASC

	AVERAGE FFI INCOME PER HECTARE	% DP OF FFI	NET FFI INCOME (EXCL. DP)
Dairy	€1,118	31%	€771
Cattle Rearing	€285	162%	€(177)
Cattle Other	€380	129%	€(110)
Sheep	€315	132%	€(101)
Tillage	€566	76%	€136

These statistics support the argument that a number of Irish farmers would welcome the development of a biomethane industry as an alternative source of income.

EMISSIONS

Agriculture currently accounts for 35.3% of Ireland's total GHG emissions[24] – whilst releasing the majority of N_2O and CH_4 emissions which have a global warming potential 265 and 28 times that of CO_2 respectively.



Agriculture accounts for approximately:

- 93% of total CH_4 and N_2O emissions
- 2.8% of total CO_2 emissions.

FIGURE 8 BREAKDOWN OF IRELAND'S GHG EMISSIONS, SOURCE EPA

Agricultural emissions primarily stem from CH_4 produced by livestock, N_2O from manure management, application of manures to soil, deposition of excreta by grazing animals, synthetic nitrogen fertiliser application to soils and CO_2 from the application of urea and lime to soils. Agriculture is also a source of transboundary air pollutants such as ammonia, nitrogen oxides, non-methane volatile organic compounds and particulate matter[25].

Reducing agricultural emissions has considerable challenges and AD plants present one of the few technological solutions. The development of AD plants provide farmers with an opportunity to pursue decarbonisation and pioneer low-carbon technologies. Crucially, AD plants provide farmers with a means to improve manure management (by capturing methane from slurry). The use of digestate can also displace emissions associated with chemical fertiliser production.

24 EPA (2021) Agriculture
25 EPA (2020) Ireland's Environment An Integrated Assessment

WATER QUALITY

The EPA's most recent report[26] found that Irish water quality has declined, mainly from excess nutrients and sedimentation entering water courses. Increased cattle numbers and fertiliser use have resulted in higher nutrient loadings which adversely impact water quality. Substantial improvements have been made to address this issue via increased storage capacity and improved farm infrastructure. However, significant challenges remain in order to the control nutrient run-off from land.

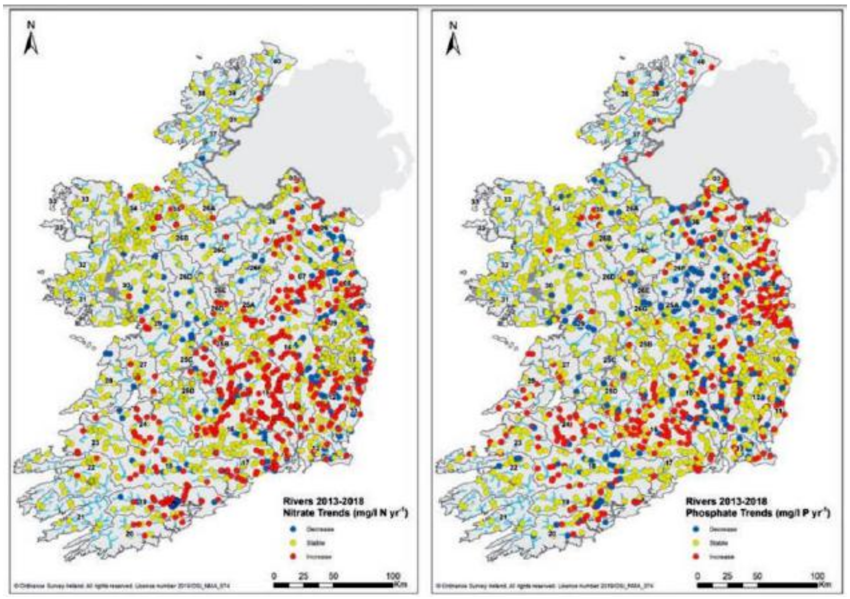


FIGURE 9 WATER QUALITY, SOURCE EPA (2020) STATE OF THE ENVIRONMENT REPORT.
Blue= Increase in water quality; Yellow= Stable water quality; Red = Decline in water quality.

There is approximately 1,452 water bodies in Ireland classified as 'at risk' of not achieving water quality status. The below figure illustrates that agriculture impacts just over half (780) of these water bodies.

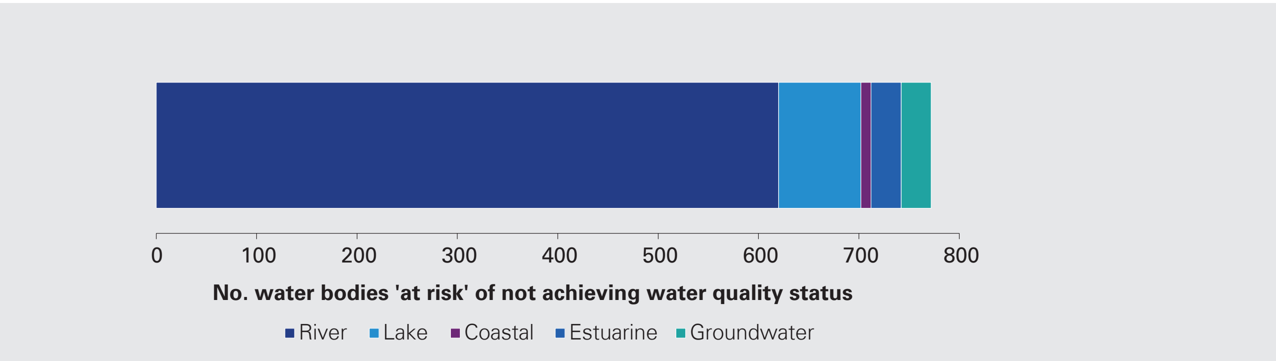


FIGURE 10 WATER BODIES IN IRELAND CLASSIFIED AS AT RISK OF NOT ACHIEVING WATER QUALITY STATUS IMPACTED BY AGRICULTURE SOURCE EPA

26 EPA (2020) Ireland's Environment An Integrated Assessment

BIODIVERSITY

Biodiversity is fundamental to agricultural production. However, global biodiversity is declining in response to land use and cover change[27]. Increasing populations are anticipated to put greater strain on the natural environment in order to meet demands for food and biofuels - which aid in decoupling the negative relationship between energy requirements and the climate. The success of this is somewhat dependent on global soil quality, which is heavily controlled by above and below ground biodiversity.

Agriculture is one of the main pressures on Ireland's protected habitats and species. The below graphic summarises the National Parks and Wildlife Services ("NPWS")[28] findings on the percentage of habitats and species impacted in terms of pressures/threats of medium and high importance form agriculture.

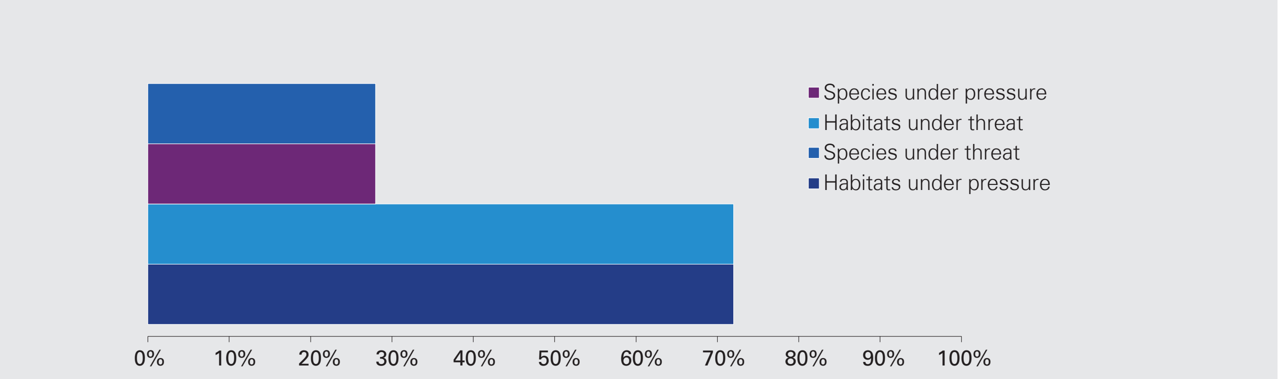


FIGURE 11 % HABITATS AND SPECIES UNDER PRESSURE AND THREAT OF MEDIUM AND HIGH IMPORTANCE FROM AGRICULTURE, SOURCE NPWS

Grasslands support biodiversity more than other ecosystems, however those used for agriculture often employ management practices which do not facilitate conditions for biodiversity. Currently, perennial ryegrass occupies much of Ireland's grassland, however its ability to foster a diverse range of fauna is poor. Furthermore, dependence on chemical fertilisers and increased tillage result in chemical leaching and landscape fragmentation which disrupt the habitats of vital grassland biota[29]. Homogenous plant communities are thought to support lower levels of biodiversity given their inability to supply a diverse range of habitat requirements.

There is evidence to suggest that plant richness is positively corelated to biodiversity, as the heterogenous nature of the ecosystem provides niches relative to varying fauna[30]. As such, the implementation of MSS as a feedstock for AD plants which comprise of grass, legumes and herbage to replace homogenous pastures may enhance biodiversity.

To summarise, the latest EPA report indicates that the long-term trends for water quality, air quality, GHG emissions and biodiversity are poor and declining from the last measurements in 2015. This represents a great challenge to Irish agriculture. However, the development of a successful biomethane industry coupled with enhanced nutrient management planning represents an excellent opportunity to reset and refine our systems to deliver better environmental outcomes at a local level.

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27 J.R. Krebs, J.D. Wilson, R.B. Bradbury, G.M. Siriwardena., The second silent spring Nature, 400 (6745) (1999), pp. 611-612

28 NPWS (2019) The Status of EU Protected Habitats and Species in Ireland

29 Klimek, S., Hofmann, M. and Isselstein, J., 2007. Plant species richness and composition in managed grasslands: the relative importance of field management and environmental factors. Biological conservation, 134(4), pp.559-570.

30 Seibold, S., Gossner, M.M., Simons, N.K., Blüthgen, N., Müller, J., Ambarlı, D., Ammer, C., Bauhus, J., Fischer, M., Habel, J.C. and Linsenmair, K.E., 2019. Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature, 574(7780), pp.671-674.

4 Overview of AD

PROCESS SUMMARY

AD is the process in which microorganisms break down organic material (such as manure or grass silage) in the absence of oxygen to produce biogas and digestate. Biogas can be upgraded to biomethane and used to displace natural gas via grid injection and digestate can be used as a replacement for chemical fertiliser. The graphic below provides an overview of a typical AD process:

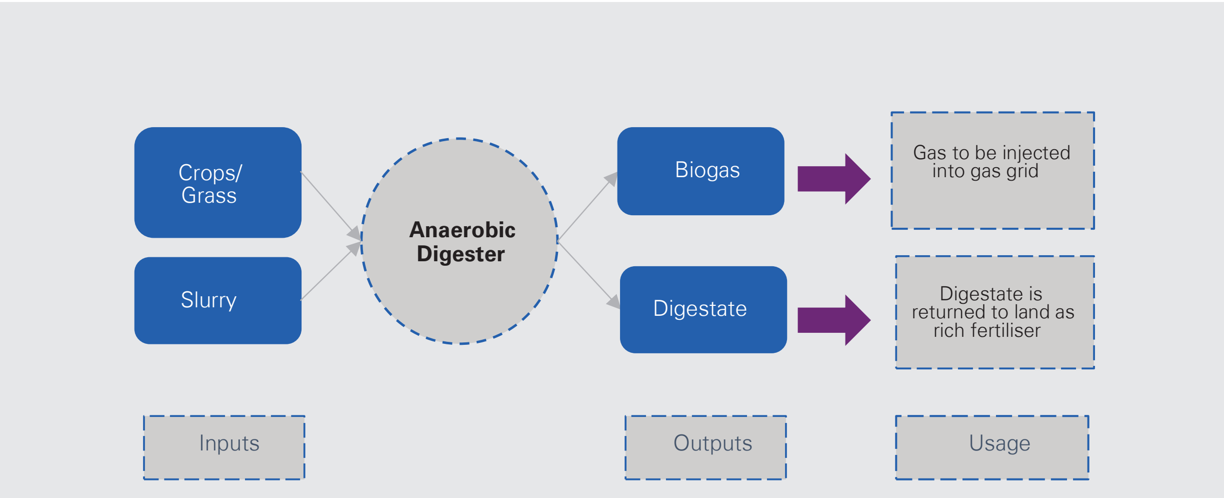

FIGURE 12 OVERVIEW OF AD PROCESS

In 2019, approximately 26 TWh of biomethane was produced across Europe. There are c.725 biomethane plants in Europe – the majority of which utilise agricultural feedstock. The rollout of European biomethane facilities between 2011 – 2019 is summarised below. Ireland's latest National Energy and Climate Plan has set an indicative target of 1.6 TWh indigenous biomethane for 2030 and in 2020 the first biomethane was injected into the Irish grid.[31]

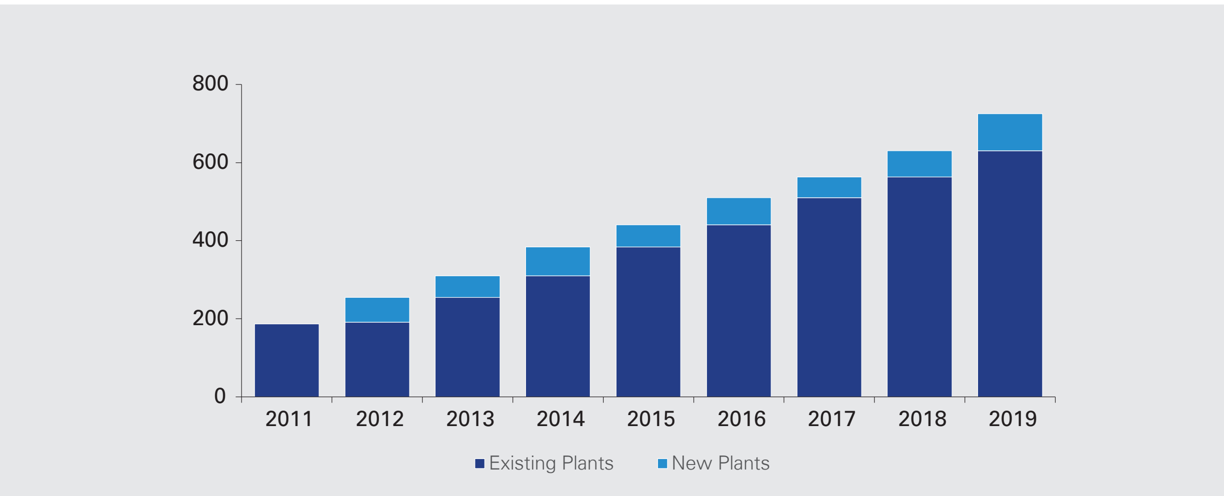

FIGURE 13 BIOMETHANE PLANTS ACROSS EUROPE, SOURCE EBA

31 European Biogas Association (2020) EBA Statistical Report 2020

The NI industry provides a strong validation of the proven technology and suitability of Irish feedstocks for the production of biogas. NI AD plants mainly use grass silage and slurry as feedstock. An illustrative plant layout of an existing operational large-scale AD plant located in Co. Donegal, Ireland, utilising gas clean-up and gas tanker transportation is set out below.

