National Heat Study

Sustainable Bioenergy for Heat

Spatial Assessment of Resources and Evaluation of Costs and Greenhouse Gas Impacts

SEAI Sustainable Energy Authority of Ireland

Sustainable Bioenergy for Heat:

Spatial Assessment of Resources and Evaluation of Costs and Greenhouse Gas Impacts

Report 7 of the National Heat Study

February 2022

V1.0

The National Heat Study and assiocated reports were commissioned by a project team across the SEAI Research and Policy Insights Directorate and developed with the assistance of Element Energy and Ricardo Energy and Environment.

Disclaimer

Sustainable Energy Authority of Ireland

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of Communications, Climate Action and Environment.

Key insights

Everyday economic activity produces a range of low-value and sustainable biomass resources that are suitable for energy production. These by-products and wastes from households, businesses, agriculture, and forestry could provide about 6.5 TWh of Ireland's fuel, or about 4% of primary energy supply.
Just over two-thirds of this resource is currently being used. These resources are unlikely to increase significantly in the future - an additional 1.2 TWh could be available by 2050. These resources are often available at low cost, and their use is sustainable (for example, they have low upstream GHG emissions.)

Growing energy crops offers an opportunity to increase the domestic bioenergy resource substantially. This needs to be done in a sustainable way to minimise upstream emissions, align with circular and bioeconomy goals, and avoid increasing emissions in non-energy sectors.
Nationally appropriate sustainability governance is required to ensure this.

Making land available to grow energy crops will require changes in land use and in farm management practices to increase the productivity of grass land sustainably.
It will require actions in both the agricultural and energy sectors.

Growing grass as an energy crop for anaerobic digestion to produce biomethane should be based on cultivation systems which minimise nutrient input while still achieving a sufficient yield, for example by including nitrogen fixing species such as red clover in the grass mix.
Even for such grass systems, for the produced biomethane to meet sustainability criteria, the grass silage needs to be mixed with slurry in a 50/50 mix when anaerobically digested.

Spatial analysis shows that for almost all regions where grass silage is most likely to be grown, enough slurry is available nearby to allow co-digestion of the silage with slurry in a 50/50 mix.
In parts of Galway where particularly high levels of grass silage production is forecast, this may not be the case and the additional grass silage could be transported to areas of less advantageous additional grass silage opportunities to produce biomethane.

Based on current national herd forecasts, biomethane production from a grass silage/slurry mix, could deliver 2.7 TWh of biomethane equivalent to 5% of current gas supply.
Other food waste resources and pig slurry could increase this to 3.7 TWh. If beef farming were to decline further making more land available for energy crops then injection of an extra 1.4 TWh could be possible. In this case total biomethane injection of up to 5.1 TWh or 10% of current gas supply would be possible.

Developing perennial energy crops such as short rotation coppice willow could take longer to develop than growing grass silage, due to the currently underdeveloped supply chain. However they could deliver more energy and higher greenhouse gas savings than biomethane from grass silage.
This is dependent on there being an end use for perennial energy crops in the energy system.

High level analysis suggests that the substantial levels of energy crop planting evaluated here are compatible with an afforestation target of 8,290 ha per year.
Further research into how these two objectives could be integrated into a cohesive land-use change policy or plan would be useful, as would a more detailed analysis to ensure that there are no conflicts if ambitions for afforestation or energy crop planting are above those examined here.

Imports of wood pellets and bioLPG could increase available bioenergy resources.
Strong sustainability governance is needed to ensure that these imports also meet appropriate sustainability criteria. This is likely to restrict the regions from which wood pellets can be imported and limit bioLPG imports to bioLPG produced from waste feedstocks.

Acknowledgements

SEAI, Ricardo Energy and Environment and Element Energy and would like to convey our thanks to the following organisations and individuals for their valuable input to the study.

- **COFORD Council:** Eoin O'Driscoll
- **Coillte:** Sharon Fitzpatrick
- **Devenish Farms:** David Hagan
- **Department of Agriculture Food and the Marine:** Fergus Moore, John Redmond, Michelle Kearney, Patrick Barret, Philp Blackwell, Tony Quinn,
- **Department of the Environment, Climate and Communications:** Andre Caldicot, Brian Quirke, Carmel Fields, Fiona McManus, Kevin Brady, Kevin O'Donaghue
- **EPA:** Bernard Hyde
- **Ervia**: Paul Ahern, Gearoid Fitzgerald, Andrea Ahern, Des McCabe,
- **GNI:** Ian O Flynn, Ian Kilgallon, Niamh Gillen
- **IE NETS project team:** Dr. Barry McMullin (DCU); Prof. Mike Jones (Trinity)
- **Irving Oil**: Mike King, Niamh Callanan, Brian Dillon
- **National University of Ireland, Galway**: Rory Monahan
- **National University of Ireland, Cork** : Richard O'Shea, Jerry Murphy
- **Teagasc:** Barry Caslin , Dominika Krol, Elodie Ruelle, Fiona Thorne, Jeskow Zimmerman, Karl Richards. Trevor Donnellan, Maurice Deasy, Michael O'Donovan.

To avoid doubt, this acknowledgement does not imply endorsement by the stakeholders listed, and this report is solely the work of Ricardo Energy and Environment, Element Energy and the Sustainable Energy Authority of Ireland.

Contents

Executive summary

Ireland's Climate Action legislation has set legal requirements for greenhouse gas emissions reductions. By 2030, emissions must be 51% less than in 2018, and by 2050, the Irish economy must be carbon neutral [1]. The carbon budgeting process described by the legislation will set out the annual emissions reduction trajectory and set greenhouse gas limits for each sector of the Irish economy to meet these targets. These limits represent Ireland's contribution to the principal aim of the Paris Agreement: to kerb global temperature increases by restricting the total amount of greenhouse gas emissions emitted into the atmosphere.

Reducing and removing heat energy emissions is a difficult challenge. Over the last decade, many businesses and households have added insulation, installed more efficient technology and used less solid fuel. However, annual emissions from energy used for heating have been on an increasing trend since 2014, when Ireland emerged from the effects of the global 2008 recession. Annual CO_2 emissions from energy used for heat (excluding electricity generation) were 12% higher in 2020 than in 2014; emissions from the residential sector were up 18%, services were up 13% and industry increased by 9%.

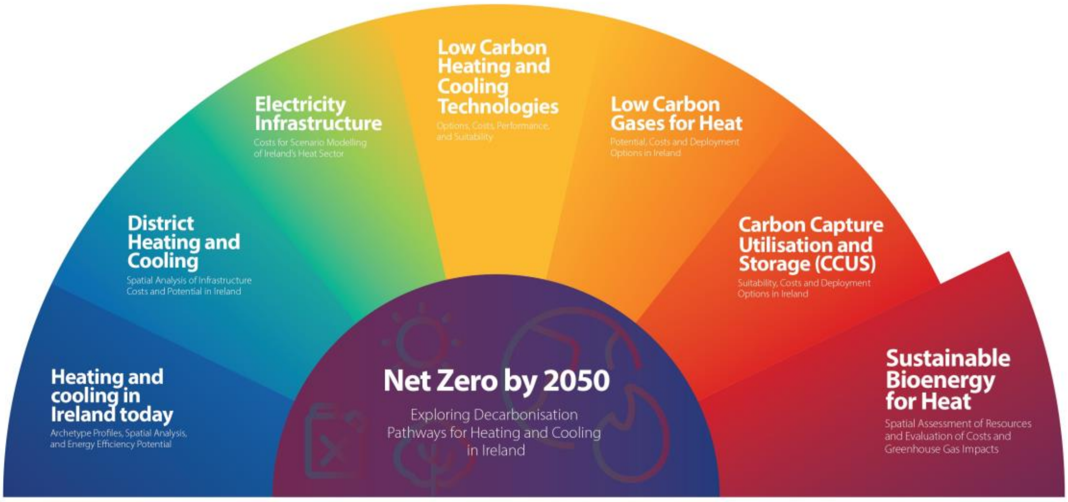
The Irish Government has published a Climate Action Plan that identifies actions to turn these trends around. The Plan, revised annually, specifies actions that aim to keep emissions within the carbon budget limits for each sector. The first Plan required under the Climate Legislation was published in late 2021 [2]. Several of the measures identified in the Plan rely on the outcome of the work of this National Heat Study to inform the policy ambition.

The National Heat Study aims to provide a rigorous and comprehensive analysis of the options to reduce CO_2 emissions associated with heating in Ireland. The Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the study. The project was carried out in close collaboration with the Department of the Environment, Climate and Communications. As well as contributing to national policy, the findings also supported Ireland's second submission to the EU of a National Comprehensive Assessment of the potential for efficient heating and cooling, as required by Article 14 of the Energy Efficiency Directive.[1] The data, assumptions and outcomes of the National Heat Study are detailed in eight technical reports (*Figure 1*).[2] The project leaves SEAI with an enhanced modelling and analysis capability to continue providing insights and tackling further work. It has enabled a comprehensive stakeholder engagement that has delivered insights and information and started many new important discussions. It also provides a detailed set of data and information to inform broader research efforts in Ireland.

[1] SEAI, 'Comprehensive Assessment of the Potential for Efficient Heating and Cooling in Ireland, report to the European Commission'. 2021 [Online]. Available: https://www.gov.ie/en/publication/e4332-introductory-text-for-publication-of-the-national-comprehensive-assessment-on-govie/#

[2] Available at SEAI webpage: https://www.seai.ie/data-and-insights/national-heat-study/

Figure 1: Overview of the reports contributing to the National Heat Study



This report, *Sustainable Bioenergy for Heat,* serves as a standalone document detailing the analysis carried out to estimate the availability, cost and sustainability of bioenergy resources in Ireland. The analysis was overseen by an advisory group, with representatives from the Department of Agriculture, Food and the Marine, Department of the Environment, Climate and Communications, Teagasc and the Environmental Protection Agency.

Bioenergy is a low carbon fuel that can be used to replace carbon intensive fossil fuels. The use of organic fuel to create bioenergy releases carbon dioxide (CO_2) into the air, but this is offset by new plants that consume that CO_2 during growth. However, sourcing and processing biomass for energy can itself create CO_2 and other greenhouse gas emissions. Therefore, it is vital to ensure that the biomass is sourced in a sustainable way that minimises these additional greenhouse gas emissions and any other environmental impacts. About 4.8 TWh of bioenergy resources are already used in Ireland [3]. This report examines what additional resources are available or could be developed sustainably under a range of scenarios developed for the National Heat Study.

This analysis examines the availability, price and sustainability of three types of bioenergy resources as shown in *Figure 2*.

Figure 2: Overview of bioenergy resources considered in the study

	By-Products, residues, and wastes	Energy Crops	Imports
Forestry Sector	• Forestry thinnings and harvesting residues • Sawmill residues		• Wood pellets
Agriculture	• Straw • Cattle slurry • Pig Slurry	• Grass Silage for AD • Perennial energy crops (e.g., SRC willow or miscanthus)	
Waste	• Waste wood • Residual waste • Food waste • Industrial food waste • Tallow • Used cooking oil		• BioLPG
Quantity	Quantity dictated by activity in sector generating co-products; little opportunity to influence quantity, focus on increasing collection and use	Opportunity to increase resource given land availability, the right policy signals, and end market	Can be used to bolster domestic resources
Cost	Often low cost but competing uses	Higher cost but no competing uses	Often low cost but competing uses
Sustainability	Generally good sustainability – few upstream GHG emissions	Need to ensure produced in a sustainable way that minimises emissions	Need to ensure sourced sustainably; long transport distances will increase upstream GHG

Bioenergy resources that are currently available and utilised are generally those that are a by-product of other activities or a waste. They include:

- Thinnings and residues from harvesting activities in forestry and residues created during the processing of timber in sawmills.
- By-products and wastes from the agricultural sector: straw from cereal production, cattle and pig manures.
- A wide range of wastes including food waste and used cooking oil from households, catering and the commercial sector, wastes from food processing including tallow from rendering animal carcasses, wastes from processing of dairy products, slaughter house waste, waste wood, and the organic component of residual waste from households and the commercial sector.[3]

These bioresources have several common characteristics. They are available now, typically at a relatively low cost. Additional greenhouse gas emissions associated with their use for bioenergy are generally low. Their

[3] Residual waste is the waste left after recyclable materials and food waste are removed.

use can help address other environmental issues and is in line with the aims for a circular economy by utilising by-products and wastes instead of disposing of them. However, the quantities of these bioresources are unlikely to increase significantly in the future, as the quantities generated are driven by activity in the primary industry itself and not by demand for bioenergy. The driving activities are not influenced by how the energy system changes. Therefore, the quantity of each of these bioresources is assumed to be the same under each of the scenarios modelled in the National Heat Study.

Significant increases in bioenergy resources could, however, be achieved by cultivating energy crops. These include:

- Grass for use in Anaerobic Digestion (AD) plant to produce biomethane. This has been a prominent feature of recent policy discussions, with widely differing views on its sustainability and viability. Therefore detailed modelling of this resource was carried out as part of this assessment.
- Perennial energy crops, such as miscanthus and short rotation coppice willow, for use in combustion and other thermochemical energy production technologies, potentially including power plants equipped with carbon capture and storage. Currently, in Ireland, only minimal amounts of perennial energy crops are used to generate energy.

The analysis here and elsewhere indicates that sustainability requirements under the Renewable Energy Directive for heat produced from biomethane will not be met unless grass is co-digested with significant quantities of slurry. Slurry's highly liquid content means that it is not economic or environmentally desirable to transport it long distances to an AD plant. While grass silage can be transported over greater distances, it is still desirable from both an economic and environment standpoints that the necessary quantities of both resources are located within a relatively small radius from the plant. In addition to identifying the total quantity of silage and slurry which could be available, a spatial analysis was also conducted in order to check that sufficient quantities of both grass silage and slurry were likely to be available within a small enough radius of an AD plant.

In determining the total quantity of grass silage that might be available, only the production that would not compromise the availability of grass necessary to support the national herd as either grazing or fodder is considered. This is done by working out the changes in grazing and fodder requirements resulting from future changes in the size and composition of the national herd. Parcels of land on farms where the productivity of the grassland could be improved are then identified, allowing more livestock to be supported on a smaller area. The number of dairy cows in the national herd is forecast to increase; thus on dairy farms an increase in productivity is needed to support an increased number of dairy cows. On the other hand, the suckler herd is forecast to decline, with beef farms requiring less land to support the livestock. This is because, firstly, the number of livestock on farms is assumed to fall (in line with the changes in the national herd) and, secondly, because the productivity of some grassland areas can be improved. Once the land no longer required for grazing or fodder production on beef farms is identified, its suitability for growing energy crops is assessed. Also considered, based on the size of the area identified, is how likely it was that farmers would switch to energy crop production.

To ensure that the upstream greenhouse gas (GHG) emissions from grass silage production were minimised, the production of grass silage from a red clover/rye grass mix is modelled. Growing this mixed sward rather than just ryegrass allows application levels of nitrogenous fertilisers that lead to emissions of the GHG nitrous oxide from the soil to be reduced. A further assumption is that all of the nitrogen applied came from digestate from the AD plant rather than synthetic fertiliser.

The National Heat Study considered four energy system scenarios with different themes. *Table 1* shows the different assumptions for each scenario in relation to the development of the national herd, and whether grass silage for AD or perennial energy crops would be grown. The 'Stable Herd' projection formed the basis of the projections for greenhouse gas emissions from livestock in the National Climate and Energy Plan [4]. Under this scenario, the dairy herd increases by 10% by 2030, but the suckler herd reduces by 23%, giving an overall reduction in the national herd of 0.5%. The Land Use Change (LUC) scenario was created for input into the National Heat Study analysis. It is assumed that a desire to reduce livestock emissions from agriculture leads to a more significant reduction in the suckler herd, of 45% (about 440,000 head) by 2030, compared with that in the Business As Usual (BAU) stable herd projection. The dairy herd is assumed to show the same increase as in the BAU scenario. Overall, the national herd is reduced by almost 600,000 head (8.4%) to 6.5 million.

Table 1: Energy crop assumptions under the National Heat Study energy scenarios

	Baseline (Business as Usual)	Decarbonised Gas	High Electrification	Balanced	Rapid Progress
Energy system theme	Current policy	Policy supports expansion of the gas grid, implementation of CCS/BECCS* in power and industry, the production of green hydrogen,	Focus on electrification and energy efficiency. The gas network extent reduced.	Diverse policy supports electrification alongside use of green hydrogen and biomethane, implementation of CCS/BECCS in power and industry	Policy supports electrification in the near-term alongside the increased use of biomethane in the gas grid, implementation of CCS/BECCS in power and industry,
Energy crops theme	No drive to increase production of energy crops	Maximise grass silage and biomethane production	Maximise perennial energy crops	Mix of grass silage and energy crops	Maximise grass silage and biomethane production
Herd scenario	Stable Herd	Stable Herd	Stable Herd	Stable Herd	Land Use Change
Increase in productivity of grasslands	No	Yes	Yes	Yes	Yes
Use of land 'released' due to changes in herd	Grass silage	Grass silage	Perennial energy crops	50% grass silage 50% perennial energy crops	Grass silage

*Carbon capture and storage(CCS)/ Bioenergy with carbon capture and storage (BECCS)

Figure 3 shows the development of the domestic bioenergy resource over time under each of the scenarios. The domestic bioenergy resources considered in this study are estimated to amount to 6.5 TWh in 2020, about 4% of primary energy supply.[4] Just over two-thirds (4.4 TWh) of these resources were utilised for bioenergy in 2020[5], suggesting that bioenergy use could be increased. In addition to these domestic resources, about 2 TWh of imported bioenergy was used, of which three quarters was liquid biofuels for transport with the remainder being wood pellets for co-firing in power stations and for biomass boilers.

By 2030, the potential bioenergy resources could increase by around a third in the Baseline scenario, with most of the increase coming from:

- Grass silage grown for AD on land no longer needed for grazing and fodder as the suckler herd declines
- An increase in sawmill residues as more sawlogs are harvested and processed
- More small roundwood from thinnings and increased harvesting operations.

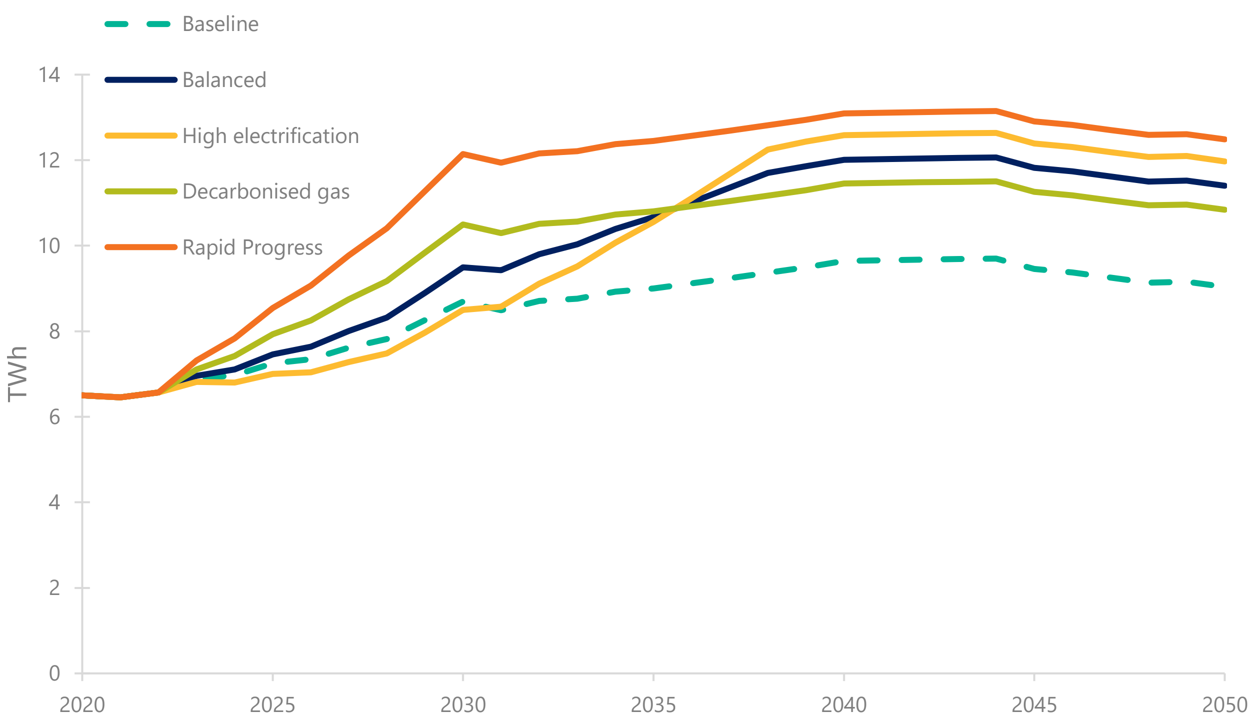
[4] Based on primary energy supply for 2019 and 2020 from [5], [3]

[5] An additional 0.4 TWh of biogas from sources not considered in this study (landfills and AD of sewage sludge) were also used in 2020 [3].

There are also small increases in the amount of food waste from domestic and commercial premises, as the separate collection of these resources improves, and larger quantities of wastes from slaughter houses and milk processing are assumed to be available. There is, however, a decline in the amount of residual waste as recycling and separate collection of food waste are assumed to increase.

In the period 2030 to 2050, the accessible bioenergy resource is forecast to increase by another 5%, due mainly to further increases in sawmill residues and, to a lesser extent, further increases in food waste collection. However, quantities of small round wood available for bioenergy decline and quantities of residual waste fall further, so that the overall increase is relatively small.

Figure 3: Total domestic bioenergy resource under the five modelling scenarios



As described earlier, the Decarbonised Gas scenario assumes that efforts are made to ensure that grassland productivity and utilisation are increased, allowing more land to be freed up to produce grass silage. This increases resources by 1.8 TWh per year by 2030 compared to the Baseline. The Rapid Progress scenario, explores the impact of a more significant reduction in the suckler herd, and in this scenario the additional land, which is then available to grow grass silage for AD, leads to an extra 1.6 TWh compared to the Decarbonised Gas scenario in 2030 (3.4 TWh more than the Baseline).