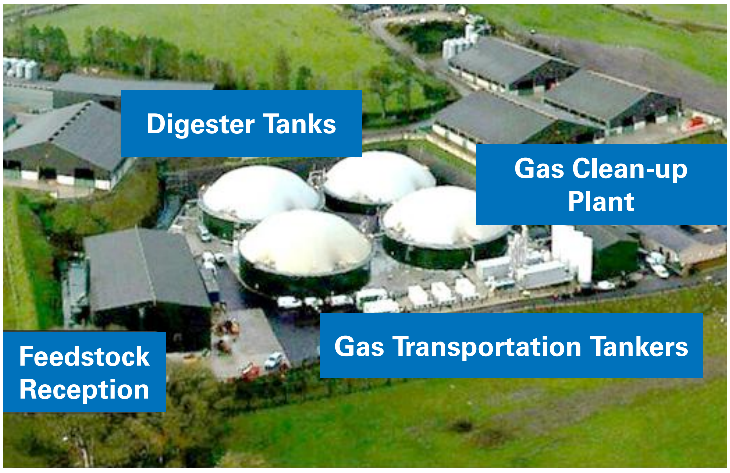

FIGURE 14 EXAMPLE OF A LARGE-SCALE AD PLANT IN CO. DONEGAL

ABILITY TO SUSTAINABLY GROW INCREMENTAL FEEDSTOCK FOR AD

This report has adopted a base case volume of biomethane deployment in line with the NECP 2021-2030 indicative target of 1.6 TWh by 2030. To provide further granularity of biomethane deployment, this report refers to a deployment model through a scheme known as Project Clover ("deployment model"), which is an industry-led collaboration between some of the leading Irish agri-food companies seeking to establish a national biomethane industry. The deployment model assumes the roll-out of 125 x 20 GWh farm-scale biomethane AD plants by 2030 that are fed on agri-based feedstock.

In order to deliver the 2.5 TWh biomethane c.125,000 acres of agricultural land (1.1% of Ireland's agricultural land base) would be needed to produce the required 2.6 m (wet) tns of plant-based feedstock (equivalent to 5% of the current volume of grass silage produced annually in Ireland), alongside 1.75 m tns of slurry (equivalent to 4% of the slurry currently captured in Ireland).

The deployment model assumes that AD plants are deployed nationally and mainly connected through a remote virtual pipeline of compressed gas tankers that transport biomethane from AD locations to centralised grid injection points. There is scope for larger plants (40 GWh and larger) to have direct connection to the gas network for direct biomethane injection into the grid.

Overview

The dominant land use in Ireland is grassland, which cover approximately 4,088,200 ha of land area (excluding rough area)[32] – as summarised in the below table.

TABLE 2 GRASSLAND AREA AND USAGE IN IRELAND

GRASSLAND TYPE	HECTARES
Improved pasture*	109,900
Permanent pasture	3,978,300
Commonage & rough grazing	444,100
Total grassland	4,532,300
Total grassland excl. Commonage & rough grazing	4,088,200

Much of the grassland used for grazing is currently under-utilised, and through improved management of livestock and improved grass cultivation, additional land could be freed from grazing and be available for additional silage production

32 CSO (2020)

The most widely sown grass species across global temporal regions is perennial ryegrass ("PRG")[33]. There are small quantities of legume species (mainly white clover) sown in conjunction with these swards. These grasslands may offer a unique resource opportunity for Ireland to stimulate the development of an indigenous rural biomethane industry.

Since the abolition of the milk quotas in 2015, Ireland has experienced a sharp increase in the dairy sector, including an increase in the size of the national dairy herd. This trend has led to competition for access to land for expansion in the traditional dairy heartlands. It is also expanding into traditional beef producing areas. As a result, the price of land is rising as demand begins to outstrip supply. Teagasc has predicted that this trend will continue until 2026, with an increase in the dairy herd and a small decline in the suckler beef herd. The net effect is expected to be a slight increase or stable national herd.

Against this backdrop we have assessed the opportunity for incremental feedstock to be produced on existing grassland to supply an indigenous Irish biomethane industry. We have focused our analysis on land currently utilised within the beef sector as we believe it has the biggest opportunity to increase the production of forage on farm whilst maintaining current production levels. It is a fundamental aim of this report to identify whether farm businesses would be able to maintain current beef production and produce excess forage over and above that required by their beef enterprise for sale to a locally situated AD plant.

HISTORIC RESEARCH ON FEEDSTOCK AVAILABILITY

There has been a number of comprehensive studies conducted on this topic to date, including recent work by O'Shea et al. (2017)[34] which assessed the spatial opportunity to produce incremental volumes of grass silage above what is currently required for feed. This study estimated that the grass silage resource in excess of current requirements was c.35.67 TWh/a from c.7.75m tnDM of grass silage. Further research by McEniry et al. (2013)[35] gave a range of c.1.7m tnDM to 13.2m tnDM of grass silage available for AD plants in Ireland.

LAND AVAILABILITY ANALYSIS

The current Teagasc National Farm Survey outlines average suckler production, as summarised in **Table 3**. There is a lag in production on beef farms compared to dairy farms. This gap is identified as a key opportunity for incremental forage production for AD plants. Teagasc estimates that the top 25% of dairy farmers can produce at least 14 tnDM/ha and runs 'Grass10' to encourage all farmers to increase their production to 10 tnDM/ha. It is this benchmark yield of 10 tnDM/ha that this report has marked as being technically achievable on the vast majority of beef farms in Ireland.

TABLE 3 AVERAGE BEEF VS. DAIRY PRODUCTION

	BEEF ENTERPRISE	DAIRY ENTERPRISE
Farm Size	32	58.9
Herd Size (cows)	24	83
Stocking Rate LU/ha	1.15	2.1
Grass Utilised tnDM/ha	6	9.1

33 Grogan and Gilliland (2011)
34 O'Shea (2017) Pathways to a renewable gas industry in Ireland
35 McEniry et al. (2013) How much grassland biomass is available in Ireland in excess of livestock resources?

This report targets the production of an additional 4 tnDM/ha over the current status quo. To achieve this, the following technical interventions are required:

- Correcting soil nutrition deficiencies
- Installing or upgrading grazing infrastructure on the farm
- Sowing MSS on the farm

To quantify the production capacity of land, one must consider the following parameters:

- Soil nutrition
- Water quality
- Compliance with the RED II sustainability criteria
- Livestock density in Ireland
- Farmer age and technical ability

Teagasc national soil fertility trends show that 21% and 18% of dairy and drystock farms respectively have optimum fertility i.e. optimum pH, phosphorus and potassium levels. Conversely, between 79% and 82% of soils on dairy and drystock farms nationally are at suboptimal fertility. Addressing this suboptimal fertility presents a major opportunity. However, it requires a multifactorial response and an in-depth knowledge to ensure optimisation of forage production whilst maintaining local ecosystem integrity.

Spatial Considerations for AD plants

In order for biomethane to comply with the RED II protocol, it will require between 40-55% inclusion of cattle and pig slurry. Ireland currently produces c.100m tns of slurry per annum, of which c.40m tns is collected[36]. The deployment model would utilise c.2m tns of slurry per annum (5% of collected material), which we consider achievable, and, given slurry spreading challenges, desirable for the wider agri sector.

Since it is uneconomic to transport slurry large distances, it is preferable to locate AD plants in close proximity to slurry arisings, with the silage feedstock travelling further if required. While this may introduce elements of locations constraint in some regions, the spatial analysis suggests that most regions have significant quantities of slurry available to accommodate AD infrastructure

As well as slurry inclusion, there are a number of additional factors to be addressed prior to establishing a biomethane industry, including:

- Access to land to grow biomass for AD plants
- Appropriate locations for AD plants

We have considered these criteria below in our quantification of suitable land for increased forage production. It should be noted that the below sections focus on the identification of key opportunities to sustainably grow incremental forage to support a biomethane industry. However, there are additional locations across Ireland that would benefit from a slurry management perspective to address the challenges of complying with the Nitrates Directive, such as the Mitchelstown catchment area in County Cork. As such, the areas identified as optimum from an incremental forage production perspective are not the only locations that should be considered when developing AD plants across Ireland.

36 EPA, March 2018, Ireland's Transboundary Gas Emissions 1990-2016

Proximity to Beef-Focused Areas

The map below illustrates the spatial distribution of the national dairy and beef herds. As noted, beef producing farms offer the greatest opportunity to increase forage production.

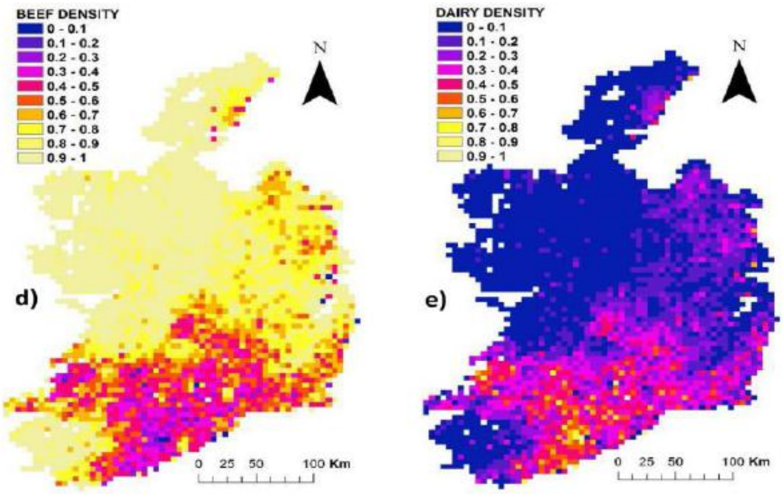

FIGURE 15 TRATOLAS ET AL., (2020) BEEF AND DAIRY CATTLE POPULATIONS DENSITY IN IRELAND

Exclusion of High Nature Value Land

High Nature Value ("HNV") farmland is extensively managed farmland that has high biodiversity, enhanced ecosystem services and societal value. This farmland is important for the conservation of semi-natural habitats and the plants and animals within them. These farms occur most frequently in areas that are mountainous or areas where natural constraints prevent intensification. Farming is important in these areas as it sustains the biodiversity of these landscapes which is integral for maintaining their HNV.

Research conducted by Moran et al. (2021) mapped the spatial distribution of HNV farmland across Ireland (Fig 16). The paper estimates that there is approximately 1.5 m ha of HNV farmland in Ireland. For this report, the HNV map is used as a proxy to screen for areas that are unlikely to meet the RED II protocol. It should be noted that this is a high level screening exercise and it is recommended that where an area of land is identified within a high HNV zone, enhanced screening or an Environmental Impact Assessment ("EIA") is conducted to ensure that the proposed project would comply with the RED II protocol.

Landowner Technical Ability

The landowner's technical ability to increase production in a beef and forage enterprise is of critical importance. Taylor et al. (2020) showed that for average beef producing farms, high performance across all key performance indicators is key for achieving the greatest profitability. Simply put, management must focus on all relevant areas to drive productivity. In this case, there is no optimal pareto principle to focus on, this requires excellent management skills across animal husbandry, agronomy and farm management. Where these skills are lacking, they must be augmented with external expertise to ensure a successful outcome on farm. Taylor et al. (2020) also showed the link between advisory services and farm profitability. The development of human capital and access to the appropriate advisory services is expected to be of critical importance for achieving the required agronomic output for an AD facility. In its Grass10 Report[37], Teagasc observed strong success in yield performance for those who participated in its education programmes, noting that "701 grassland farmers that participated in the 42 Grass10 courses in 2019/20 increased grass production by 1.8 tonnes DM/h".

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37 Teagasc Grass10 Report 2017-2020

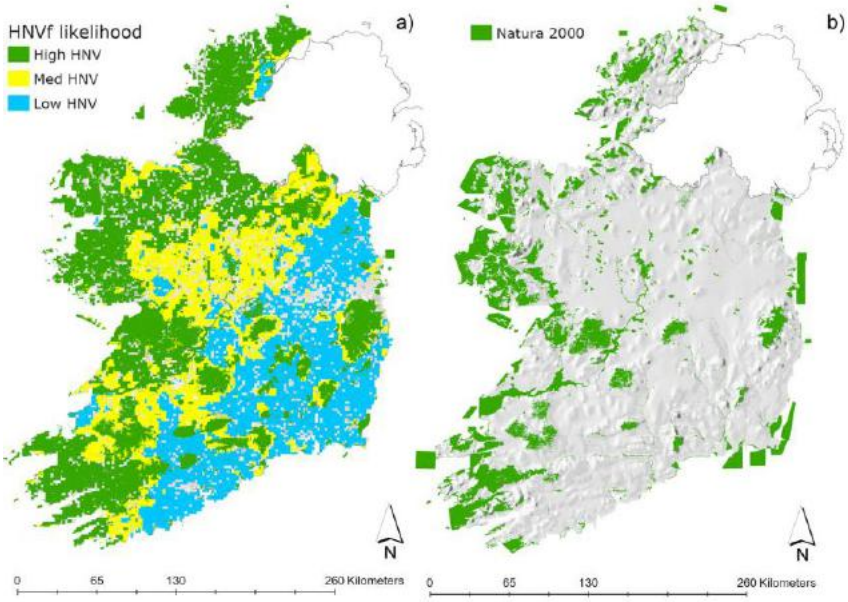


FIGURE 16 MORAN ET AL. (2021) HIGH NATURE VALUE FARMLAND AND NATURA 2000 DESIGNATED SITES SPATIAL DISTRIBUTION IN IRELAND. NOTE THAT HNV SITES AND NATURA 2000 SITES OVERLAP.