The High Electrification scenario explores the possibility of using land released from beef production in the Decarbonised Gas scenario for perennial energy crops rather than grass for AD. Due to the time needed to establish the supply chain for energy crops and to roll out their planting, the resource from these crops in 2030 is relatively limited (1.1 TWh) but by 2050 they are able to deliver 4.2 TWh, giving an overall increase in the bioenergy resource of 3.4 TWh. This scenario has the highest overall resource in primary energy terms, for example, the energy content of the resources. This is because the energy content of the perennial energy crops that can be grown on a hectare of land is (based on the assumptions used in modelling) greater than that of the silage produced. So a hectare of land used to grow short rotation coppice willow could support delivery of 40 to 45 MWh of heat per year, about a third more than when used to grow a red clover/ryegrass mix for silage for AD (30 MWh of heat per year). This higher energy density, combined with low upstream emissions for the cultivation of willow means that the overall greenhouse gas savings achieved from using a hectare of available land to grow perennial energy crops is likely to be greater than when used to produce silage for biomethane production.

Figure 4 shows cost supply curves for the Balanced scenario for 2030 and 2050. These show the amount of resource that can be supplied at a particular cost. The costs are for the resource itself, and in most cases, they do not fully represent the cost for the feedstock that will be seen by the end-user. For example, in the case of forestry resources and perennial energy crops, these are the cost of the resource at the 'farm gate' or 'forest road' and do not include the costs of any processing such as chipping or pelleting, or the costs of distributing chips and pellets to end-users. In the case of resources used to produce biogas, the costs are for the feedstock only. They do not include the costs of operating the AD plant to produce biogas from the resource. The attractiveness of a resource to an end-user may also be affected by the ease and efficiency with which it can be converted into heat or power. These additional costs and factors are modelled and accounted for in other parts of the Heat Study, where an end-user perspective is modelled. The cost curves do, however provide an initial view of the relative cost of resources.

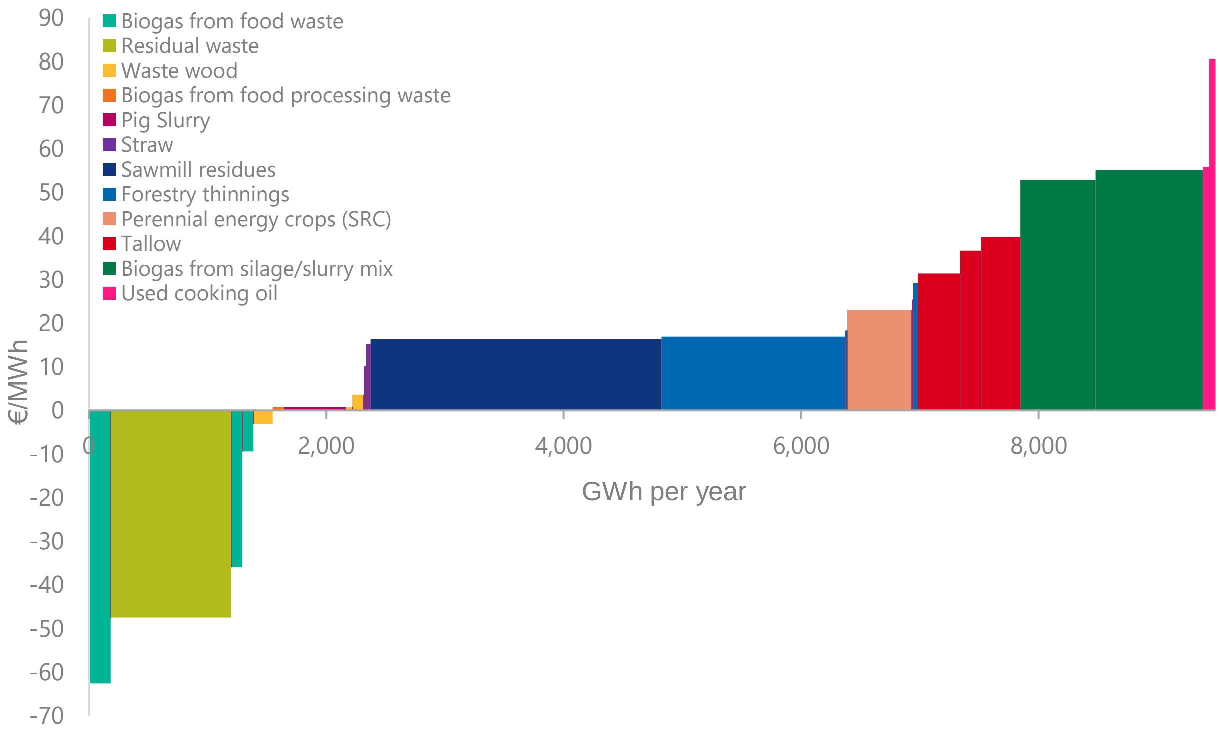
In the Balanced scenario, about 2.3 TWh (just under a quarter of total resources in 2030) are wastes that are available at zero or negative cost; for example, a producer will pay to have the waste managed by a waste facility. A further 4.2 TWh (4.5 TWh by 2050) of by-products and residues, including forestry thinnings, sawmill residues and straw, are available at a relatively low cost of under 2 c/kWh (€20/MWh). Perennial energy crops have a slightly higher cost than this, of 23 to 26 €/MWh, and biogas from a grass silage/slurry mix an even higher cost of 53 to 55 €/MWh. However, as discussed above, these costs do not include conversion and processing costs, so care should be taken in comparing them directly. By 2050, these energy crop resources comprise about a third (3.6 TWh) of the total resource. The remainder of the resource (1 TWh in 2050) is used cooking oil and tallow. While these are wastes, they command a relatively high price due to the established markets for them (such as UCO is used to produce biodiesel).

The potential for supplementing domestic resources with imported biomass fuels is also assessed. Ireland already imports some wood pellets to supplement the domestic supply of pellets in the heating sector, and if demand increases then, imports could be increased. In addition, large-scale import of wood pellets could be a feedstock of interest for any future large-scale bioenergy power plant with carbon capture and storage (BECCs) or for gasification plant to produce biomethane to help green the gas network. The sustainability of any such imports is critical, both in terms of ensuring that wood for the pellets comes from sustainably harvested forests, and that emissions associated with producing and transporting the pellets are kept as low as possible. By 2050, it is estimated that an additional 2.7 TWh of pellets from Europe, and 16.3 TWh of pellets from the US could be available for import that would meet the sustainability requirements under the Renewable Energy Directive.

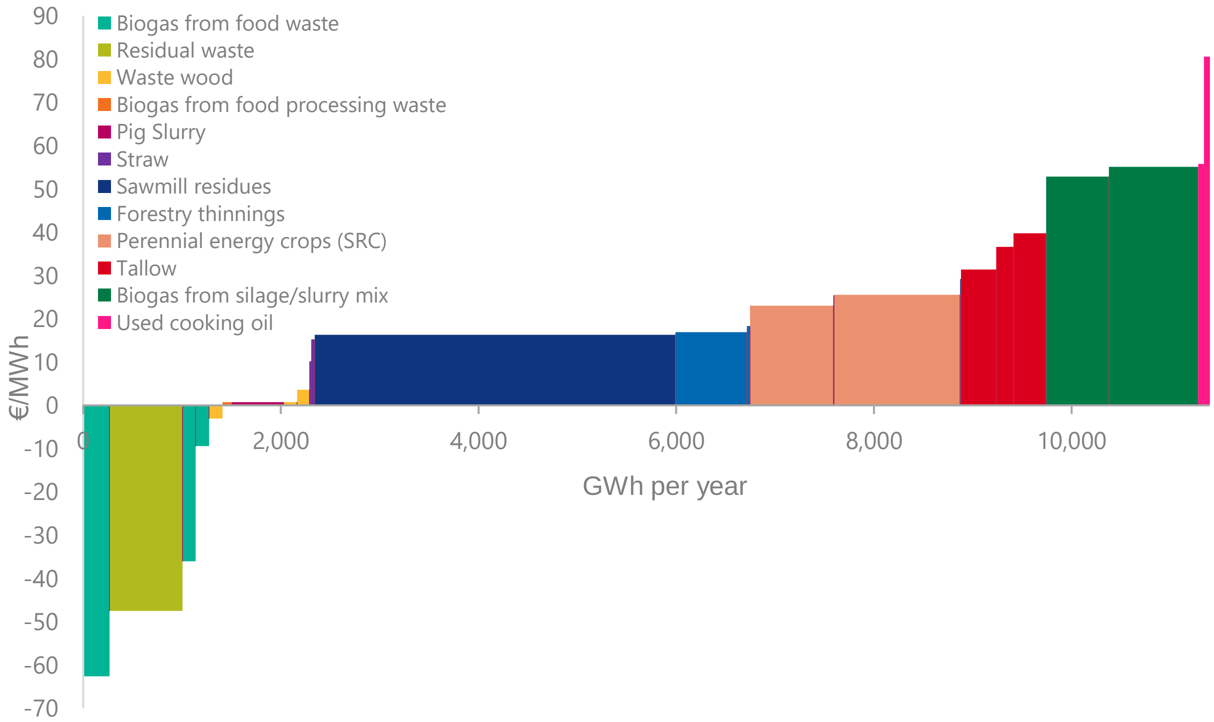
Another biofuel that Ireland has begun to import is a biomass-based substitute for Liquified Petroleum Gas (LPG). BioLPG is a direct substitute for conventional fossil fuel derived LPG, and requires no changes to storage or end use equipment. BioLPG is a co-product from the production of another biofuel, Hydrotreated Vegetable Oils (HVO), which is a substitute for diesel. Upstream greenhouse gas emissions for BioLPG are largely determined by the oil used as a feedstock for the HVO. When the feedstock is used cooking oil then heat produced from the BioLPG would meet the sustainability requirements under the Renewable Energy Directive for heat. However, when the feedstock is virgin vegetable oils, then it is unlikely the requirements can be met. HVO production is increasing in both the EU and worldwide, and much of the new capacity, particularly in Europe, is focused on using waste oils and tallow, so that sustainable BioLPG should be available. If HVO production expands as currently forecast, then we estimate that enough BioLPG could be available to replace the current consumption of LPG.

Figure 4: Resource cost supply curves for Balanced Scenario in 2030 and 2050

2030



2050



1 Introduction

Ireland's Climate Action legislation has set legal requirements for greenhouse gas emissions reductions. By 2030, emissions must be 51% less than in 2018, and by 2050, the Irish economy must be carbon neutral [1]. The carbon budgeting process described by the legislation will set out the annual emissions reduction trajectory and set greenhouse gas limits for each sector of the Irish economy to meet these targets. These limits represent Ireland's contribution to the principal aim of the Paris Agreement: to kerb global temperature increases by restricting the total amount of greenhouse gas emissions emitted into the atmosphere.

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This report, *Sustainable Bioenergy for Heat,* serves as a standalone document detailing the analysis carried out to estimate the availability, cost and sustainability of bioenergy resources in Ireland.

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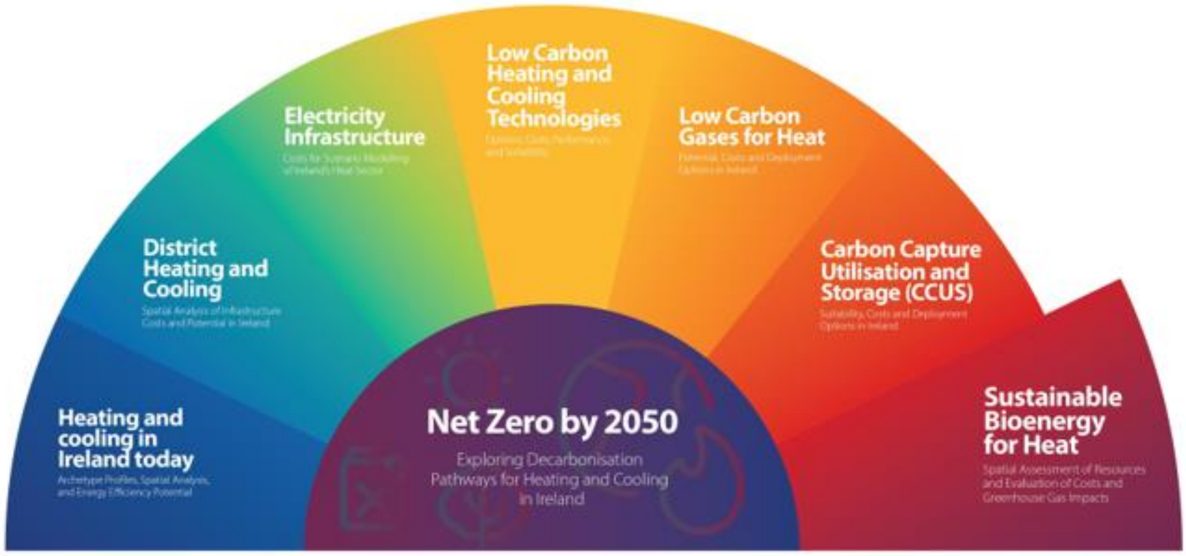
[6] SEAI, 'Comprehensive Assessment of the Potential for Efficient Heating and Cooling in Ireland, report to the European Commission'. 2021 [Online]. Available: https://www.gov.ie/en/publication/e4332-introductory-text-for-publication-of-the-national-comprehensive-assessment-on-govie/#

[7] Available at SEAI webpage: https://www.seai.ie/data-and-insights/national-heat-study/

Figure 5: Framework of reports



1.1 Objectives and scope of this report

This report examines and quantifies potential bioenergy resources in Ireland. It estimates the availability and price of key bioenergy resources and examines their sustainability. The report builds on, and updates work previously done by SEAI to estimate the bioenergy resource in 2016 [6]. The analysis was supported by an advisory group, with representatives from the Department of Agriculture, Food and the Marine, Department of the Environment, Climate and Communications, Teagasc and the Environmental Protection Agency.

Biogas and biomethane produced from a mix of grass silage and slurry in Anaerobic Digestion facilities have been a prominent feature of recent policy discussions. Different views exist on the total resource available, it's cost and its sustainability. A key focus of this work is to improve the representation of these agricultural feedstocks (grass silage) and animal manures and slurries, which could be used to produce biomethane via anaerobic digestion. This analysis examines the spatial distribution of these resources and assesses the quantities of grass silage that might be available for bioenergy without compromising its availability as fodder for the national herd. In addition, a consequential life cycle analysis (LCA) is carried out to consider the broader greenhouse gas emissions impact of using grass silage and cattle slurry for anaerobic digestion.

The report only considers the use of biomass resources for energy. The assessments of their availability for energy take into account existing competing uses, for instance animal bedding or particle board manufacture. However, it was not within the report's scope to examine new competing uses that might arise as the bioeconomy grows, such as biomass resources as feedstocks for chemicals or plastics production.

The report discusses the potential uses of each biomass resource. These potentials and costs are inputs to the modelling work carried out as part of the National Heat Study. The modelling outcomes show the extent to which the various resource potentials are used in the scenarios examined. The model and scenario analysis is described in the *Net-Zero by 2050: Exploring Decarbonisation Options for Heating and Cooling in Ireland* [8] report, and a brief description is included here.

[8] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf

1.2 Relationship to overall modelling

This work feeds into the overall modelling work conducted as part of the National Heat Study. The modelling work examines four scenarios that reach net-zero emissions in the heat sector by 2050 and a business as usual, Baseline scenario. The resource assessments in this report are aligned with the scenario descriptions where appropriate. The outputs from this work form the input data for bioenergy resources for each of the scenarios examined using SEAI's National Energy Modelling Framework (NEMF).

Each of the alternative net-zero scenarios seeks to reflect a plausible pathway to a decarbonised heat supply by 2050. They consider a variety of relevant factors including, but not limited to, the speed of transition, energy efficiency, heat networks, gas grid extent, CCUS/BECCS deployment, renewables deployment, the evolution of the power system, transport system considerations and a mix of low-carbon technology uptake. The High Electrification and Decarbonised Gas scenarios intend to capture two different pathways to net zero by 2050. The Balanced scenario aims at a middle ground between these two. It accounts for a technology mix that is cost effective, feasible to implement and aims to minimise the risk of over-dependence on any single technology. As the most ambitious scenario, Rapid Progress reflects a future where decarbonisation measures are achieved earlier. It explores how soon net zero in the heat sector might be achievable and what the challenges are, paying particular attention to the period to 2030. *Figure 6* summarises the scenarios.

Figure 6: High-level details of the Baseline and net-zero scenarios

Relationship to Overall Modelling

Baseline	Business-as-usual scenario where all sectors continue to use carbon-intensive practices.
	Limited deployment of heat networks, new technologies or fuel switching.
	Includes policy measures from the 2019 Climate Action Plan that had existing implementing measures such as funding and planning or legislation in place by the end of 2020.
	It does not achieve net zero by 2050.
High Electrification	Weighted towards electrification, coupled with minimal amounts of bio-derived gases, CCUS and green hydrogen.
	High levels of heat networks deployment and significant efficiency uptake.
	Achieves net zero by 2050.
Decarbonised Gas	Weighted towards green hydrogen use, CCUS infrastructure or bio-derived gases, or both, coupled with domestic and commercial fuel switching to green hydrogen or bio-derived gases, or both.
	Low levels of heat networks deployment and efficiency uptake.
	Achieves net zero by 2050.
Balanced	Progresses steadily and comprises a mix of cost-effective deployment of low-carbon technologies (electricity, bio-derived gases, green hydrogen).
	Medium level of industrial CCUS, heat networks and efficiency deployed.
	Achieves net zero by 2050.
Rapid Progress	Accelerated progress, driven by policy targets; all low-temperature applications are quickly electrified, while bio-derived gases are prioritised for industry sites.
	High levels of heat networks deployment and energy efficiency uptake.
	Achieves net zero by 2050.

High-level details of the Baseline and Scenarios examined

1.3 Overview of bioenergy resources

Bioenergy is a low carbon fuel that can replace carbon intensive fossil fuels. The use of organic fuel to create bioenergy releases carbon dioxide (CO_2) into the air, but this is offset by new plants that consume that CO_2 during growth. However, sourcing and processing biomass for energy can itself create CO_2 and other greenhouse gas emissions. Therefore, it is vital to ensure that the biomass is sourced in a sustainable way that minimises these additional greenhouse gas emissions and any other environmental impacts.

Bioenergy resources already contribute to the energy mix in Ireland. This report examines what additional resources are available or could be developed sustainably.

It begins by examining those bioenergy resources which are a by-product of other activities or a waste. These include:

- Thinnings and residues from harvesting activities in forestry, and residues created during the processing of timber (Section 2)
- By-products and wastes from the agricultural sector: straw from cereal production and animal manure (Section 3)
- A wide range of wastes including household food waste, wastes from the food and drink sector, and waste wood (Section 4)

Bioresources which are by-products and wastes have several common characteristics. They are available now, typically at a relatively low cost. Additional greenhouse gas emissions associated with their use for bioenergy are generally low. Their use can help address other environmental issues and align with circular economy aims by utilising by-products and wastes instead of disposing of them. However, the quantities of these bioresources are unlikely to increase significantly in the future, as the amounts generated are driven by activity in the primary industry itself and not by demand for bioenergy. Population growth, waste policy and forestry industry activities are examples of underlying drivers for waste and forest materials. These are not influenced by how the energy system changes. Therefore, the quantity of each of these bioresources is assumed to be the same under each of the scenarios modelled in the National Heat Study.

Significant increases in bioenergy resources could, however, be achieved by cultivating energy crops. These include crops such as:

- Grass for use in Anaerobic Digestion (AD) plant to produce biomethane.
- Perennial energy crops, such as miscanthus and short rotation coppice willow, for use in combustion and other thermochemical energy production technologies.
- Starch and oil crops, such as wheat and oilseed rape, are used to produce transport biofuels.

Currently, only minimal amounts of perennial energy crops are used to generate energy in Ireland. The availability of suitable land and competition with existing agricultural activities are key issues to assess when evaluating future energy crop potential. Energy crops must be cultivated on land that avoids negative environmental impacts. They must also avoid compromising other existing land uses such as livestock farming, cereal crop cultivation or afforestation. Underscoring everything is the sustainability of the crop. It is vital that the sustainability of the option is thoroughly evaluated and that greenhouse gas emissions associated with the cultivation of energy crops do not compromise the climate mitigation benefits of their use. Each of these aspects and the potential future availability of energy crops is discussed in Section 5. As the future development of energy crops is likely to be heavily influenced by policy on bioenergy and policy on agricultural development, particularly on the size of the national herd, alternative scenarios for energy crop development, corresponding to the overarching scenarios described above, were developed. These are also described in Section 5.

The final way in which bioresources could be increased is to supplement domestic resources with imported biomass fuels. Ireland already imports some wood pellets to supplement the domestic supply of pellets in the heating sector, and if demand increased then, imports could be increased. In addition, large-scale import of wood pellets could be a feedstock of interest for any future large-scale bioenergy power plant with carbon capture and storage (BECCs) or for gasification plant to produce biomethane to help green the gas network. The sustainability of any such imports is critical, both to ensure that wood for the pellets comes from sustainably harvested forests and that emissions associated with producing and transporting the pellets are kept as low as possible. Section 6.1 discusses potential sources and quantities of imported wood pellets, together with sustainability implications.

Another biofuel that Ireland has begun to import is a biomass-based substitute for Liquified Petroleum Gas (LPG). BioLPG is a direct substitute for conventional fossil fuel derived LPG, and requires no changes to storage or end-use equipment, so it can be an easy way for existing LPG users to decarbonise their heat supply. Section 6.2 discusses the potential sources and availability of BioLPG.