Figure 15 and 16 could be overlaid and spatially analysed to show locations within Ireland that offer an opportunity to grow more forage for AD plants. This work is outside the scope of this report, however these figures have been visually assessed to identify potential areas for incremental forage production. As shown in **Fig 17**, the midlands region, north Wexford and east Donegal are promising locations. It is important to note that where an area of HNV occurs, these regions would be excluded or would be subject to a higher level of EIA.

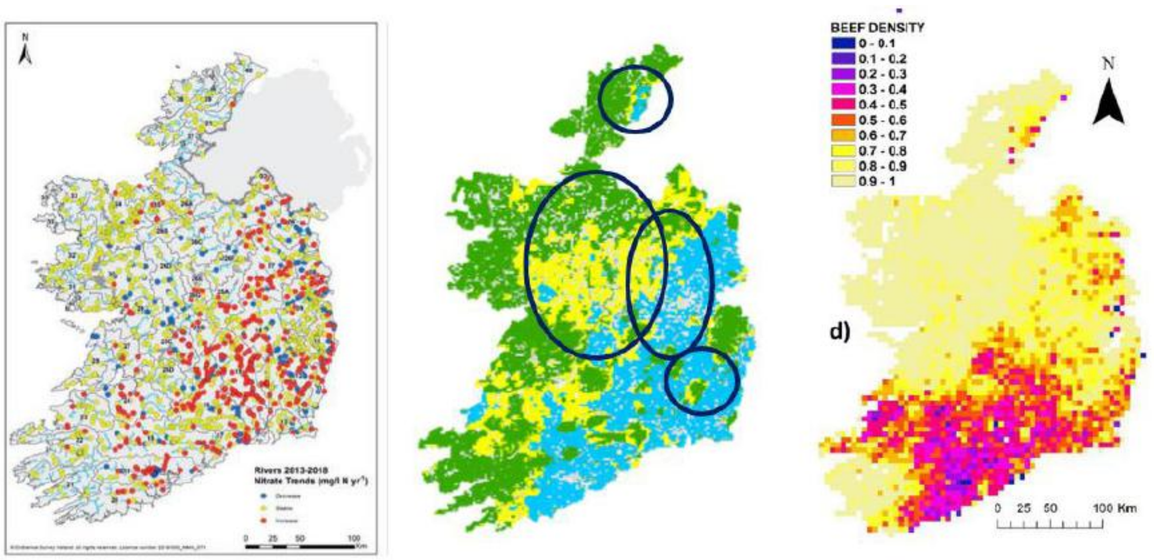


FIGURE 17 POTENTIAL LOCATIONS OF INCREMENTAL FEEDSTOCK PRODUCTION FOR AD (PROXIMITY TO BEEF HERDS) – EXCLUDING AREAS OF HNV AND LOW WATER QUALITY -

Quantification of surplus feedstock potential across Ireland

Figure 17 provides a high level spatial analysis of suitable locations for growing surplus forage most likely to comply with the RED II protocol. Further analysis of CSO data is presented in **Table 4** which shows that there is approximately 4.5m ha of available grassland in Ireland, of which we have calculated that c.768k ha is available to grow incremental forage for a biomethane industry. This figure is derived by subtracting areas of HNV farmland, commonage and rough grazing areas and grassland devoted to dairy enterprises from the total grassland area. We have sensitised down this resulting figure by 30% based on CSO data and the Teagasc National Farm Survey to exclude a portion of smallholdings that may not be willing to change practices. Up to 6 years of real-world data from Dowth has demonstrated that sustainable growth and utilisation of pasture on a wide variety of farms that are below average production is possible with adequate measurement and management to soils (fertility and biology) and pasture (management and sward type).

Assuming a conservative incremental fodder production of 4 tnDM/ha can be achieved across this available land, we would estimate incremental fodder production of 3.1m tnDM. This availability is within the ranges previously produced by O'Shea and McEniry as referenced above. This volume of feedstock would exceed the requirements of the deployment model (2.5 TWh) assumed in this report which would utilise c.0.6 m tnDM per annum.

This volume of incremental fodder would enable the production of c.9.5 TWh of biomethane which we believe is conservative since the potential opportunities from food waste and tillage crop rotations have not been included.

This potential volume of biomethane is in excess of the NECP 1.6 TWh target and the more ambitious target option in the Government's Renewable Heat Obligation consultation of c.5.5 TWh (approximately 10% of current heat demand).

We understand Teagasc is currently conducting an even more detailed spatial analysis which will be available in 2022. It is recommended that the results of this analysis are considered when available.

TABLE 4 POTENTIAL LAND AVAILABLE FOR INCREMENTAL SILAGE PRODUCTION

	TOTAL HECTARES	NET PRODUCTIVE AREAS (HA)
Total grassland in Ireland		4,532,300
Commonage & rough grazing	444,100	
HNV farmland	1,500,000	
	- 1,944,100	
Productive grasslands		2,588,200
Dairy farms & dairy rearing activities	-1,491,200	
	1,097,000*	
Potential land available		767,900
	UNIT	
Potential feedstock availability	m tnDM	3.1
Potential biomethane production	TWh	9.5

* Discounted by 30% to allow for farmer demographics and minimum viable size of farm holding to produce incremental forages

ROLE OF MULTI-SPECIES SWARDS IN BIOMETHANE PRODUCTION

MSS are a promising feedstock for AD plants given their high yields with lower fertiliser requirements in addition to co-benefits relating to biodiversity and carbon sequestration. 'Heartland' is an experiment based in Dowth which is investigating the potential for MSS in Irish grazing systems. The experiment covers 36 ha in total with equal land areas under four different swards types. The aim of the study is to compare the agronomic performance of MSS in a co-grazing experiment consisting of cattle and sheep – given that there is little known about the effects of grazing and animal performance and the persistency of MSS in Irish conditions. The experiment started in March 2020, with the swards being established in July 2019.

The main advantages of MSS are:

- Decreased nitrogen use, whilst maintaining forage yields equal or over and above the yields of PRG
- Increased animal performance for animals grazing MSS compared to PRG
- Improved animal health for animals eating MSS compared to PRG

The swards types are as follows:

- Old permanent pasture ("PP") (naturally diverse and low productivity)
- Perennial ryegrass ("PRG") monoculture (control)
- 6 species sward ("6S", "6 MSS", "6SP"): PRG, Timothy, Red and White clover, plantain and chicory
- 12 species sward ("12S", "12 MSS", "12SP"): PRG, Timothy, Cocksfoot, Red and White clover, Sainfoin, Birdsfoot Trefoil, plantain, chicory, yarrow, sheep's parsley and salad burnet

TABLE 5 THE NITROGEN (N) INPUT VARIED ACROSS THE SWARD TYPES

SWARD	NITROGEN APPLICATION (KG N/HA/YR)
Perennial ryegrass	170
Permanent pasture	135
6 MSS	70
12 MSS	70

In terms of the fertilising regime, the PP and PRG swards received fertiliser throughout the grazing season from March until early September, whereas the MSS only received two fertiliser applications before and after the first grazing rotation. The experiment is in Dowth, which has been subject to the Soil Improvement Programme since 2014 **(see section 5)**. The pH status and nutrient status of phosphorus and potassium are considered sufficient and non-limiting to grass MSS growth. Applications of phosphorus and potassium are applied to the experimental platform where required.

Each sward type is co-grazed by sheep and cattle at a stocking rate of 2 LU/ha from March to November/December each year. In 2020, the MSS produced 40% more herbage than the PRG sward despite receiving 60% less fertiliser and 50% more herbage than the PP sward despite receiving approximately 50% less fertiliser **(Figure 18).**

The aim of the study is to compare the agronomic performance of MSS in a co-grazing experiment consisting of cattle and sheep

In addition, from mid-March to mid-June, there was a drought with soil moisture deficits of 65 mm in Ireland. During this period, the MSS were growing at an average 75 kg DM/ha/day while the PP and PRG swards were increasing on average 20-25 kg DM/ha/day, thus showing the potential of MSS to offer on-farm resilience to drought periods **(Figure 19)**.

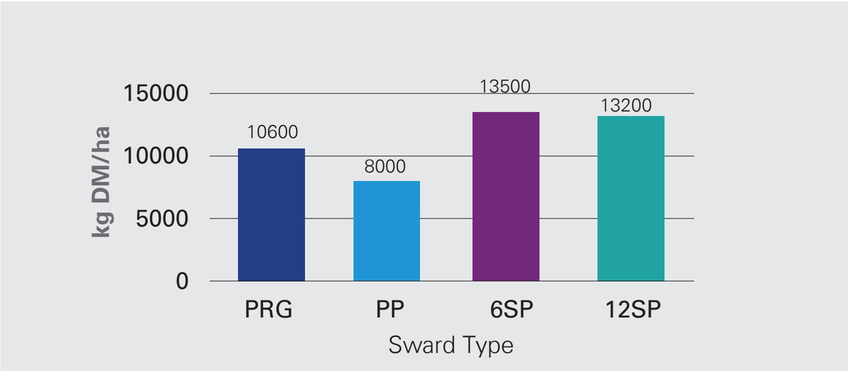


FIGURE 18 THE EFFECT OF SWARD TYPE ON ANNUAL DRY MATTER (KG) PRODUCTION PER HECTARE PER YEAR

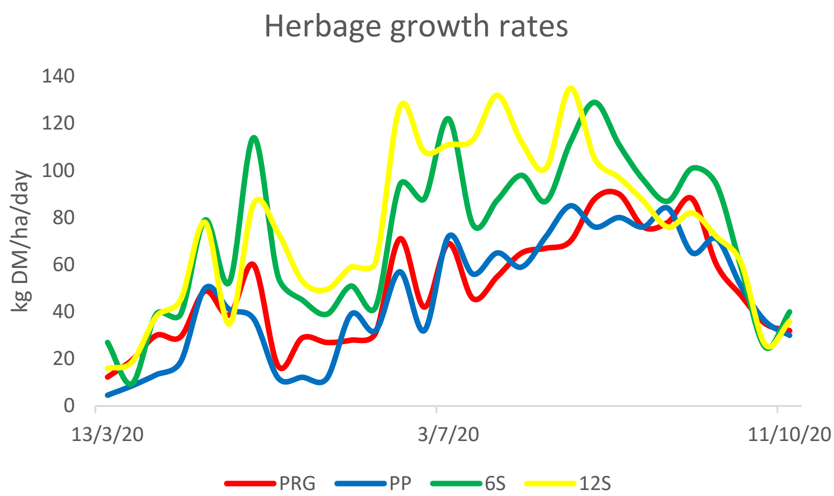


FIGURE 19 THE EFFECT OF SWARD TYPE ON THE DAILY HERBAGE GROWTH RATE (KG DM/HA/DAY), HIGHLIGHTING IN PARTICULAR THE GROWTH DURING THE DROUGHT.

In terms of animal performance in 2020, average daily gain ("ADG") was 0.21 kg/day for heifers grazing the 6S sward than the PRG or PP sward **(Figure 20)**. Lamb ADG was higher for lambs grazing the 6S sward than lambs grazing either the PP or the PRG sward. Lamb growth rates and kill out percentages were higher for lambs grazing the 12S sward (49.4%) compared to those grazing the PRG (45.7%) and the PP swards (44.5%). Lambs grazing the 6S sward had reduced days to slaughter (109) compared to lambs grazing the PP (137) and PRG (149) swards **(Figure 21)**. The growth rate of lambs provides evidence that there is more energy in MSS compared to PP and PRG and by proxy can be used to infer that they have the potential to produce higher biogas yields.

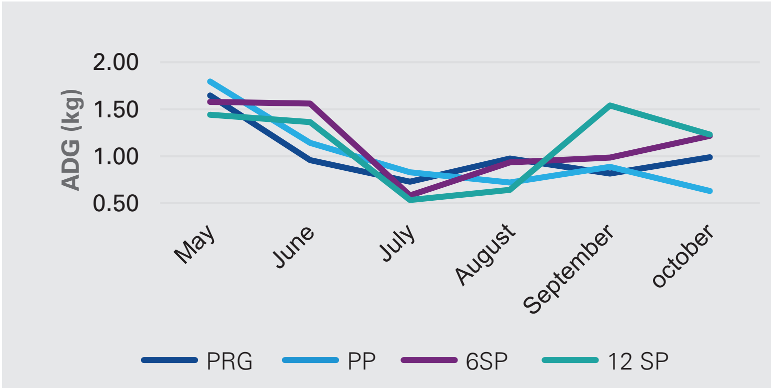


FIGURE 20 THE EFFECT OF SWARD TYPE ON CATTLE MONTHLY AVERAGE DAILY GAIN (KG/DAY).