Ireland already imports substantial quantities of bioethanol and biodiesel in order to meet requirements under the Biofuels Obligation Scheme to incorporate biofuels into the transport fuel supply and is likely to continue to have a heavy reliance on imports in the future. Potential levels of imports were estimated in the previous bioresources study for SEAI [6] and were not updated in this study due to the focus on bioresources suitable for the heat sector.

Overall resource availability is summarised in Section 7.

2 Forestry based resources

2.1 Forestry thinnings

2.1.1 What is the resource and how can it be used?

Management of forests produces a range of forestry products of different quality, composition and value. For example, sawlogs, stakewood and pulpwood for use in panel board mills and paper mills. The highest value product is sawlogs, and forest managers typically aim to maximise the production of these. The lower value material is suitable for wood fuel and includes:

- **Small roundwood**: smaller size material that is produced when the forest is finally harvested and is unsuitable for use as sawlogs.
- **Thinnings**: small roundwood removed from the forest to thin plantations to allow larger diameter trees to flourish.
- **Harvesting residues** from final harvest operations, excluding those that must remain in the forest for environmental reasons.

Some drying or processing is usually necessary to prepare the material for use as fuel. Most wood is left in the forest to dry ('season') for up to 12 months before use. Wood may be used as logs in domestic boilers and stoves or processed into chips or pellets. These may be used in power stations as the primary fuel or co-combusted with fossil fuel or in industrial CHP plants to produce electricity and heat. They can also be used in boilers that provide space and water heating in buildings and process steam in the industry sector. These are available in a range of sizes suitable for small scale use in the residential market, larger-scale use in the services sector and the large scale boilers used in industry. In the future, wood may also be converted into renewable transport fuels by using advanced techniques currently at the demonstration stage.

Chipping of wood may occur at the forest roadside or in a processing plant. Pelletising wood involves further drying and processing but has the advantage that pellets are a more energy-dense form of fuel, which are easier to handle and transport. In the future other techniques, such as torrefaction or steam explosion, could be used to pre-process wood and improve handling and transport.

2.1.2 Availability and price

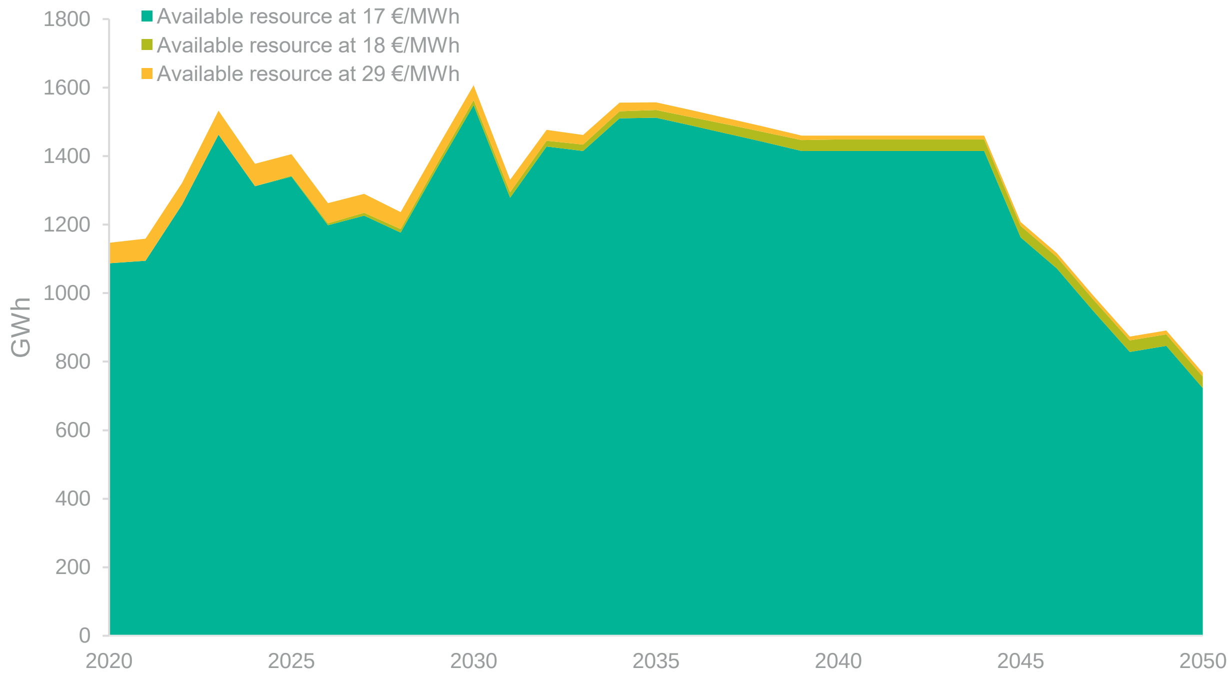
Ireland's forest resource is spread widely across the country. Ownership is split between the State forest, managed by the commercial semi-state company Coillte, and privately owned forest. The forest area in 2017 was 0.77 Mha. The current policy is targeting 8,290ha of newly planted forest each year. Should this be achieved, the forest area would reach about 1.25 Mha by 2046, or 8% of the land area. The Council for Forest Research and Development (COFORD) forecast the harvesting activity of wood and residues for state-owned and private forestry holdings. The latest forecasts run to 2035 and are based on current areas of forest and future afforestation [7]. They include wood that may be harvested during thinning operations as well as at the final harvest. The COFORD report also estimates the quantity of harvesting residues that could be obtained from the forest. The estimate considers the land topography and the need to leave some residues in the forest, particularly on peat lands. For 2035 - 2050, this analysis uses data from a draft long-term forecast of private forestry harvesting activities, kindly provided by DAFM. Harvesting activity from state-owned forests is assumed to remain at 2035 levels.

Demand projections for wood in other sectors were used to understand the quantity of harvested wood residue available for bioenergy. Demand for stakewood and pulp for panel board to 2025 are based on estimates in the COFORD wood mobilisation report [8]. Post-2025, demand for stakewood is assumed to grow at 1% a year. Demand for pulpwood for panel board manufacture also grows 1% per year to 2040, after which demand is assumed to remain at 2040 levels until 2050 [9]. Demand for other markets, for example, animal bedding, is taken as the average demand from 2014 to 2018-based on historical data [10].

Small roundwood from the final harvest of trees is estimated to have a price of €17/MWh (€32/m^3) based on work that established the costs of wood chipping and the price of the wood chip [11]. Residues collected at harvesting are assumed to initially be available at a price of €29/MWh (€36/m^3) based on data on trials conducted by COFORD [13]. Over time the costs of extracting first thinnings are assumed to fall as investments are made in whole-tree harvesting equipment, and some of this resource becomes available at a lower price of €18/MWh (€35/m^3).

The availability of small roundwood and harvesting residues is shown in *Figure 7* and is forecast to substantially fall after the mid-2040s due to the age structure of private sector woodland. A complete data set is provided in Appendix 1.

Figure 7: Availability of small roundwood and harvesting residues for bioenergy (2020 – 2050)



2.2 Sawmill residues

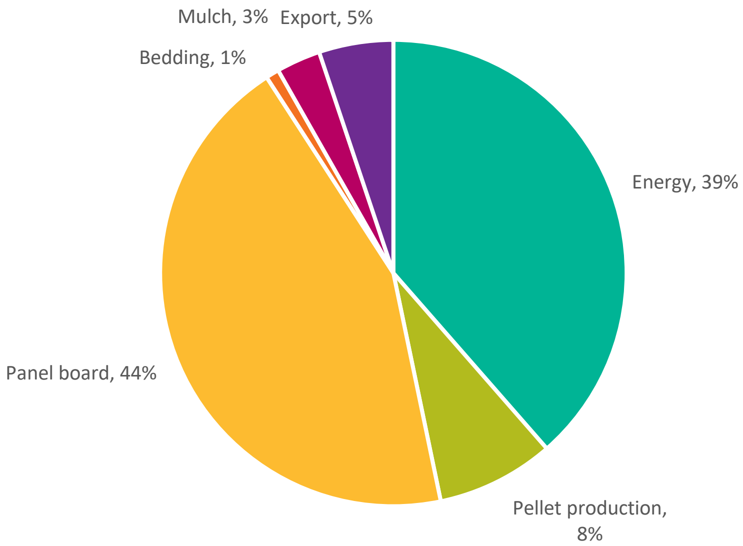
2.2.1 What is the resource and how can it be used?

When harvested timber is processed in a sawmill, wood chips, sawdust and bark are produced along with sawn timber. These are collectively known as sawmill residues. Panel board mills also produce bark and sawdust residues when they debark small roundwood to produce wood chips to manufacture the panel boards.

Sawmill residues can be combusted in an appropriate plant to produce heat and/or power. In the case of wood chips and sawdust, they can also be processed into wood pellets or briquettes, fuel forms that are more easily handled and transported. Panel board mills already use a significant amount of these residues to produce heat and power to meet their onsite energy needs. Some sawmill residues are also processed into pellets and sold for use in boilers.

There are several competing uses for sawmill residues, as shown in *Figure 8*. The most prominent use is for panel board production, but some are also used for animal bedding. Bark residue is often used for mulch. Almost half of the residues are used for energy. From 2014 to 2018, 39% of the available residues was used to fuel boilers and CHP plant, much of it within the timber and panel board industry. 8% of the residues were used to produce wood pellets for use as fuel in boilers.

Figure 8: Uses of sawmill and panel board mill residues (average 2014 to 2018)



Source: [10]

2.2.2 Availability and price

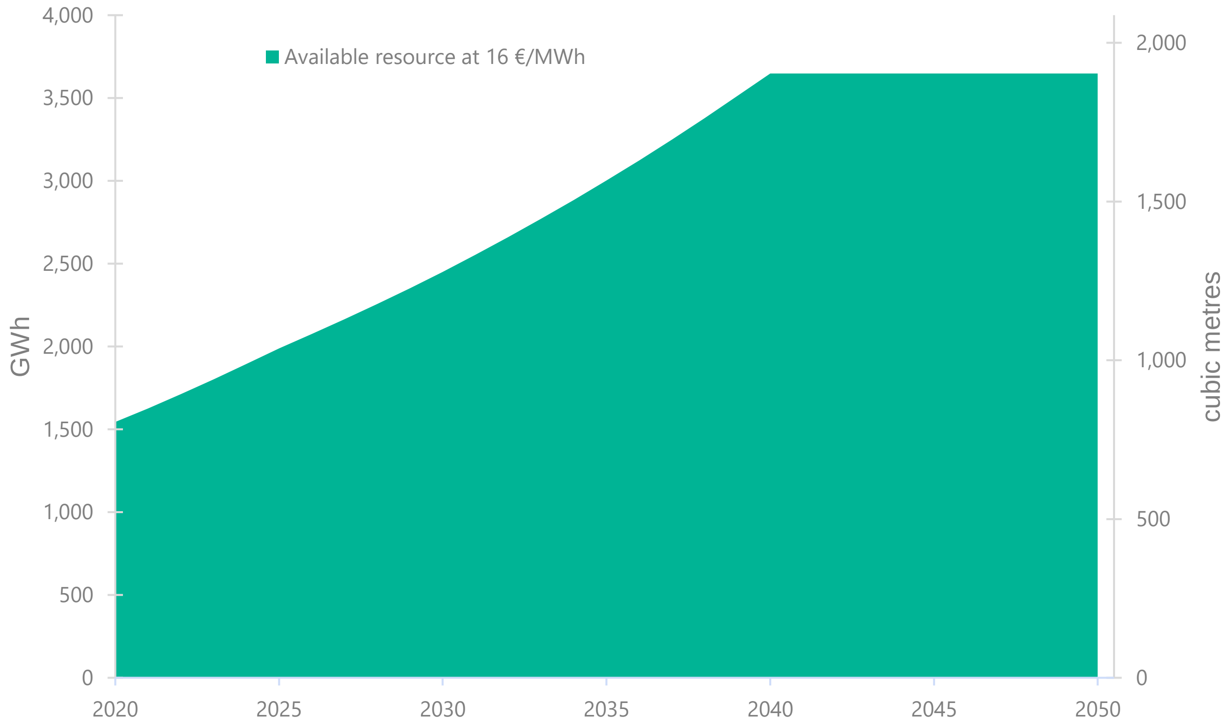
The quantity of sawmill residues produced depends on the throughput at sawmills. The quantity of board mill residues depends on the quantities of pulpwood debarked at the board mill. The proportion of the overall resource available for energy purposes depends on the size of competing markets.

Future throughput at sawmills to 2025 is forecast and based on the COFORD wood mobilisation report [8]. For later years, this is based on data provided by DAFM [9], which projects throughput rising by ~3% per annum from 2025 to 2050. Post-2040 sawmill throughput is assumed to plateau in line with forecasts for forest harvesting activity and volumes. Forecasts of pulpwood used by panel board manufacturers are discussed in more detail in Section 2.1.2. These throughput forecasts are combined with values for the average ratio of residues generated to wood processed over the last five years for which data is available (2014 to 2018) [10]. Demand for residues in the panel board sector is assumed to rise as in Section 2.1.2, and bark mulch and animal bedding remain at the average levels seen between 2010 and 2018.

As a large proportion of the residues are used directly at the site where they are generated, price data is not available. Therefore, a price for the residues of €16.3/MWh (€32/m3) is evaluated based on the contribution they are estimated to make to the current final price of pellets produced at one of the sawmills in Ireland.

The availability of sawmill residues is shown in *Figure 9* and is forecast to more than double between 2020 and 2050 due to increased throughput as sawmills; a complete data set is given in Appendix 1.

Figure 9: Availability of sawmill residues for bioenergy (2020 – 2050)



3 Agricultural wastes and residues

3.1 Cattle and pig slurry

3.1.1 What is the resource and how can it be used?

Slurry and manure from cattle can be processed in an anaerobic digestion (AD) plant to produce biogas, a mixture of methane (CH_4) and carbon dioxide (CO_2). The biogas can either be combusted in a boiler to supply heat or a gas engine to produce electricity and heat. Alternatively, it can be upgraded to pure biomethane (by removing the CO_2 and other impurities), injected into the natural gas grid or used directly as a vehicle fuel. As slurry and manure feedstocks have a low energy density, they are expensive to transport. This means the AD plant must be near the feedstock and may not be close to the gas grid. In this circumstance, the biomethane can be injected into a pressurised container which can be trucked to a centralised grid injection point or directly to an energy user's site.

Anaerobic digestion plants can range widely in size. A typical small scale plant located on the farm is about 100 kWe upwards in size, but 'micro scale' plant – from 10kWe upwards are available and in use in several European countries. It is also possible to have a much larger centralised plant (CAD) that can take waste from several farms and 'co-digest' the slurries with other organic material such as grass silage (see Section 5.2) or food waste (see Section 4.2 and 4.3). Larger plants have economies of scale advantages. Capital costs are typically lower on a per kWe of installed capacity basis than smaller-scale plants. Even a small scale plant requires slurry from a large number of animals (a 100 kWe AD plant could require slurry from approximately 1,000 dairy cows or over 6,000 pigs). Supplementing the AD plant with other feedstocks and slurries, or combining slurries from many farms in a co-operative venture, can increase the number of farms where AD is applicable and increase the amount of resources used while adhering to animal by-product regulations. Using slurry in an AD plant has the additional advantage that it can help avoid emissions associated with storing slurry; this is explored further in Section 5.2.6.

3.1.2 Availability and price of cattle slurry

The quantity of slurry available is directly related to the number of cattle in the national herd. Agricultural policy is one of the main factors that influence herd size. Two scenarios were considered to allow exploration of alternative hypothetical scenarios for this:

- Business as Usual (BAU) scenario – the 'Stable herd' projection formed the basis of the projections for greenhouse gas emissions from livestock in the National Climate and Energy Plan [4]. Under this scenario, the dairy herd increases by 10% by 2030, but the suckler herd reduces by 23%, giving an overall reduction in the national herd of 0.5%.
- A Land Use Change (LUC) scenario was created for input into the National Heat Study analysis for a 'Rapid Progress' scenario described in section 1.2. In this scenario, it is assumed that a desire to reduce livestock emissions from agriculture leads to a more significant reduction in the suckler herd, of 45% (about 440,000 head) by 2030, compared with that in the BAU stable herd projection. The dairy herd is assumed to show the same increase as in the BAU scenario. Overall, the national herd is reduced by almost 600,000 head (8.4%) to 6.5 million.

For each type of cow (dairy cow, suckler cow, under 1-year male etc.), the amount of organic matter excreted annually, and the percentage of that organic matter going on average to different types of management systems - slurry, straw/solid manure and pasture - was obtained from the Environmental Protection Agency (EPA). These datasets are used to calculate the GHG emissions from animal waste management systems in the GHG National Inventory [12]. In this analysis, the data is used to calculate the amount of organic matter in slurry for each type of cow. These were combined with the forecasts of future livestock numbers to estimate the total slurry arising in 2030 (*Table 2*). The biogas produced from slurry was estimated based on a biogas yield of 20 Nm^3 biogas per tonne of slurry, assuming a dry matter content of 7%, which is 55% biomethane content in the biogas, therefore 11 Nm^3 of biomethane per tonne of slurry. *Table 2* shows the herd size and quantities of slurry produced in the two scenarios.

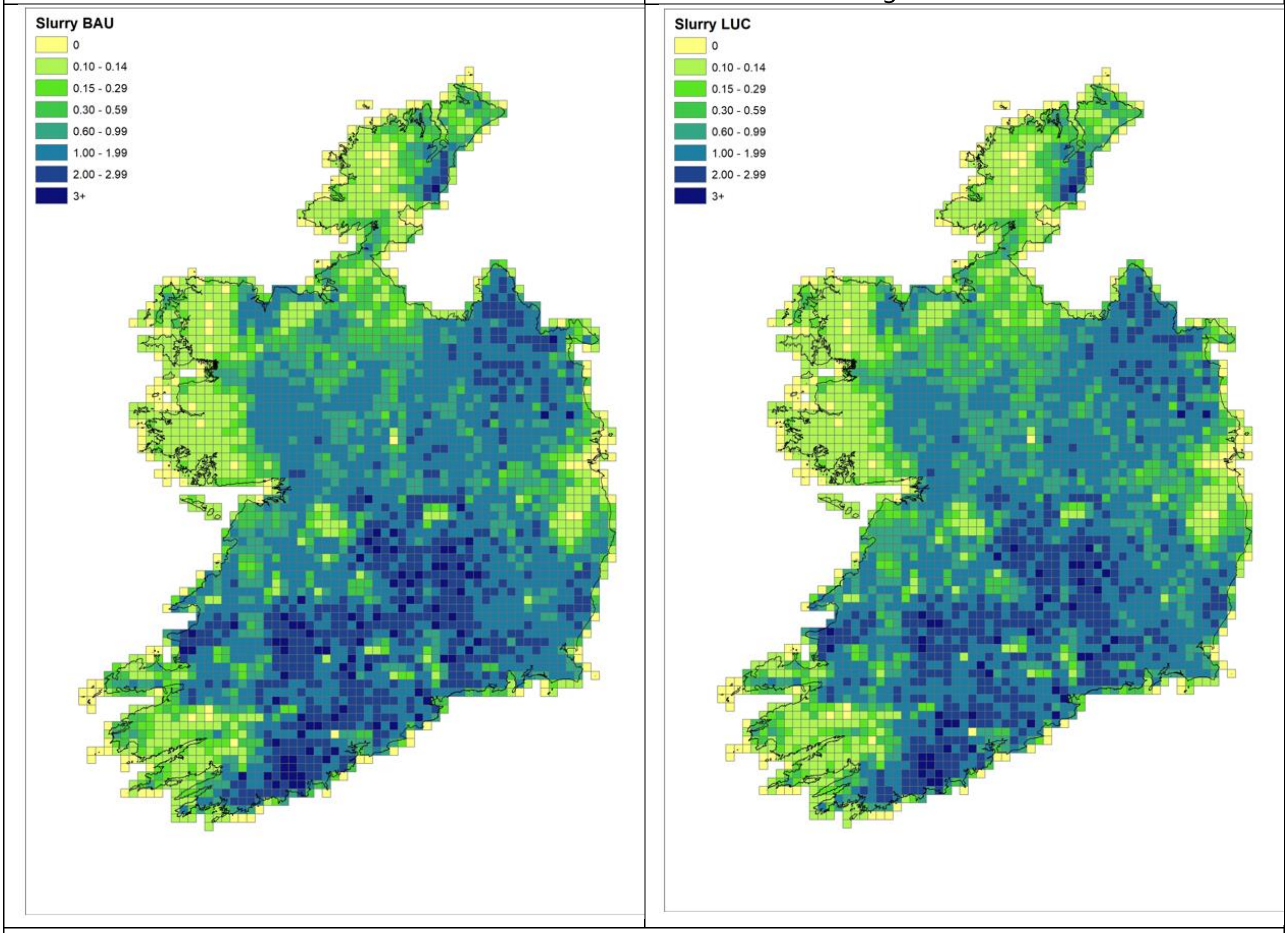
Table 2: Slurry and biomethane production potential under BAU and LUC scenario in 2030

	2020	2030 BAU scenario	2030 LUC scenario
Herd size (million head)	6,886	6,851	6,286
Slurry (thousand tonnes per year)	31,652	31,657	29,157
Potential biomethane yield (GWh per year)	3,563	3,563	3,282

Table 2 also shows the amount of biogas equivalent to full use of all the slurry available in AD. However, the realisable potential is likely to be much lower than this. There is not enough slurry on many smaller farms to support an AD plant. Due to its dilute nature and low biogas yield per tonne, it is considered that cattle slurry is most likely to be used in conjunction with other feedstocks with a higher biogas yield. There has been much interest in co-digesting it with grass silage, and this is considered further in Section 5.2. The low biogas yield of slurry means that it is generally not economic or desirable to transport it long distances. Hence, the spatial distribution of the slurry resource is important. The spatial location of the slurry was mapped by combining the estimates of slurry per head of livestock with the geographical data on the location of livestock from the Animal Identification and Movement System (AIMS) held by DAFM (*Figure 10*).