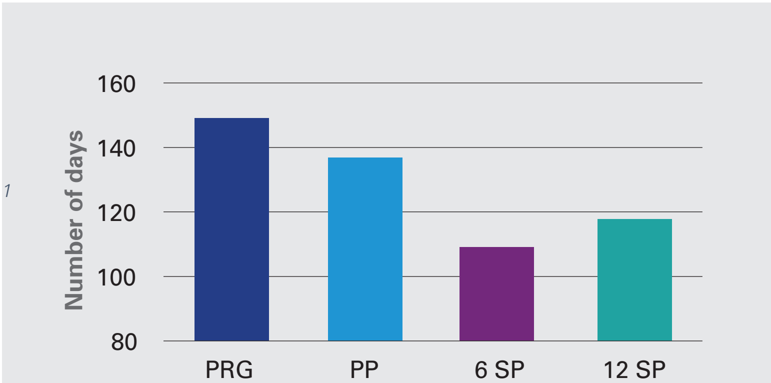


FIGURE 21 THE EFFECT OF SWARD TYPE ON LAMB DAYS TO SLAUGHTER

This provides evidence that there is more energy in MSS compared to PP and PRG and as such may produce higher biogas yields

Sward performance

In 2020, both MSS mixes out yielded the control PRG sward by approximately 2 tnDM/ha. This was achieved with 100 kg/ha less artificial nitrogen application. The reason for this is the legumes (nitrogen-fixing plants) in the sward. In conjunction with bacteria in their roots, these plants can make their own nitrogen to feed themselves and the plants around them. For these swards to thrive, the soil conditions, pH, phosphorus and potassium levels must be optimum to ensure these yields are obtained. Our current understanding is that if soil nutrition is below optimum, similar to PRG, the yield and persistency of MSS will be less than was demonstrated.

Animal performance

The animals' growth performance on MSS is also superior to those that were grazing the PRG swards. The hypothesis for this is that more energy and nutrients in the forage keep animals on a higher plane of nutrition that drives this performance. Also, there are superior health benefits for the animals by way of lower parasite burdens that also helps drive this performance.

Inputs

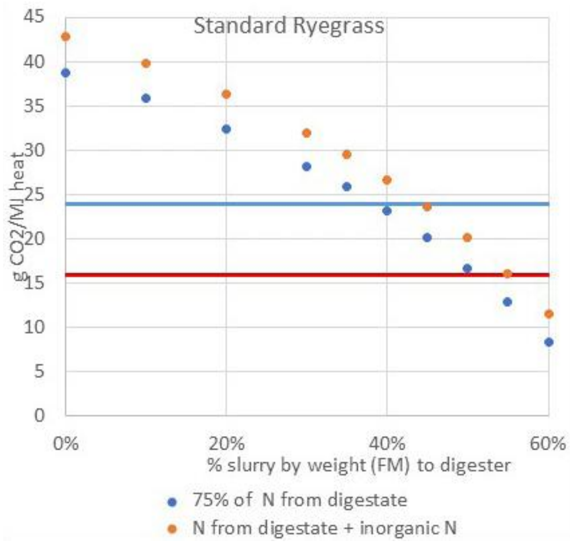
The reduction of nitrogen coupled with increased animal performance is the main advantage of MSS. As noted, the soil nutrition must be optimum for these types of swards – with Teagasc research showing just 20% of Irish soils are at optimum fertility. To implement MSS at a large scale initially, extra fertiliser will be required to build soil nutrition levels, after a period of time, when nutrition levels are adequate, these can be reduced to satisfy maintenance levels, i.e. replacing the nutrients removed in the forage.

Biodiversity

MSS are understood to have a positive impact on biodiversity. In summer 2020, the Heartland project conducted a pilot study comparing the earthworm abundance under the MSS and PRG. Earthworms are an indicator species for overall soil health and biodiversity. The study demonstrated a 300% increase in earthworm abundance under the MSS swards compared to the PRG swards, thus indicating that MSS can enhance soil health and biodiversity.

In addition, the "Smartgrass" research project conducted by University College Dublin, focused on introducing biodiversity into the farming landscape. The project studied biodiversity at the macro scale, looking at diversity in grassland swards and at the microscale, by analysing insect populations such as parasitic wasps and beetles. The study consisted of 108 plots of grass, clover, chicory, plantain and MSS sampled in June and August 2014. The study used parasitic wasps and beetles as proxies for insect abundance. The study showed that MSS increased the abundance of wasps over straight grassland, receiving 90 kgN/ha. Wasps had a negative correlation with nitrogen. The highest abundance of wasps was found in plots that received no nitrogen inputs in August. The abundance of wasps in June was lower than in August. As nitrogen inputs increased, the quantity of wasps decreased. Beetles were most present in plots dominated by legumes. As with wasps, beetles were more abundant in August than in June. Insect numbers increased in abundance where MSS were present (vs. straight grass). These results show that wasp abundance can predict species richness, wasps act like an indicator species and that MSS swards can support higher numbers of adult beetle numbers.

Of relevance to biomethane production is the higher energy level and nutrition levels that could lead to higher biogas yields resulting from the integration of MSS into farming systems. In conclusion, co-grazing MSS is understood to improve overall heifer and lamb performance whilst reducing chemical fertiliser use and can enhance soil biodiversity in grazing systems. It is recommended to implement the Soil Improvement Programme (**section 5**) 2/3 years in advance of beginning to supply to an AD facility to ensure optimum yields of forage can be achieved and that soils are at optimum nutrition levels.

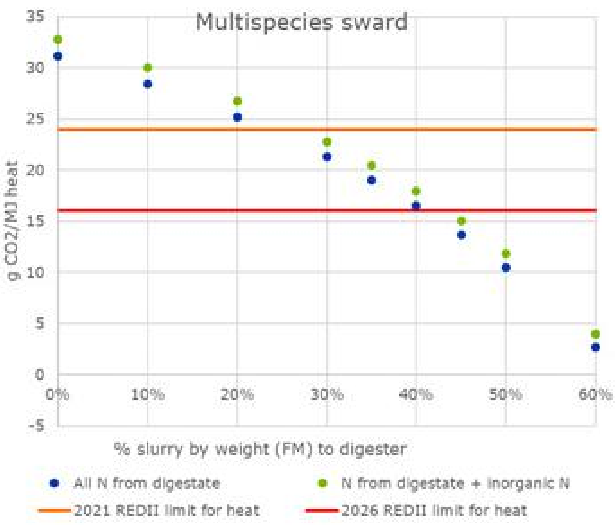


SCENARIO 1 - PERENNIAL RYEGRASS

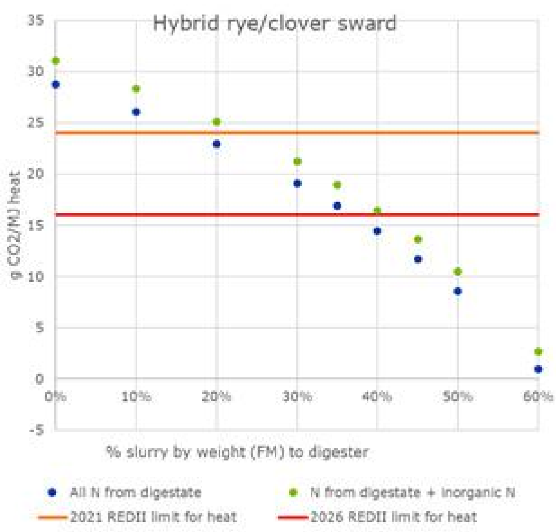
Ability to meet RED II criteria

It is essential that RED II compliance is achieved to ensure the development of a sustainable biomethane industry in Ireland. This report has developed three scenarios (**section 6**) which integrate different sward types: Scenario 1 (PRG); Scenario 2 (MSS); and Scenario 3 (hybrid system "HYB"). To understand the ability of each of these scenarios (and their associated inputs) to meet the RED II sustainability criteria, the project team worked with the SEAI, Ricardo Energy & Environment and Teagasc. The scenarios were taken by Ricardo and ran through the SEAI RED II compliance model. Each of the scenarios can achieve RED II compliance by incorporating a proportion of slurry as outlined below.

For S1 PRG the model predicted that between 55% and 60% slurry would be required to meet the RED II criteria using a mixture of inorganic N/digestate N. However, if 75% of the N requirement was met by digestate, the proportion of slurry needed would be reduced to between 50% to 55%.



SCENARIO 2 - MULTI-SPECIES SWARD



SCENARIO 3 - HYBRID SYSTEM

The Ricardo analysis predicted that both S2 MSS and S3 HYB on a forage only basis would not comply with the RED II. For S2 MSS to achieve compliance with the 70% reduction target, approximately 29% slurry inclusion by weight is required. For HYB this drops to a 21% slurry inclusion[38]. This can be offset against the forage production's impact to achieve the required 70% reduction in 2021. To comply with the 80% reduction by 2026, an inclusion of approximately 43% slurry by weight will be required for S2 MSS and an inclusion of 41% slurry by weight for S3 HYB, respectively.

38 Slurry inclusion is required because by harvesting the methane from slurry, it is prevented from being released to the atmosphere, thereby having the effect of being carbon negative

Transforming digestate into a biofertiliser enables this ‘waste’ problem to be converted into an economic opportunity.

NUTRIENT EFFICIENCY: DIGESTATE, SLURRY AND CHEMICAL FERTILISER

Nutrient composition of digestate

The nutrient composition of digestate varies with feedstock used, processing technology implemented and the quality of the land where it is applied.

During the digestion process organic nitrogen (N) is released as ammonium and therefore more available for plant uptake. The amount N available depends on the nutrient value of the feedstock used for AD plants. More N becomes available from livestock slurry digestate versus raw slurry or other feedstock entered into the digestor. Digestion increases the availability of N, therefore increasing the availability of using digestate as a fertiliser.[39] However, care should be taken to mitigate the ammonia emissions.

Phosphate (P) may not be significantly impacted through the AD process and as a result will still need to be managed carefully during application[40]. Previous studies on digestate and P availability vary greatly as to whether P accessibility to the plant is increased or decreased post-AD. Research also surmises that although P content may not change during digestion, its availability to the plant as organic P increases[41].

Potassium, sulphur, calcium and magnesium are not found to be altered significantly during digestion and thus depend on the feedstock used in AD plants.

Digestate as a biofertiliser

Digestate in its raw form is comparable to cattle slurry, hence nutrient rich and remains a challenge in nutrient dense regions, where it can impact water, land and biodiversity. These challenges, in addition to waste storage and transport costs have hindered the development of digestate as a key value provider for AD plants. However, transforming digestate into a biofertiliser enables this 'waste' problem to be converted into an economic opportunity[42]. Nutrient recovery technologies aim to increase the availability of nutrients in digestate through various methodologies.

Digestate biofertilisers are capable of enhancing grass growth beyond expectations of the nutrient performance. An Irish study comparing the efficacy of biofertilisers in comparison to undigested cattle slurry found a wide variation in quality dependent on the feedstock used[43]. The development of biofertilisers from digestate has become increasingly relevant to AD plants to meet regulatory requirements and to provide an alternative source of income for AD operators[44].

Studies have found multiple appropriate technologies to recover nutrients from digestate and to market it as a biofertiliser should the technical performance and infrastructure exist in an AD plant. The nutrients harvested from these processes are described as 'renewable nitrogen and phosphorous solutions' and are capable of increasing the viability of widespread collection of feedstuffs, reducing the overall cost of biomethane and providing valuable nutrients for use on farm.

The application of biofertilisers can be greatly encouraged through clear legislation, ease of spreading with existing equipment and improvement in overall granulation of the substance in order to spread uniformly. The nutrient release of biofertilisers needs to be considered with an examination of digestate quality, conversion methodology and climate in which the biofertiliser is spread[45].

Digestate vs. Slurry

Digestate is available in three main forms: whole, liquid and fibre. Whole digestate is similar to cattle slurry with low dry matter content; liquid digestate has the solid form removed; and fibre digestate is a solid material, comparable to compost. The separation of digestate fractions is advantageous to reduce the volume of liquid for storage and spreading, increase the efficiency of nutrients in the dried portion, and reduce the need for mixing prior to spreading which would result in increased ammonia release[46]. Digestate can lead to a reduced risk of pollution, decreased odour and pathogens compared to untreated slurry[47]. Research conducted by NUIG, UCD, Green Generation and Teagasc funded by DAFM highlighted the key environmental benefits of digestate which should encourage its adoption as an organic fertiliser, such as the reduction in pathogen load to environment compared with land spreading of slurry.

39 Vaneeckhaute et al. (2017)
40 Lim et al. (2015)
41 Vaneeckhaute et al., (2017)
42 Vaneeckhaute et al., 2017
43 Coehlo et al., 2016
44 Vaneeckhaute et al., 2017
45 McCabe et al., 2019
46 Frost & Gilkinson, 2010
47 Frost & Gilkinson, 2010

The use of digestate as a replacement for untreated slurry can displace significant GHG emissions – c.54 kgCO_2e/tn slurry[48]. However, estimating the avoided GHG emissions from the use of digestate in place of untreated slurry is complex and varies depending on the kind of animal, its diet, climatic conditions and manure management system. Slurry is typically stored in open tanks which release methane and is then applied to land as an organic fertiliser. By diverting slurry for biomethane production, a portion of its emissions can be captured and energetically used. Slurry has significantly higher CH_4 emissions than digestate. Over longer time periods, given its recalcitrant nature, slurry has been shown to produce twice as much N_2O compared with digestate[49].

Although odour emissions are reduced from the use of digested slurry, it can increase ammonia emissions compared to undigested slurry[50]. This is largely due to the AD process increasing the pH, leading to an increased availability of ammonia nitrogen. There are a number of methods to overcome this challenge, such as increased infrastructure for digestate storage, including covering stores and injecting digestate into the soil or reducing the pH of the slurry to counteract the ammonia.

Digestate vs. Chemical fertilisers

According to the Anaerobic Digestion and Bioresources Association, "1 tonne of artificial fertiliser replaced with digestate, saves 1 tonne of oil, 108 tonnes of water and 7 tonnes of CO_2 emissions". The ability of biofertiliser to displace conventional fertiliser, described as the N Fertiliser Replacement Value ("NFRV"), varies between 15-100% depending on the treatment of digestate, application method and soil type [51].

Digestate can reduce fossil-based emissions from chemical fertiliser production which can be up to 5.3 kgCO_2e/kg N. However, digestate emissions can exceed mineral fertiliser emissions for storage due to the potential loss of N as evaporated ammonia and for use on land due to the fact that emissions decrease with increasing nutrient content of materials i.e. digestate has a lower nutrient content than concentrated mineral fertiliser and requires more transportation and more field application, increasing emissions[52]. Improved emission savings could be made by processing digestate into a concentrated form, treating it with stabilising agents, implementing optimal application techniques (during the growing season) and spreading during optimal weather conditions.

Impacts of soil microbiota and fertility

AD should not compromise or undermine soil fertility and Ireland's natural resource base. There are concerns that using excess digestate to fertilise directly may impact the soil microbiota and soil fertility given that digestate contains more mineral nitrogen and less organic matter than the non-digested input materials (e.g., untreated animal slurry, plant residues or green manure biomass).[53] Moller (2015) conducted a review on the impacts of AD, concluding that:

- The direct effects of AD on long-term sustainability in terms of soil fertility and environmental impact at the field level are of minor relevance.
- The most relevant effects of AD on soil fertility and N emissions will be expected from indirect effects related to cropping system changes such as changes in crop rotation, crop acreage, cover cropping, and total amounts of organic manures, including digestate.
- The remaining organic fraction after AD is more recalcitrant than the input feedstocks leading to a stabilisation of the organic matter and a lower organic matter degradation rate after field application, enabling a similar reproduction of the soil organic matter as obtained by direct application of the feedstock or by composting of the feedstock.
- The main direct effects of AD at field level are short-term effects on soil microbial activity and changes in the soil microbial community.

Many reports indicate enhanced soil microbial activity after field applications of digestate in comparison to inorganic fertilisers or untreated controls.[54] Elste et al. (2010) reported that digestate enhanced the abundance and biomass of earthworms. Others reported a clear shift in the structure of the microbial community in response to digestate application in comparison to an undigested feedstock[55]. From these reports, it can be concluded that digestate application can enhance soil biological activity. However, comparisons of parameters describing the soil

48 Amon et al. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle and pig slurry and influence of slurry treatment

49 Research by Stephen Nolan (2020) (Green Generation, NUIG, Teagasc & DAFM)

50 Immovilli et at., (2014)

51 McCabe et al., (2019); SYSTEMIC (2020) Mineral Concentrate; Agriculture and Horticulture Development Board Nutrient Management Guide (RB209) Organic Materials

52 Timonen et al. (2019)

53 Johansen et al. (2013)

54 Alburquerque et al. 2012b; Bachmann et al. 2011, 2014; Galvez et al. 2012; Kautz and Rauber 2007; Lošák et al. 2011; Odlare et al. 2008, 2011; Ross et al. 1989; Schröder et al. 1996;Walsh et al. 2012a, b; Clements 2013

55 Chen et al. 2012; Abubaker et al. 2013

microbial activity such as basal respiration, substrate-induced respiration, specific growth rate, or N mineralisation capacity indicate that the effects of digestate application on the promotion of soil microbial activity are lower than the effects of application of the undigested feedstock in the short-term[56].

The influence of AD on soil microbial activity is also mediated by:

- Feedstock used: digestate with a high degradability of organic matter such as clover-grass has a stronger effect on short-term soil microbial activity than digestate with a low degradability such as silage maize[57].
- Soil type: the effects of adding digestate and undigested cattle slurry on bacterial community structure are greatest in the sandy soil[58].

Land Application

In terms of digestate application, due to the release of ammonia at spreading, injection application of digestate is recommended. This also allows plants to uptake nutrients more efficiently. Application periods during peak growth is recommended. In line with regulatory guidance, digestate application should be avoided in Autumn or Winter. Best practice application of digestate is in line with slurry applications and should be avoided if soil is waterlogged, frozen, snow-covered, or recently drained, or near water-ways[59].

Mitigation of emissions from AD

The successful mitigation of emissions from AD facilities requires the employment of best management practices and technologies. The combination of these two levers are expected to greatly reduce the impact of an AD facility. Management practices consist of integrating best practice and compliance with regulations to ensure that AD facilities and their associated feedstock limit adverse environmental impacts. In addition, the use of technology to mitigate, improve and valorise product inputs and outputs from the AD plant can also play a key role in reducing the environmental impact of an AD plant.

The primary pollutants associated with digestate are:

- Methane
- Ammonia
- Nitrous oxide
- Eutrophication of waterways

Methane

AD plants capture methane for use as an energy source. The RED II protocol shows that AD reduces GHG emissions from animal slurries and as such is counted as a negative balance, i.e. the more slurry that an AD facility uses, the greater the avoided methane emissions from slurry. AD plants can also release fugitive methane and carbon dioxide. However, this risk is considered to be minor given the design, monitoring and quality of AD systems currently on the market. In addition, the release of gas from AD plants represents an economic loss to the operator and as such is expected to be remediated efficiently should the risk arise.

Ammonia

During AD, the pH and temperature of the feedstock is increased. These two factors result in the chemical conversion of a proportion of the nitrogen present into mostly ammonium and ammonia. The equilibrium is dependent on the pH and temperature of digestate and will change from one AD facility to another. The management, storage and application of the digestate will ultimately dictate the proportion of ammonia lost to the atmosphere from digestate. The main management considerations are:

- **Storage:** to avoid ammonia loss to the atmosphere, digestate should be stored in a covered tank/ lagoon at all times. When left exposed to the sun and wind, it can lose up to 40% of its nitrogen.
- **Application:** when applying digestate, it should be injected into the soil so the ammonia is trapped. In some cases, this is not always feasible, for example, in stony soils. Here, a dribble bar system is recommended with flexible pipes applying the digestate to the surface in rows. The second application technique relates to the amount of digestate used per application. Lower amounts will lead to reduced emissions. Applications should

56 Merz 1988; Reinhold et al. 1991;Schröder et al. 1996
57 Johansen et al. 2013
58 Abubaker et al. 2013
59 McCabe et al., 2019

be based on the minimum nutrient requirement that is necessary to grow the crop successfully. Multiple applications throughout the season will help to elevate the risk of emissions.

- **Acidification:** Teagasc studies[60] have shown that the acidification of slurry can reduce emissions by 85- 96%. These studies are ongoing but provide a technique that can be employed to manage ammonia emissions. However, a balance must be reached between reducing the pH of the digestate to a level that stops emissions without impacting the pH of the soil from its agronomic optimum of 6.3 for grassland. As digestate is a high pH material, managing this trade-off could be easily and effectively designed.

Nitrous oxide

Nitrous oxide (N_2O) is produced from the reduction of nitrogen, a process that mainly happens in soils. This is a natural process that is continuously happening in soils. However, when more nitrogen is added to soils, it increases the rate of nitrous oxide emissions. There are many factors that can influence the rate of emissions, such as soil texture, the amount of nitrogen reducing bacteria in the soil and the local climate. Research shows that, on average, digestate can reduce nitrous oxide emissions from 40 g N_2O to 25 g N_2O per kg of N applied as slurry and digestate.

- Reducing nitrogen use: the key method to reduce N_2O is to avoid nitrogen applications in the first instance. In Scenario 2 (**section 7**) the use of MSS allows for a significant reduction of nitrogen inputs. The Irish EPA GHG inventory notes that for every kilo of nitrogen, as Calcium Ammonium Nitrate application avoided, 1.49 g N_2O[61] is avoided.
- Soil health: nitrous oxide emissions are greater in soils that are waterlogged or compacted and have less oxygen present. Agricultural practices such as the Devenish Soil Improvement Programme that relieve this compaction to maintain and achieve good soil structure can help to reduce N_2O emissions.
- Best practice: the current guidance through Good Agricultural Practice for SI 605 of 2017[62] provides an excellent pathway to reducing N_2O emissions. Applying nitrogen little and often is a way to combat emissions. Landowners should apply the minimum nutrient requirement needed to grow the crop. Multiple applications throughout the season will help to alleviate the risk of emissions. It is generally accepted that spring applications of manures and slurries mitigate nutrient run-off and leaching. In addition, agricultural practices that enhance soil aeration and enable good drainage would also mitigate N_2O emissions following the application of digestate.

Eutrophication of waterways

A major environmental concern with land application of digestate is the potential contamination of surface and ground waters with excess nitrogen and phosphorus. Most studies show that digestate is richer in terms of its nutrient content. For nutrient leaching, digestate should be deemed to have at least a similar impact on water bodies as slurry. However, AD reduces the Biochemical Oxygen Demand ("BOD")[63] of the slurry. The BOD is a measurement of the polluting potential of a slurry. The higher the BOD, the higher the potential for water pollution. Digestate has been shown to reduce the BOD by 40%, limiting its water polluting potential compared to animal slurries.

Similar to ammonia and nitrous oxide emissions, best management practices can protect water quality. The nutrient leaching potential following the application of digestate depends on factors such as fertilisation strategies, soil texture, topography, precipitation and cropping systems. Best management practices that mitigate nutrient leaching include nutrient management planning to predict the nutrient supply for the crop grown and the use of soil tests.

Good governance for water quality will adhere to the code of Good Agricultural Practice SI 605 2017 to protect watercourses. Properly trained agronomists should be engaged to ensure that landowners understand the correct procedures for nutrient application in accordance with legislation.

60 Kavanagh et al. (2019) Mitigation of ammonia and greenhouse gas emissions from stored cattle slurry using acidifiers and chemical amendments

61 Richards et al. (2018) Improved Irish Nitrous Oxide Emission Factors and Mitigation Measures

62 https://www.gov.ie/en/publication/c9563-rural-environment-sustainability-nitrates/

63 https://www.afbini.gov.uk/articles/1-benefits-anaerobic-digestion

Technology solutions

Biorefinery

Nitrogen is in excess in all grasslands. The crude protein of grass in Ireland is approximately 20- 22% where cattle graze, which is above their metabolic needs, and as a result, cattle excrete this excess nitrogen. This is similar for forages used for AD - where there is excess nitrogen in the system above the needs of the plant's microbiology. Nitrogen requires a greater level of management to ensure it is used efficiently as a fertiliser without adversely impacting the environment. Nitrogen and its derived compounds (protein) are a valuable resource. There are several technologies that can be deployed at a plant level that will capture and valorise excess nitrogen. Centralised AD plants can enable these technologies to achieve economies of scale.

There is an ongoing EIP (Innovation in Agriculture) project in Ireland (Biorefinery Glas)[64] which focuses on biorefining. Biorefining is an intermediary step in the process of making silage. It converts freshly harvested grass into a range of products by pressing it through a plant that removes the grass's juices.

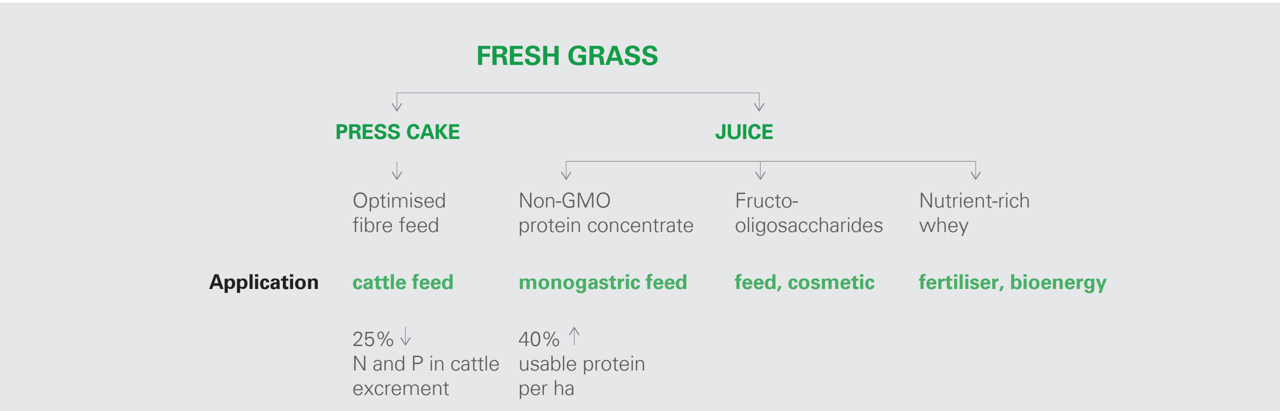


FIGURE 24 SCHEMATIC OF THE PROCESS, SOURCE HTTPS://BIOREFINERYGLAS.EU/

There are four products made during the biorefinery process:

- **An optimised cattle feed fibre - press cake**

The feed produced can be fed to cattle as a grass/ silage alternative. Trials to date[65] in dairy cattle have shown that press cake is at least as good as a silage alternative, with milk production levels being maintained compared to the standard diet. Nitrogen and phosphorus excretion levels can also be reduced by 25%.

- **A non-GMO protein concentrate feed for monogastrics.**

When pigs[66] were fed a dried, concentrated version of the protein extracted from the grass, they had better average daily weight gains. The concentrate can be a source of alternative protein for monogastrics in Ireland, albeit with some supplementation of essential amino acids. Note the supplementation of amino acids is standard practice in pig production.

- **A high-value sugar stream of fructo-oligosaccharide.**

Fructo-oligosaccharides in grass whey[67] which are highly valuable compounds that can be used in animal feed as probiotics and in the cosmetic industry.

- **Grass whey for fertiliser or bioenergy applications.**

The grass whey and the whey from the fructo-oligosaccharides streams are shown to have a high methane yield and exhibit a high biological methane potential. Both substrates would make very good feedstock for an AD plant and are highly degradable. It is also understood that the ammonia production from these substrates was low.

From this research, it can be surmised that it would be beneficial to have a biorefinery process located with an AD

64 https://biorefineryglas.eu/
65 https://biorefineryglas.eu/wp-content/uploads/2021/03/Biorefinery-Glas-Deliverable-2.1-Exec-Summary.pdf
65 https://biorefineryglas.eu/wp-content/uploads/2021/03/Biorefinery-Glas-Deliverable-2.1-Exec-Summary.pdf
66 https://biorefineryglas.eu/wp-content/uploads/2021/03/Biorefinery-Glas-D2.4.pdf
67 https://biorefineryglas.eu/wp-content/uploads/2021/03/Biorefinery-Glas-D2.5.pdf

plant. The key advantages of biorefining for AD are (1) a greater valorisation of the feedstocks and (2) a reduction in the environmental impact from nitrogen on the local ecosystem.