Figure 10: Location of slurry under BAU and LUC scenario

Business as Usual | Land-use Change Scenario



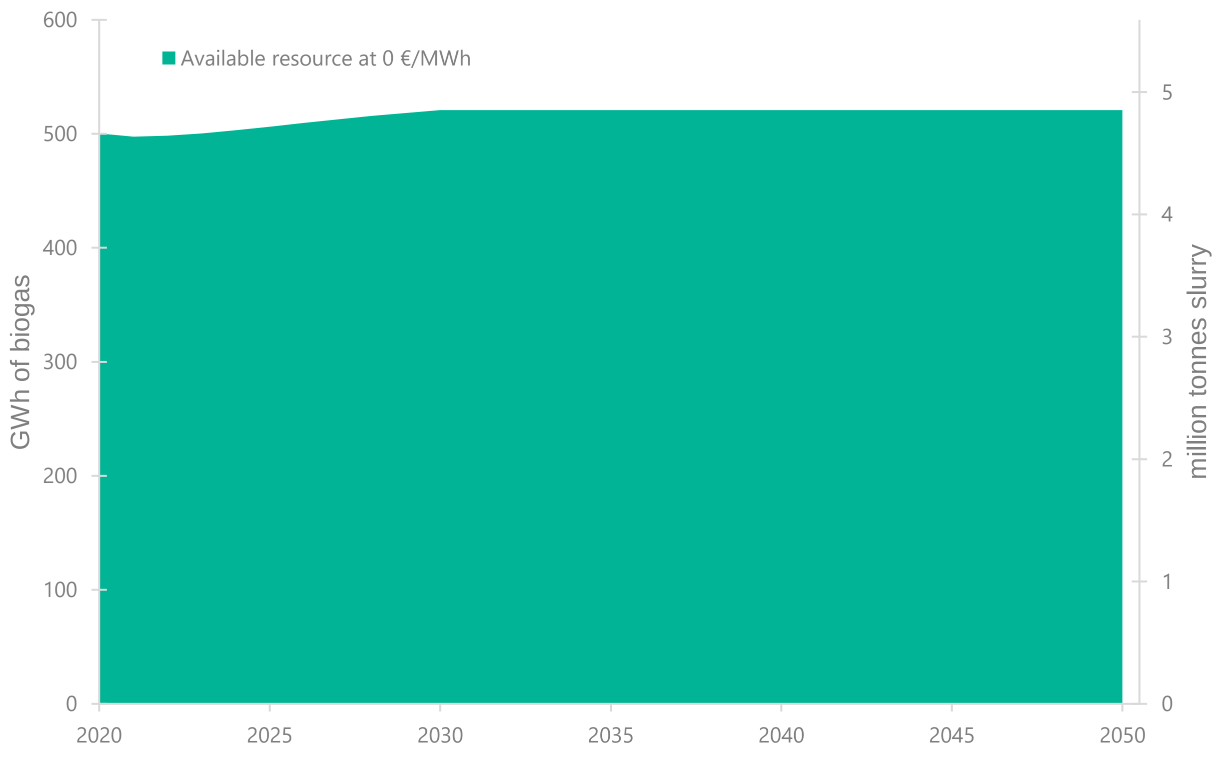
Legend: Values are potential biogas production from slurry located within 5 km square grid (GWh biogas/year)

3.1.3 Availability and price of pig slurry

A high proportion of the national pig herd is kept in a relatively small number of large herds. 175 herds, containing more than 3,000 pigs each, account for 85% of pigs (1.4 million) [13]. This means that much of the pig slurry generated each year occurs in high enough concentrations to be utilised in the AD plant. The pig herd size to 2030 was based on forecasts from the 'Stable herd' projection, which forms the basis of the projections for greenhouse gas emissions from livestock in the National Climate and Energy Plan [4]. This forecasts that the number of pigs will increase by about 5% by 2030. As no projections are available post 2030, the herd is assumed to remain at its 2030 level until 2050. It is assumed that all slurry from herds larger than 3,000 animals could be available for use in AD plants. On average, it is assumed that each pig produces 3.3 tonnes of slurry each year, with each tonne of slurry capable of producing 107 kWh of biogas. The pig slurry is assumed to be used on or very close to the pig farm, and as there are no transport costs, it is assumed to be available at €0/tonne.

Figure 11 shows the quantities of pig slurry estimated to be available and the total amount of biogas that it could yield when anaerobically digested. Some of this biogas will be used at the AD plant itself, for instance to provide heat to the digester or for pasteurisation. There will also be some fugitive emissions. The exact quantity depends on the design of the AD plant, but typically the quantity of biogas that is available for energy for export from the plant is under 90% of the biogas yield shown in *Figure 11*. A complete data set is given in Appendix 1.

Figure 11: Availability of pig slurry for bioenergy (2020 – 2050)



3.2 Straw

3.2.1 What is the resource and how can it be used?

Straw is a by-product from growing commercial crops such as wheat, barley and oats, and can be combusted to produce electricity and/or heat. Straw bales can be burnt whole but are best opened and either chopped or shredded or fed in sections into the combustion plant; straw can also be pelletised. In the future, the development of gasification and pyrolysis techniques could allow more efficient combustion of straw for power production. Alternatively, advanced biofuel conversion technologies are being demonstrated, which produce bioethanol from straw – a biofuel that can be blended with petrol. The density of straw is relatively low (about 0.46 t/m^3 for baled straw). This means it has only a moderate energy density (6.7 GJ/m^3). It is relatively bulky to transport, and significant distribution distances can add substantially to the cost. It is therefore typically used locally.

3.2.2 Availability and price

The total straw resource is estimated by multiplying crop areas for wheat, barley and oats by typical yields per ha for the various types of straw [14]. Over the last five years, the area devoted to these crops has fallen by about 13%, to 267,000 ha in 2019 [15]. Further decline is considered undesirable from a food security perspective, and the recent Food Vision 2030 strategy proposes an expansion of tillage production [16]. No projections of future cereal areas were available, so areas were assumed to remain constant at 2019 levels. This analysis excludes stem residues from Oil Seed Rape (OSR) production, as it is difficult to harvest. Data on its combustion characteristics also indicate that it is not a good fuel for combustion.

Straw is often ploughed into fields where it is grown. This recovers its intrinsic fertiliser value and can be achieved at a relatively low cost. The quantity of straw used in this way depends on its market and practical considerations such as the weather, ground conditions, and availability of storage space. Some farmers may choose to chop straw while harvesting for ploughing into the fields later. A decision at harvest time carries a relatively low cost since the harvesting machinery is generally equipped to chop as it goes. In contrast, a decision by a farmer to chop later or bale carries a higher cost. It is assumed that at least 2% of the straw production estimated is ploughed in regardless of the market conditions for straw.

There are already several uses for straw, such as animal bedding (all types of straw), animal feed (barley straw), and mushroom compost (wheat straw). Use for animal bedding is estimated from the previous bioenergy report [6], on requirements for straw bedding of 132.7 t per thousand head of cattle[9], and the assumptions about future herd size discussed in Section 3.1.2. The use of straw in mushroom production is estimated in [19] and advice from Teagasc [18] that straw comprises about 39% (DM) of the mushroom compost. The use of straw in mushroom production is assumed to remain constant. These competing uses for straw account for almost all (about 99%) of the resource, leaving little remaining potential for energy.

The price of straw can fluctuate considerably from year to year, depending on the yields achieved at harvest. Prices were assumed to be similar to those forecast in the previous bioenergy report, 40 to 80 €/tonne of straw (10 to 25 €/MWh), based on analysis by Teagasc of average straw prices [20].

The availability of straw for bioenergy is shown in *Figure 12*; a complete data set is given in Appendix 1. The area devoted to cereals, and associated straw production, is assumed to remain constant over the projection period. The variation in straw availability for bioenergy shown in *Figure 12* is thus due to fluctuations in the competing demand for use as cattle bedding (as demand for straw for mushroom compost is also assumed to remain constant). As discussed in Section 3.1.2, the dairy herd is assumed to increase in the period to 2030, and the suckler herd to decrease, leading overall to a small reduction in the national herd of 0.5% by 2030. This leads to a reduced demand for straw bedding in 2030 compared to 2020, hence increased availability of straw for bioenergy. However, in interim years, the herd size grows slightly before contracting and this means that in 2024, all available straw is required for bedding leading to no availability for bioenergy.

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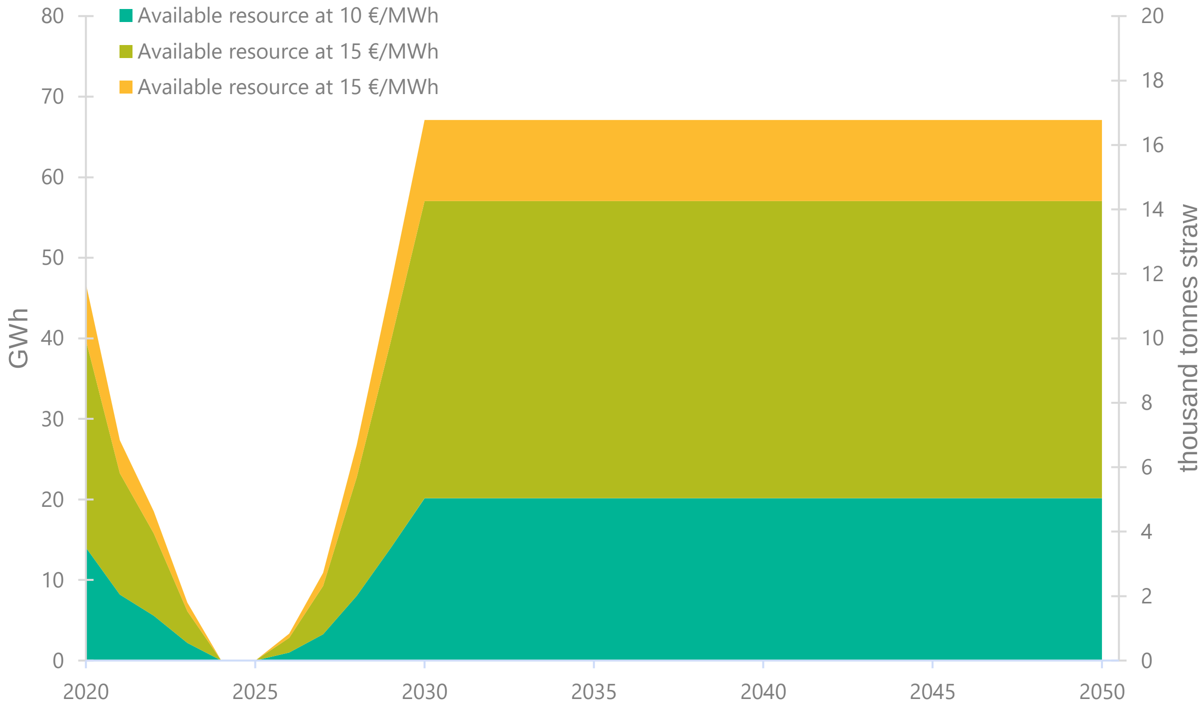
[9] In the previous report straw use per head of cattle was estimated based on data from [17] which was adjusted based on advice from Teagasc [18] to account for changes in cattle management since publication of [17]

Figure 12: Availability of straw for bioenergy (2020 – 2050)



4 Wastes and by-products

4.1 Residual waste

4.1.1 What is the resource and how can it be used?

In 2018, Ireland produced 2.9 million tonnes (Mt) of municipal solid waste (MSW); just over half (53%) came from households, with the remainder (47%) coming from commercial premises [21]. About a million tonnes were recycled (such as paper, cardboard, metals, glass), and some were composted or sent to AD (food waste, and parks and garden waste). The remainder was sent to landfill dumps. However, waste legislation is reducing the amount of waste sent to landfills every year. The EU Landfill Directive (1999/31/EC) has required Member States to progressively reduce the amount of biodegradable MSW (BMSW) sent to landfills[10], thereby encouraging the use of other waste management routes. In 2018, only 0.4 Mt of MSW was landfilled, with 1.2 Mt going for energy recovery.