Ammonia Harvesting

Ammonia harvesting[68] is an evaporation process that separates and removes ammonia from digestate. During this process, digestate is converted into a concentrated fertiliser, ammonium sulphate solution, a sludge and clean water. The water from the digestate is removed by vacuum evaporation using waste heat from the AD plant. Ammonia harvesting can be deployed in two ways:

- The first way is post-AD to treat digestate by removing water (reducing transport costs) and removing ammonia (to reduce its environmental impact during application).
- The second way integrates a "kidney ring" process. The ammonia harvesting unit is plumbed into the main tank and processes the digestate during the AD process. It strips the ammonia to ammonium sulphate solution but then pumps the water and sludge back into the reactor vessel for further energy recovery. This enables the plant to use feedstocks of a higher calorific value and to extract more energy but maintaining the same footprint. The AD plant will stabilise at a higher organic loading rate than previously while reducing its nitrogen impact on the local environment.

Slurry dewatering solutions

Valordig[69] is an example of a filtration system that can be used to dewater slurry on-farm. Farm slurries are typically 5-10% dry matter i.e. 90- 95% water. The Valordig technology removes c.60% of the water through filtration and a reverse osmosis unit – concentrating the energy into 40% of the original material. Reducing slurry's water content has a material effect on transport and capex requirements for the AD plant. The Valordig system is a mobile unit which could dewater slurries from a number of individuals farms, enabling a more concentrated material to be brought to a centralised AD plant.

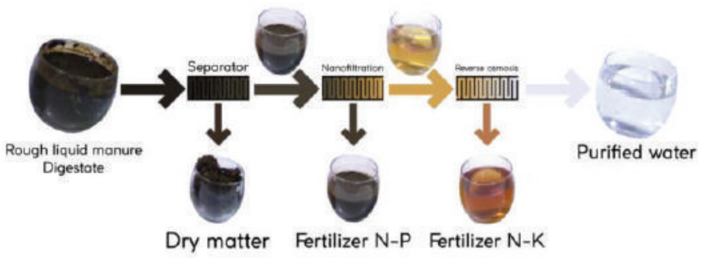


FIGURE 25 SOURCE: *https://nereus-water.com/en/valorization-of-digestate-valordig/*

The combination of the best cultural practices and technological solutions provide an opportunity for AD plants and their value chains to reduce their environmental impacts and to valorise and optimise the feedstocks and processes implemented. As a result, compliance with the RED II will be easier to achieve, value chain economics can be improved and environmental impacts can be reduced.

Best agronomic practice in Europe for nutrient management

All European countries are bound and held to the nutrient regulations as stipulated by the Water Framework Directive 2000/60/EC. The key metric for protecting water quality in agriculture is a cap on the application of nitrogen. This is done by limiting the amount of nutrients from livestock and the amount of nutrients that are permitted from artificial fertiliser or other organic manures. The livestock stocking rate is 170 kg N/ ha (equivalent to the nitrogen excretion of 1.9 dairy cows). There is a derogation available to increase this stocking rate to 250 kg N/ ha. These limits guide fertiliser application rates throughout Europe and are transposed into national law in all Member States. Different Member States have different local rules on the management of digestate at a national level, but all national legislation is framed by the Water Framework Directive.

68 https://biogastechnik-sued.de/en/btsued/products/digestate-evaporation-vapogant/

69 localpower.ie

Belgium

Belgium has good practical laws on fertiliser application. They rely on the export of slurries and nutrients to the Netherlands and France to comply with their nutrient loading.

An overview of their nutrient application rules is as follows:

- Submission of a nutrient management plan;
- A recent soil analyses, N demand of the crop;
- Analysis of the manures being applied;
- The application of livestock manure, other fertilisers and chemical fertilisers on arable lands is not permitted from the 1 September to 15 February;
- Injection or drop pipes in grassland and cultivated land; and
- Injection or incorporation within two hours (immediately on Saturday for livestock manure) on non-cultivated arable land, but the time is increased to 24 hours for manure, compost and other fertilisers with low ammoniacal nitrogen ammoniacal (N content < 1 kg/1,000 kg (1,000 litres).

In Belgium, AD is not considered a form of manure processing as the nutrient value of the digestate is enhanced during its processing. Minimum required storage periods for manures are:

- 9 months for animals still in the housing unit
- 6 months for free-range animals
- 3 months for housing unit manure
- No obligation for poultry: manure removed from the building after each cycle.

Germany (Lower Saxony)

Lower Saxony in Germany faces significant water quality pressures. The German Government has introduced enhanced nutrient management planning to reduce the pressure on water quality.

The application of nutrients on the farm, requires:

- Submission of a nutrient management plan
- A recent soil analyses, N demand of the crop
- Analyse of the manures being applied
- Site conditions
- Growing conditions
- N demand of the crop
- Phosphate contents of the soil
- Crop rotation is permitted

Prohibited application techniques for manure are:

- Solid manure spreader without controlled manure feed to the distributor
- Liquid manure / slurry tankers with free outlet on the distributor
- Central upwardly radiating impact distributor
- Liquid manure cart with vertically arranged centrifugal disc
- Rotary jet sprinkler for sprinkling manure
- Ground level application on cultivated fields

From February 2020, liquid organic and liquid organic-mineral fertilisers must be placed in strips on the soil or injected directly into the soil, this will apply to all grassland in 2025.

Storage capacity required for manures:

- 6 months for liquid manure, manure, silage slurry, fermentation residues
- 2 months for solid manure of hoofed or cloven-hoofed animals, compost from 01/01/2020
- 9 months for farms with more than 3 LSU (livestock units) / ha and for farms without their own crop or grassland from 01.01.2020

Closed (no-application) period for fertilisers with significant N-content:

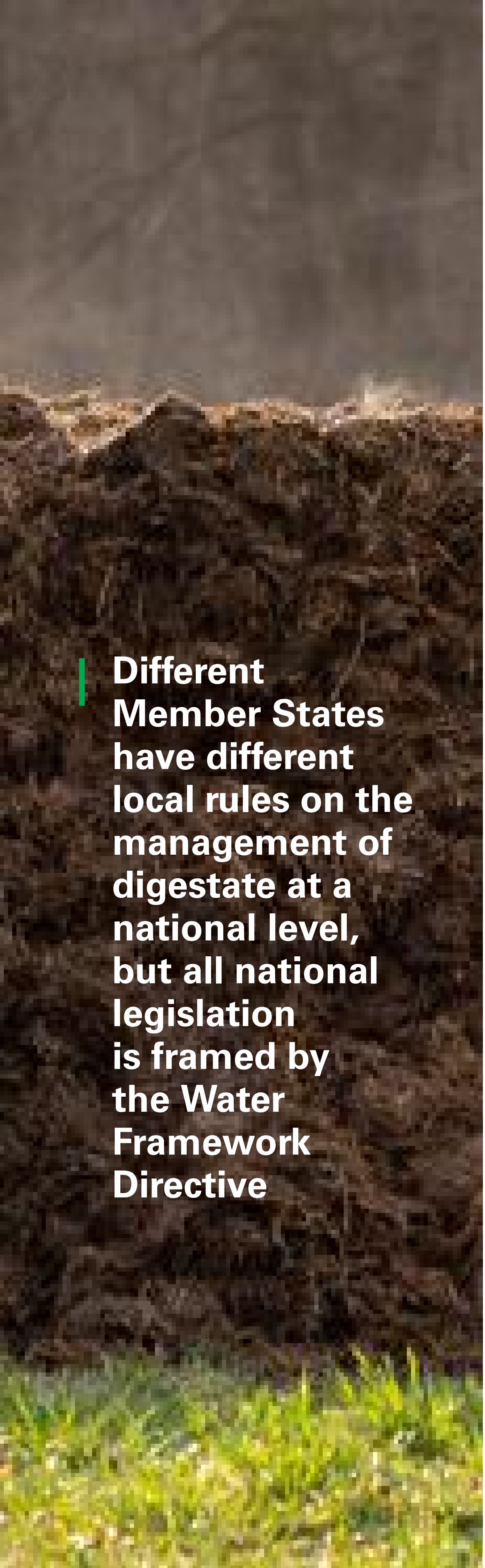
- 1 November - 31 January for grassland, perennial field food
- After harvest - January 31 for farmland

Netherlands

The Netherlands has a very rigorous method for calculating the nitrogen and phosphorus demand for crops and soil that must be followed. Of the 3 countries analysed, it is the most complex.

Nutrient management on farm includes:

- Submission of a nutrient management plan
- A recent soil analyses, N demand of the crop
- Analyse of the manures being applied
- Each load of digestate must be sampled nutrient loading (N & P and heavy metals)
- Site conditions
- Growing conditions
- N demand of the crop
- P demand of the crop
- Storage capacity needed to overcome periods during which soil application of fertilising products is forbidden.



Farmers cannot apply any manufactured fertilisers or organic manures if a field is either:

- For areas with sloping landscapes, obligatory cultivation of catch crops
- For intensive livestock farms without enough land for manure application. The surplus of nitrogen and phosphorus caused by the production of manure is regulated

Method of application:

- Manure and digestate can be applied by an NH_3-emission preventing method. It is obligatory to place the fertilising product in the soil. Most common is a form of injection (e.g. narrow band, shallow injection).
- In tillage ground incorporation within 24 hours

Closed (no-application) period for fertilisers with significant N-content:

- Grassland
  - Slurry- Middle of February to end of August
  - Solid start of February to the end of August
- Arable
  - Slurry- Start of February to end of July
  - Solid start of February to the end of August

From the above review, the common themes in European nutrient management pre and post AD are (1) adherence to the Water Framework Directive as a minimum standard; (2) the submission of a detailed nutrient management plan that addresses soil nutrient status, the nutrient value of the digestate and the nutrient requirements of the crop that is grown; (3) application techniques that minimise the risk of nutrient run-off and ammonia emissions are industry best practice and should be followed – recommended techniques should follow Low Emission Slurry Spreading advice provided by Teagasc; and (4) the provision of enough storage capacity at the AD facility and the facility's farms is of fundamental importance. All European countries have closed periods where no application is allowed.

5 The Devenish Soil Improvement Programme

Soil health is a fundamental requirement for achieving optimal yields and ensuring continued, sustainable production. The Devenish Soil Improvement Programme ("SIP") is a holistic programme to promote soil health, soil nutrition and sustainable growth. SIP targets three key pillars of soil health:

- **Physical structure**
- **Chemical analyses**
- **Biological composition**

These three areas are intrinsically linked. When all three areas are optimised, soil health and plant growth are at the maximum potential. Examples of the interventions that can be used on farm are:

Physical

- Aeration to disrupt surface compaction and allow AIR into the soil. Aeration improves surface drainage, stimulates rooting and enables AIR penetration in support of SOIL LIFE

Chemical

- Analyse soil for key chemical parameters:
  - Liming status
  - Available nutrients (Phosphorus, Potassium, Sulphur)
  - Calcium - Magnesium balance
  - Develop a lime/fertiliser programme to optimise soil fertility
  - Correct Calcium—Magnesium balance to create a more "open" stable soil structure, to allow air interchange, provide an environment for soil life to flourish, encourage nutrient release from soil reserves and improve drainage.

Biological

- Compost (aerobically digested) slurry with DIGEST-IT, a liquid microbial culture.

The SIP has been developed to reduce compaction by taking the following key actions:

Steps

Physical

- Conduct an exploratory walk and dig test holes to find and identify compaction
- Aeration to disrupt surface compaction, improve surface drainage, stimulate rooting and support life in soil

Chemical

- Analyse soil for key chemical parameters to check:
  - pH status
  - Available nutrients (Phosphorus, Potassium, Sulphur)
  - Calcium - Magnesium balance
- Develop a lime/fertiliser programme to optimise soil fertility
- Correct Calcium—Magnesium balance to create a more "open" stable soil structure, allow air interchange, provide an environment for soil life to flourish, encourage nutrient release from soil reserves and improve drainage
- Analyse forage samples to correlate nutrients in soils to nutrients in forage

Biological

- Analyse the soil for basel respiration to access the microbiological level.
- If soil is deficient in biology, a biological inoculant can be added to stimulate and kick-start the soil's biology. Products Like Digest It and Soil and Seed to inoculate the soil and kick start this process.

The final step is the development of a multi-year SIP. This Programme considers the agronomic performance of the farm, the starting point of soil health and the intended use of outputs i.e. which animal or process the forage is being produced to supply.

FARMER CASE STUDIES

Case study 1

Kieran McCarthy is a dairy farmer in west Cork working closely with Devenish on the Soil Improvement Programme. The Soil Improvement Programme is designed to measure and manage the soil's nutrition. The Soil Improvement Programme is a holistic programme designed to improve soil health, grass yield, and quality, which is critical for productivity and animal health. Kieran has been working with Devenish through Bandon Co-op

Kieran is a very progressive farmer always looking to push the productivity and profitability of his enterprise. He was an early adaptor of the Soil Improvement Programme in 2018 and has seen impressive enhancements in performance. Kieran says that the Programme is a major factor in helping him to grow more and better quality grass. He is growing 20% more grass in 2020 than in 2019, up from 10.54 tnDM/ha to 12.6 tnDM/ha in 2020. In addition, there has been a 24% increase in milk solids sold per cow from the farm between 2016 to 2019. Those incremental gains have helped to position his herd amongst the co-op's top 25% performers.

"The Soil Improvement Programme has enabled me to adopt a much more focused management approach and achieve a good return on investment from minimal effort," he explains. The key to growing more grass has been the application of the correct nutrients in the proper ratios to improve grass yield and soil health. Growing more grass has enabled me to match the stocking rate and expand the herd from 120 to 174 cows whilst, milk solids have increased 24% per cow, and the herd has maintained a compact calving, with 87% calving within a six-week calving period.

Kieran is discovering the importance of soil biology and its role in nutrient cycling and keeping his soil at the right indexes to optimise growth. "That is why I add Digest It to my slurry. Apart from reducing crusting and energy required to agitate the tank, the slurry is easier to spread with a trailing shoe, there's less smell, and I'm noticing more worms are in the soil" - an indicator of improved soil health and biodiversity.

"I turn cows out on the grazing platform mid-February and aim to get as much grass into the diet as possible. Whilst I have made significant strides over a relatively short period, I want to continue to grow more quality grass and increase solids while reducing the need for artificial fertilisers and improve the health of my soil consistently".

Case study 2

Martin Heaney is a dairy farmer from Navan Co Meath and is a dual supplier to Glanbia and Lakeland Dairies. He is also a member of the Boyne grazers discussion group. He farms 240 cows on 140 ha. Martin joined the SIP in 2015, "I wasn't happy with the amount of grass that I was growing especially in Spring and Autumn compared to other farmers in the region".

The SIP has given Martin a comprehensive framework to manage soil nutrition and health on farm. The detailed soil tests are a deep dive into the soils on the farm and allow for a bespoke nutrition programme to be designed for optimisation. The beauty of the SIP is that it is a whole farm approach. Although it starts with the soil, it considers the grass grown and its impact on the cow's nutrition.

In the last 5 years, Martin has been a strong advocate and practitioner of the SIP. His grass growth is averaging 14 tnDM/ha. Martin is happy with this growth rate, simply stating, "there is enough grass for the cows to eat, especially in the spring and the autumn, and I'm happy with that".

In 2019 Martin moved to phase two of the Programme, which is maintaining yields while reducing inputs. He has achieved this through:

- Implementing the SIP
- The use of MSS
- Biological inoculation of the soil with Soil and Seed

A farm-scale trial was conducted in conjunction with Thompson and Joseph and Albion Labs. The aim of the trial was to reduce nitrogen and increase the nutrient composition of the grass grown on-farm.

NITROGEN FERTILSER APPLICATION			
		Nitrogen application (kg/ha)	
DATE	N FERTILSER	CONTROL	TREATED
1st May 2019	Urea	56	31
22nd May 2019	Protected Urea	50	25
30th June 2019	Protected Urea	50	25
2nd August 2019	Protected Urea	38	19

Results

GRASS DM YIELD			
		Grass DM Yield (kg/ha)	
DATE	N FERTILSER	CONTROL	TREATED
19th May 2019	Grazed	1800	1800
8th June 2019	Grazed	1600	1600
29th June 2019	Grazed	1200	1200
31st July 2019	Silage	3000	3000
7th September 2019	Grazed	1800	1800
Total		**9400**	**9400**

Note. Martin uses a method to measure grass growth called “eyeballing”. This is a visual method used by experienced farmers to measure grass. It means that figures are approximated rather than quantified.

MINERAL COMPOSITION				
	Control		Treated	
DATE	Phosphorus %	Molybdenum mg/kg	Phosphorus %	Molybdenum mg/kg
19th May 2019	0.31	3.69	0.32	2.67
8th June 2019	0.41	3.29	0.43	3.09
7th Sept 2019	0.45	0.84	0.50	0.79
Mean	**.39**	**2.61**	**0.42 (+7.7%)**	**2.18 (16.5%)**

Over the period May—September, following the Soil and Seed application, nitrogen applications equated to 194 kg/ha (control) and 100 kg/ha (treated). Although nitrogen applications were reduced by 48% on the treated plot, grass DM yields were identical to those recorded on the control plot at 9,400 kg/ha as reported by Martin.

Two minerals that are sensitive to soil health, phosphorus and molybdenum, were measured at the start of three grazing rotations in May, June and September. Overall, phosphorus increased by 7.7% and molybdenum reduced by 16.5%. Phosphorus is essential for energy utilisation in both plants and animals. Molybdenum is a significant antagonistic element to copper availability and represents a risk factor for cow fertility.

This farm trial demonstrates that with a sustained focus on optimising soil nutrition and health, it is possible to maintain grass yields while reducing the nitrogen inputs and increasing the quality of nutrition from that grass.

6 A Model of Irish Suckler Beef Scenarios for Future AD plants

DEVENISH SUSTAINABLE SYSTEMS MODEL

This section presents a multi-scenario model to better understand the impacts of farm-scale AD plants across Ireland. Specifically, this model assesses the likely impacts of growing extra forages on-farm informed by the work at Dowth and current literature and policies on Irish farms. The model's baseline uses the Teagasc National Farm Survey (2019) statistics. The Devenish Sustainable Systems Model (the "model") is based on a 32 ha farm. 31 ha is productive grasslands, 0.25 ha is non-productive (farmyard and tracks) and 0.75 ha are hedgerows and other non-productive areas that are biodiverse. The farm is stocked at 1.15 LU/ha, with national average soil fertility and predominantly permanent pasture.

TABLE 6 THE DEVENISH SUSTAINABLE SYSTEMS MODEL (TEAGASC NFS, 2019)

	ASSUMPTIONS
Farm Size	32 ha
Herd Size	26 cows
Stocking Rate	1.15LU/ha
Grass Utilised	6 tnDM/ha

The model focuses primarily on implementing best practice to boost productivity on-farm using three different sward types:

- Scenario 1: Sowing a perennial ryegrass sward (S1 RG)
- Scenario 2: sowing a MSS system (S2 MSS)
- Scenario 3: Hybrid system – 50% MSS for grazing by the cattle and hybrid ryegrass/ red clover mix for sale to the AD facility (S3 HYB)

Each scenario was compared using several parameters, including:

- Nutrient balance and flow
- Digestate and grass sold
- The total yield of herbage
- Silage AD
- Carbon footprint
- Potential carbon offsets.

The role of other enterprises has not been examined to the same extent. However, in a 'clustered' AD plant set-up, dairy, pig, tillage, horticulture, and other enterprises would be involved through the provision of animal slurry or other feedstock.

S1 RG: All perennial ryegrass

Historically, this farm kept suckler cows and produces weanling cattle (300 kg cattle for sale at 9 – 10 months old) from the 31 ha of grass. The model will use this baseline. It assumes that the productivity of the cattle enterprise will remain constant. Using the baseline farm data in **Table 6**, S1 RG is split between weanling cattle production from suckler cows on 15.5 ha and producing top-class silage from the other 15.5 ha. The remaining hectares include hedgerows and farmyard area. The silage area is cut three times and sold to the local AD plant. It is assumed the farm has an average soil fertility as outlined in the Teagasc Soil fertility report 2020. To improve productivity, the farm will adopt a comprehensive soil fertility programme and reseed with ryegrass lays in Year 1 and 2. Output in this model is curtailed by soil nutrition. Achieving a surplus of nutrients to build soil nutrition is critical. All nutrition inputs come from slurry and digestate with artificial fertilisers making up the balance.

S2 MSS: All Multispecies Swards

In S2 MSS, the same baseline is taken as in S1. The enterprises are also split between weanling cattle production from suckler cows on 15.5 ha and producing top-class silage from the other 15.5 ha. It is assumed the farm has average soil fertility as outlined in the Teagasc Soil fertility report 2020. To improve productivity, the farm will adopt a comprehensive soil fertility programme and the pasture will be reseeded with MSS between Year 1 and 2. This forage is utilised as both animal and AD feedstock. The output in this model is curtailed by soil nutrition. Achieving a surplus of nutrients to build soil nutrition is critical. All nutrition inputs come from slurry and digestate, with artificial fertilisers making up the balance.

S3 HYB: Hybrid Multispecies Swards for weanling enterprise and Ryegrass for selling silage

In S3 HYB, the same baseline is taken as in S1 and S2. This is a hybrid scenario that splits the enterprises between weanling cattle and silage production, similar to S1 RG and S2 MSS. However, this scenario is modelled on multispecies sown and utilised where cattle are grazing. High performing ryegrass and red clover are used where silage production for AD plants is required. It is assumed that the farm has an average soil fertility as outlined in the Teagasc Soil fertility report 2020. To improve productivity, the farm will adopt a comprehensive soil fertility programme and will reseed the pastures to MSS in Year 1 and 2 on the weanling enterprise and AD silage-making, respectively. The output in this model is curtailed by soil nutrition; achieving a surplus of nutrients to build soil nutrition is critical. All nutrition inputs come from slurry and digestate, with artificial fertilisers making up the balance.

Results of the Sustainable Systems Model

The three scenarios modelled are based on practical actions achievable on a typical Irish beef farm using a whole system approach, where not only production and profitability must be taken into account but also the impact on carbon emissions and sequestration potential as well as fertiliser use and biodiversity. Maintaining the number and productivity of the national herd is considered in each scenario in addition to optimising production for incremental forage that can be used as feedstock for local AD plants.

Productivity

One of the main objectives of the study is to maintain the production of the national suckler herd. The study shows that with the appropriate management practices and investment in infrastructure, productivity and soil nutrition the suckler beef enterprise can be at least maintained on 15.5 ha of the farm. In some cases, increased output can be achieved if desired.

The following sections of this report will concentrate on the opportunity to increase yields to supply forage to locally situated AD facilities.

TABLE 7 SUCKLER ENTERPRISE PRODUCTIVITY AND STOCK NUMBERS

Cow numbers	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
S1 RG	26	26	26	27	27	27
S2 MSS	26	26	29	30	30	30
S3 HYB	26	26	29	30	30	30

All scenarios produce forage for sale to AD, demonstrated in **Table 8**. As expected S3 produces the most forage for sale to AD. The model predicts that S2 will produce less than S1, as MSS are more sensitive to soil nutrition and will take longer to achieve peak yields.

TABLE 8 SILAGE FOR AD PLANT TNDM/HA/YR

Whole Farm T DM/ha	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
S1 RG	0	168	176	179	183	185
S2 MSS	0	156	175	176	177	180
S3 HYB	0	204	216	214	216	218

Nutrient Use

Nutrient use is critical in the model. The model is designed to optimise yield whilst leaving a surplus to build soil fertility. The results represent both the cattle enterprise and silage enterprise. The most striking change in nutrient requirements is nitrogen for S2 and S3 compared to S1. In Year 2, nitrogen use for S2 and S3 drops by 54% and 20% respectively compared to S1. Phosphorus requirements for S1 and S3 are elevated compared to S2. Both S1 and S3 have a greater yield of silage which removes more phosphorus meaning it must be supplemented.

A similar trend is seen with potassium, where demand grows in all scenarios. This is a result of forage yield increasing which increases the demand for potassium to balance the system.

TABLE 9 WHOLE FARM NUTRIENT USE (N, P & K)

Total nutrients required KG's		Year 1	Year 2	Year 3	Year 4	Year 5
S1 RG	Nitrogen	6045	6045	6045	6045	6045
	Phosphorus	1360	1360	1278	1278	1178
	Potassium	5341	5453	5423	5423	5663
S2 MSS	Nitrogen	2790	2790	2790	2790	2790
	Phosphorus	1360	1360	1222	1222	1171
	Potassium	5233	5233	5291	5291	5522
S3 HYB	Nitrogen	5425	4805	4805	4805	4805
	Phosphorus	1360	1344	1277	1277	1286
	Potassium	5571	5571	5657	5657	5906

The model looks to create a surplus of phosphorus and potassium to build soil fertility. Shiel et al., (2009) shows surpluses are required over and above the crop's off-take to build soil fertility. The application of nutrients is regulated by SI 605 2017 which has been taken into account in this model. Across all scenarios, Year 1 and 2 show the biggest surplus. This is because the soil fertility indexes are at their lowest, allowing the maximum amount of nutrients to be applied. The second reason is that given yields are at their lowest, less nutrients are being removed but as yields increase, more nutrients are removed. The trade-off between maximising yield and building soil nutrition is of fundamental importance to this model. The more yield removed, the longer it takes to build soil nutrition and reduce artificial fertiliser input and this will also impact the performance of the system against the RED II sustainability requirements.

TABLE 10 MASS BALANCE OF NUTRIENTS ON THE WHOLE FARM KG/HA

Mass balance of nutrients kg/ ha		Year 1	Year 2	Year 3	Year 4	Year 5
S1 RG	Phosphorus	28	28	25	24	21
	Potassium	46	28	28	28	34
S2 MSS	Phosphorus	29	28	21	21	21
	Potassium	55	27	30	29	35
S3 HYB	Phosphorus	26	24	20	19	19
	Potassium	33	5	9	9	16

Nutrients are balanced with artificial fertiliser to make up the deficit. **Table 11-13** represents an average figure for nitrogen, phosphorus and potassium inputs for artificial fertiliser, slurry and digestate. The model assumes that the amount of digestate available to the farm is pro-rata to the amount of grass silage supplied. **Table 11-13** shows that the nutrient source remains relatively constant for the 5 years of the model.

TABLE 11 SOURCE OF PLANT NUTRITION IN S1 (%)

	Artificial Fertiliser	Slurry	Digestate
Year 1	71	4	25
Year 2	69	4	27
Year 3	68	4	28
Year 4	69	4	27
Year 5	68	4	28

Table 12 highlights the source of nutrition for the MSS swards on the farm. Reducing the use of nitrogen fertiliser reduces the need for artificial fertiliser. S2 takes longer to reach an optimised yield which means there is less of a deficit to fill with artificial fertilisers and the system can rely more on organic sources of nutrition. In this scenario, it is the addition of phosphorus and potassium fertiliser that drives artificial use, not nitrogen as the digestate can supply all of the nitrogen needs.

TABLE 12 SOURCE OF PLANT NUTRITION IN S2 (%)

	Artificial Fertiliser	Slurry	Digestate
Year 1	61	8	31
Year 2	66	12	23
Year 3	64	12	24
Year 4	51	10	39
Year 5	50	10	40

Table 13 summarises the source of nutrition for the MSS and hybrid PRG swards on-farm. S3 has the greatest yield across all scenarios, and this will require more nutrient inputs to the system. In Year 2, when all swards are reseeded, artificial fertiliser input drops to 56% due to a decline in nitrogen inputs on the MSS. However, it increases and remains above 56% for Year 3, 4 and 5 - mainly due to increased demand for phosphorus and potassium from increased yield. As yield supplied increases, so does the digestate received back. The greater yields in S3 means that it takes longer to build soil nutrition. Consequently, the ratio of artificial fertiliser, slurry and digestate remains relatively constant as soil nutrition is being optimised.

TABLE 13 SOURCE OF PLANT NUTRITION IN S3 (%)

	Artificial Fertiliser	Slurry	Digestate
Year 1	61	7	31
Year 2	56	8	35
Year 3	61	7	31
Year 4	59	8	33
Year 5	59	8	33

Net Carbon Balance

The absolute GHG emissions and a net carbon position in CO_2e for each scenario are examined in **Table 14-16**. In terms of carbon offsets, a combination of soil carbon sequestration, hedgerow sequestration and a reduction in artificial fertiliser are included. Soil sequestration factors are taken from Fornara et al., (2016), (2017) which gives a range of between 0.3 tnC/ha and 0.9 tnC/ha in Irish soils. Teagasc[70] also provides a range of 1 tnC/ha to (-) 0.4 tnC/ha (source) with an average of 0.55 tnC/ ha. Information on sequestration in hedgerows is taken from Green and Stewart (2014)[71] which estimates a sequestration potential of 1 tnC/ ha.

In S1 the absolute emissions increase as productivity increases on-farm but remain lower than the baseline year, and the intensity of production is reduced per unit of output. In terms of soil carbon sequestration, research shows that as soil pH and nutrition increases, the soil's ability to sequester carbon also increases. The sequestration rates of hedgerows are expected to remain constant as the area is predicted remain unchanged. However, there is an opportunity to enhance the rate of carbon sequestration with improved hedgerow management.

70 personal communication
71 personal communication

TABLE 14 CARBON FOOTPRINT & CARBON OFFSET FOR S1

Whole Farm T DM/ha	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint tnCO_2e	122	115	109	111	117	120
Carbon offset tnCO_2e	42	42	48	55	61	67
Net carbon emissions tnCO_2e	80	73	61	56	56	53

S2 absolute and net carbon emission are outlined in **Table 15**. The carbon footprint is the lowest carbon footprint of the three scenarios and is lower than the baseline year. This is driven by a significant drop in nitrogen use, while maintaining and increasing the production of the farm. S2 offsets more carbon compared to S1 given the significant reduction in nitrogen use and improve soil nutrition which increases sequestration rates.

TABLE 15 CARBON FOOTPRINT & CARBON OFFSET FOR S2

Whole Farm T DM/ha	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint tnCO_2e	122	98	112	100	111	111
Carbon offset tnCO_2e	42	56	62	69	75	81
Net carbon emissions tnCO_2e	80	42	50	31	36	30

Table 16 examines the absolute and net carbon emission from S3. The absolute emissions from S3 are the greatest of all the scenarios, driven by increased productivity. S3 has the greatest output in terms of cattle and silage production. Carbon offsets less than S2, due to the greater level of inputs required. As a result, S3 has the greatest net emissions across all scenarios. However, it also achieves the highest forage output of all three scenarios.

TABLE 16 CARBON FOOTPRINT & CARBON OFFSETS FOR S3

Whole Farm T DM/ha	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint tnCO_2e	122	114	123	126	134	137
Carbon offset tnCO_2e	42	45	53	61	66	72
Net carbon emissions tnCO_2e	80	69	70	65	68	65

The scenarios so far are predicated on the farmer maintaining their suckler cow herd. To further understand the impact of the beef herd, we have deconstructed scenario 2 MSS. To do this we assumed that the beef herd was retired on the farm and the farm converts to 100% forage production. The main finding is that 69% of the carbon footprint is associated with enteric methane production and nitrous oxide arisings from artificial nitrogen application.

This report doesn't advocate the reduction of a herd, but if it were to happen due to socio-economic factors such as an aging farmer population who are looking to reduce their workload, growing forage would be a possible solution to allow this to happen. In **Table 17**, scenario 2 MSS is shown without the suckler herd and producing forage only from all the farmable area.

TABLE 17 CARBON FOOTPRINT AND CARBON OFFSET WITHOUT CATTLE S2

Whole Farm T DM/ha	Baseline Year	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint tnCO_2e	51	17	8	18	9	12
Carbon offset tnCO_2e	42	56	62	69	75	81
Net carbon emissions tnCO_2e	9	-39	-54	-51	-66	-69

Emission intensity per scenario

To further understand the flows of carbon in the models, absolute emissions and intensity of forage production were examined. Absolute emissions is the metric for GHG emissions regardless of the output and intensity of the emissions is value were emissions are measured per unit of output in this case tnDM of forage. For this analysis only emissions associated with the production of silage are analysed. The emissions associated with cattle production are ignored in this analysis. On average across the scenarios, cattle production accounts for 69% of the total emissions arising.

In Scenario 1, total absolute emissions decrease from 15 tnCO_2e to 9.3 tnCO_2e. In Scenario 1 when the intensity of emissions are examined, they drop from 0.09 tnCO_2e/ tnDM to 0.05 tnCO_2e/ tnDM, the extra production of forage decreases the unit intensity. Lime is applied in Year 1, 3 and 5 in all scenarios, which accounts for jump in emissions in those years.

TABLE 18 EMISSIONS INTENSITY S1

Scenario 1	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint (forage production) tnCO_2e*	15.0	4.3	15.6	5.9	9.3
tnDM Grass produced for sale	167.9	176.2	179.1	183.3	185.0
Carbon footprint tnCO_2e/ tnDM of forage	0.09	0.02	0.09	0.03	0.05

** Carbon footprint of forage for sale only. CO_2e from the cattle enterprise not used for calculation*

Scenario 2 reduces both absolute and intensity-based emissions. The primary driver of this is the reduction in nitrogen use to grow the swards. Total absolute emissions reduce from 12.7 tnCO_2e to 7.1 tnCO_2e Lime in Year 1 and 3 cause the emissions to spike when it is applied. In terms of the intensity of emissions, they drop from 0.08 tnCO_2e/ tnDM to 0.04 tnCO_2e/ tnDM - a 50% reduction. This differs from **Table 19** as it looks at silage production on one half of the productive area, where as **Table 17** looks at silage production on all the land available on farm.

TABLE 19 EMISSIONS INTENSITY S2

Scenario 2	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint (forage production) tnCO_2e	12.7	2.1	13.4	3.8	7.1
tnDM Grass produced for sale	156.0	174.7	175.6	177.3	180.1
Carbon footprint tnCO_2e/ tnDM of forage	0.08	0.01	0.08	0.02	0.04

In Scenario 3 intensity based emissions decrease. Total absolute emissions decrease from 14.8 tnCO_2e to 9.2 tnCO_2e, while the intensity of production also decreases from 0.07 tnCO_2e/ tn DM to 0.04 tnCO_2e/ tn DM.

TABLE 20 EMISSIONS INTENSITY S3

Scenario 3	Year 1	Year 2	Year 3	Year 4	Year 5
Carbon footprint (forage production) $tnCO_2e$	14.8	5.5	15.5	5.8	9.2
tnDM Grass produced for sale	203.9	215.8	213.7	215.9	218.2
Carbon footprint $tnCO_2e$/ tnDM of forage	0.07	0.03	0.07	0.03	0.04

DISCUSSION

Soil nutrients

The model's core outputs are delivering forage for the AD facility and optimising soil nutrition as quickly as possible. These two variables have to be managed correctly. The circulatory of nutrients is paramount and achieving optimum soil nutrition is a key consideration in the first 5 years in order to reduce the amount of artificial fertilisers needed. In practice, there will be a dynamic balance between cattle slurry's nutrient value and digestate from the AD facility. If the nutrient value of slurry and digestate is greater than predicted in the model, then circularity can be achieved quicker. S2 and S3 show the best pathways to achieving this, given that nitrogen fertilisers are substantially reduced.

To achieve circularity and build soil nutrition, we recommend identifying and securing farms to supply forage as early in the process as possible. If soil nutrition could be managed and improved before forage is removed to the AD facility, it would significantly enhance soil nutrition and could also increase the forage yield available to the AD facility. A 2 year lead time to implement these practices would be beneficial.

Yield output

S3 achieves the best yield, followed by S1 and S2. Given that MSS are more sensitive to soil nutrition than PRG, S2 does not out-yield S1. In contrast, S3 achieves a greater reduction in nitrogen use compared to PRG and can also achieve greater yields as well as act as act as an excellent substrate for AD. However, one must consider the persistency of the mix when using hybrid PRG and red clover (S3) and must implement excellent agronomic practices to prolong its productive lifetime. The development of an indigenous agri-led biomethane industry should consider enlisting agronomists to advise farmers suppling forage as feedstock. MSS and HYB mixes are new technologies for most farmers. As such, having agronomic advice available to farmers would ensure better technical and environmental outcomes.

Carbon footprint

The report calculates the emissions in two ways:

- Gross emissions
- Net emissions

Gross emissions: in all three scenarios, the carbon footprint of the farm's model is related to the intensity of the product - the greater the production in the models, the higher the gross emissions. However, it should be noted that S3 is only marginally higher than S2, even though production is higher, indicating the greater carbon efficiencies achieved in S3. In terms of absolute emissions S2 gives the greatest reduction in absolute emissions, in Year 5 having CO_2e emission of 111 tns CO_2e compared to emissions of 122 of tns CO_2e in the baseline year. Each scenario has its benefit and challenges, the adaption of any of the systems will require an analysis of the market requirements, legislative framework and local environmental conditions to implement the correct system. This is also backed up with the reduction in intensity of emissions too. S2 provides a credible way to increase production on farms while reducing their greenhouse gas emissions.

Net Emissions: at Dowth, Devenish is pioneering "net carbon emissions", calculating the difference between the gross emissions and carbon sequestration on-farm. Net emissions factor in the landscape's sequestration potential i.e. the soil and hedgerows. Across the three scenarios, S1 achieves a reduction of 48%, S2 achieves a reduction of 64%, and S3 achieves a reduction of 47% in carbon emissions, respectively. Please note that these are site-specific. Detailed measurements will be required to calculate net emissions for other farms.

7 Concept of a Biomethane Charter

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

While the Charter would need to be fully developed in consultation with industry stakeholders, we have outlined below a potential approach which would incorporate a two-tier approach to ensure compliance:

(i) Tier 1 (compulsory compliance)

(ii) Tier 2 (optional best practice)

Each level of compliance will cover the following broad areas:

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

Sustainability Criteria

A fundamental objective of the establishment of an indigenous biomethane industry is to promote and enhance environmental sustainability. As such, all AD plants must be expected to meet the highest of environmental standards, including, though not limited to RED II and future RED III sustainability criteria compliance. This will ensure that AD plants will not encroach on areas of high biodiversity value, high carbon stocks or former peatlands. Where a proposed site is situated in an area of 'High Nature Value' ("HNV"), it is proposed that an Environmental Impact Assessment or screening process is undertaken to ensure biodiversity is maintained.

Participating farmers are expected to comply with the NAP regulations, such as livestock stocking rates, maximum fertilisation rates and closed periods for spreading fertilisers as well as compliance with NAP reporting requirements, such as area farmed, storage facilities and livestock numbers on farm.

Participating farmers would also be expected to align with the Statutory Management Requirements ("SMR") and Good Agricultural and Environmental Condition[72] ("GAEC") standards:

SMR	GAEC
SMR 1 Protection of water against pollution caused by nitrates.	GAEC 1 – Establishment of Buffer Strips along Watercourses
SMR 2 Conservation of Wild Birds.	GAEC 2 – Where the use of Water Irrigation is subject to authorisation, compliance with authorisation procedures.
SMR 3 Conservation of Natural Habitats and of Wild Flora and Fauna	GAEC 3 – Protection of Ground Water against Pollution.
SMR 4 Food and Feed Hygiene.	GAEC 4 – Minimum Soil Cover.
SMR 5 Restrictions on the use of substances having hormonal or thyrostatic action and beta-agonists in farm animals.	GAEC 5 – Minimum Land Management Reflecting Site Specific Conditions to Limit Erosion.
SMR 6 Pig Identification and Registration.	GAEC 6 – Maintenance of Soil Organic Matter Levels through appropriate practices.
SMR 7 Cattle Identification and Registration.	GAEC 7 – Retention of Landscape Features and Designated Habitats and Controlling Invasive Species.
SMR 8 Sheep and goat Identification and Registration.	
SMR 9 Prevention and control of Transmissible Spongiform Encephalopathies (TSEs).	
SMR 10 Plant Protection Products (PPPs).	
SMR 11 Welfare of Calves.	
SMR 12 Welfare of Pigs.	
SMR 13 Welfare of Farm Animals	

An additional criterion for consideration is alignment with the goals of the EU Farm to Fork Strategy. The headline target which is recommended to be progressed under Tier 1 is:

(i) A reduction in nutrient loss

More ambitious Farm to Fork goals recommended for alignment with the Charter are included under Tier 2 compliance.

72 https://www.gov.ie/en/publication/246da-cross-compliance/

Improved Land Management Programme

To achieve Tier 2 compliance, it is proposed that two overarching land management programmes be progressed:

Firstly, the more ambitious Farm to Fork goals:

(i) Implement new green business models that sequester carbon

(ii) Promote a circular bio-based economy

(iii) Reduce pesticide use and excess nutrients

(iv) Reduce fertiliser use

(v) Increase organic farming

It is suggested that participating famers agree to target two of the above goals in addition to the displacement of an agreed proportion of chemical fertiliser with processed digestate - depending on farm type, soil quality and location.

Secondly, participating farmers will be expected to trial the recommendations of the Devenish Soil Improvement Programme (or equivalent) to optimise soil health, nutrition and minimise soil compaction. See **section 5** for further details.

Advanced Measurement, Reporting and Verification

It is proposed that Tier 2 participating farmers be required to provide periodic reports and sampling on the wider sustainability performance of their farm. Tier 2 participants will be required to adhere to a more comprehensive measurement, reporting and verification (MRV) framework to monitor the performance of participating farms. It is proposed that the following are included for MRV:

(i) Biodiversity richness (via GPS enabled photography or sampling methods such as transects or netting)

(ii) Sampling and analysis for soil carbon

Important Notice:

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