The residual part of MSW (for example the part of MSW left, after materials have been recovered for recycling) can be processed in several ways. It can be burnt directly in an Energy from Waste (EfW) plant to produce electricity and/or heat or processed into refuse-derived fuel (RDF). RDF fuel can also be used in a dedicated WtE plant or used to fuel in other combustion plants such as cement kilns. In the future, residual MSW may also be converted into renewable transport fuels by using advanced techniques that are currently at the demonstration stage in Europe and the USA. A 200,000 t/year EfW plant burning residual MSW is now in operation in Meath, and a 600,000 t/year plant (Poolbeg incinerator) is in operation in Dublin. There are plans for a 240,000 t/year plant at Ringaskiddy in Cork, but planning permissions has not yet been granted [22].

4.1.2 Availability and price

The application of the waste hierarchy is a critical underlying principle of waste policy in Ireland [23], [24]. Under these principles, the highest priorities are to prevent the generation of waste. Recycling is the next option in the hierarchy. What remains after this can be considered for other recovery options, including energy recovery from waste. The last resort is waste disposal, which in Ireland generally involves sending waste to landfills.

The estimate of the quantity of residual waste from which energy could be recovered is consistent with this hierarchy, as wastes that can be recycled are not included in the resource estimate. Similarly, care is taken to avoid double counting of the resource by not including food waste that can be anaerobically digested to produce biogas and is estimated as a separate resource (see Section 4.2).

The quantity of residual waste collected from households and commercial premises has been estimated by first considering the amount of waste generated. The amount of recyclable materials and food waste in this household and commercial waste category which can be collected separately for further processing, are then estimated. These quantities of recovered wastes are subtracted from the amount of waste generated to give the quantity of residual waste. An estimate is then made of the 'biodegradable' proportion of this residual waste, including material of organic origins such as food, paper, wood and cardboard which have not been extracted for separate collection. Key assumptions are:

- Waste generation grows by 2.5% per year to 2030. This is the growth rate assumed for greenhouse gas projection in Ireland's National Energy and Climate Plan (NECP) [4] and reflects the fact that growth in waste had not yet been decoupled from economic growth. After 2030, as policies for waste minimisation are implemented and begin to take effect, the growth rate falls (linearly) until, by 2050, there is no growth.

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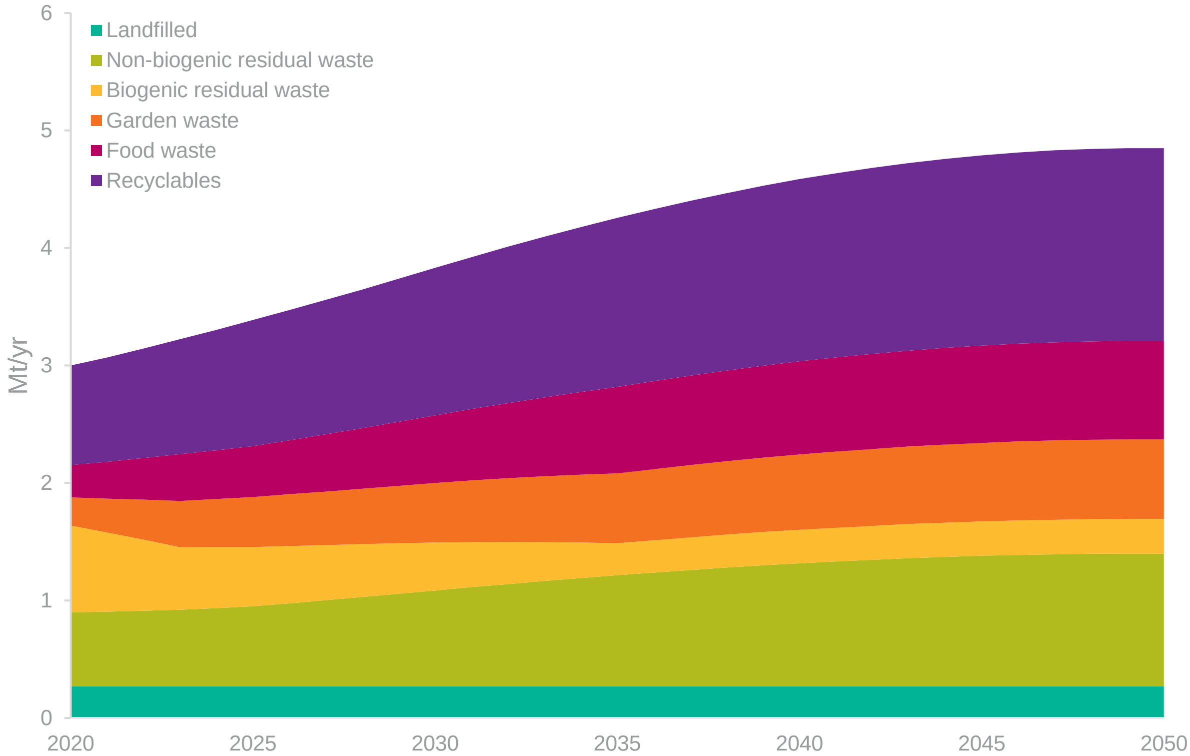
[10] To 50% of 1995 levels by July 2013 and 35% of 1995 levels by July 2016. The revised landfill directive (2018/850) requires that by 2035 the amount the amount of municipal waste landfilled is reduced to 10 % or less of the total amount of municipal waste generated (by weight).

- The recovery rate is the fraction of total materials extracted for recycling, or food and garden waste extracted for composting or AD. It is assumed that the recovery rate meets targets set in the revised Waste Framework Directive of 60% by 2030 and 65% by 2035 [25] [24]. This target rate of 65% is maintained to 2050.
- The strengthening of the regulations that require a brown bin to be provided to households to allow organic waste (food waste and garden waste) to be collected separately will increase the amount of food waste collected (see Section 4.2). This reduces the amount of food waste in the residual waste, reducing its biological content.
- Landfilling of residual waste is limited to 270 kt/year from 2020 onwards, as assumed in the NECP [4].

These assumptions result in the pattern of waste generation and management shown in *Figure 13*.

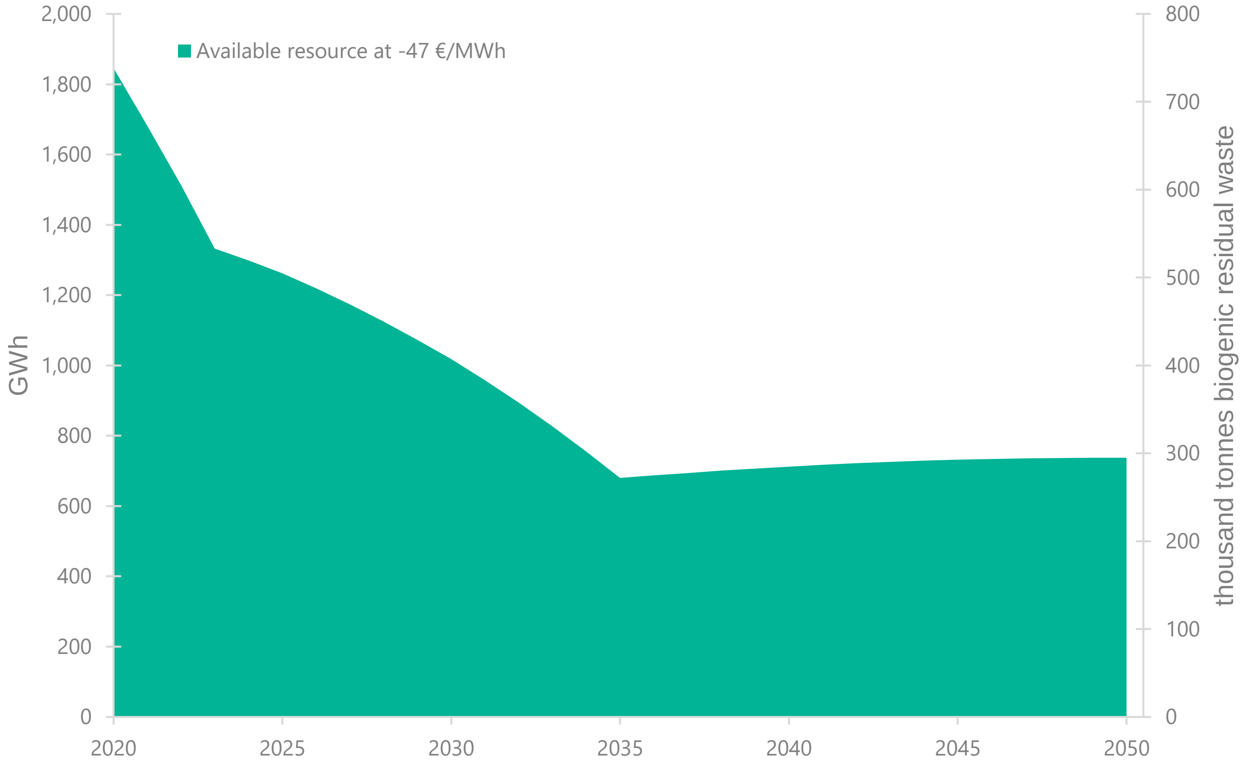
Figure 13: MSW generation and management



Waste collectors must pay to dispose of it. The disposal cost is known as a 'gate fee', and waste management facilities charge this to the waste collectors. Gate fees are typically negotiated as part of long term contractual agreements. Therefore there is little public information available on what gate fees are being charged in the market. Therefore, this analysis uses data from the UK to estimate the gate fee in Ireland [26]. In the UK, the gate fee for EfW plant is typically ~82% of the gate fee for landfill (including landfill tax). The cost of landfill was estimated previously [6] to be €70/tonne (based on data from [27] and [28], and landfill tax is €75/tonne. The gate fee for EfW plant is therefore estimated to be €119/tonne (€47/GWh).

The availability of the biogenic component of residual MSW for bioenergy use is shown in *Figure 14*; a full data set is given in Appendix 1.

Figure 14: Availability of residual waste (biogenic component only) for bioenergy use (2020 – 2050)



4.2 Domestic and commercial food waste

4.2.1 What is the resource and how can it be used?

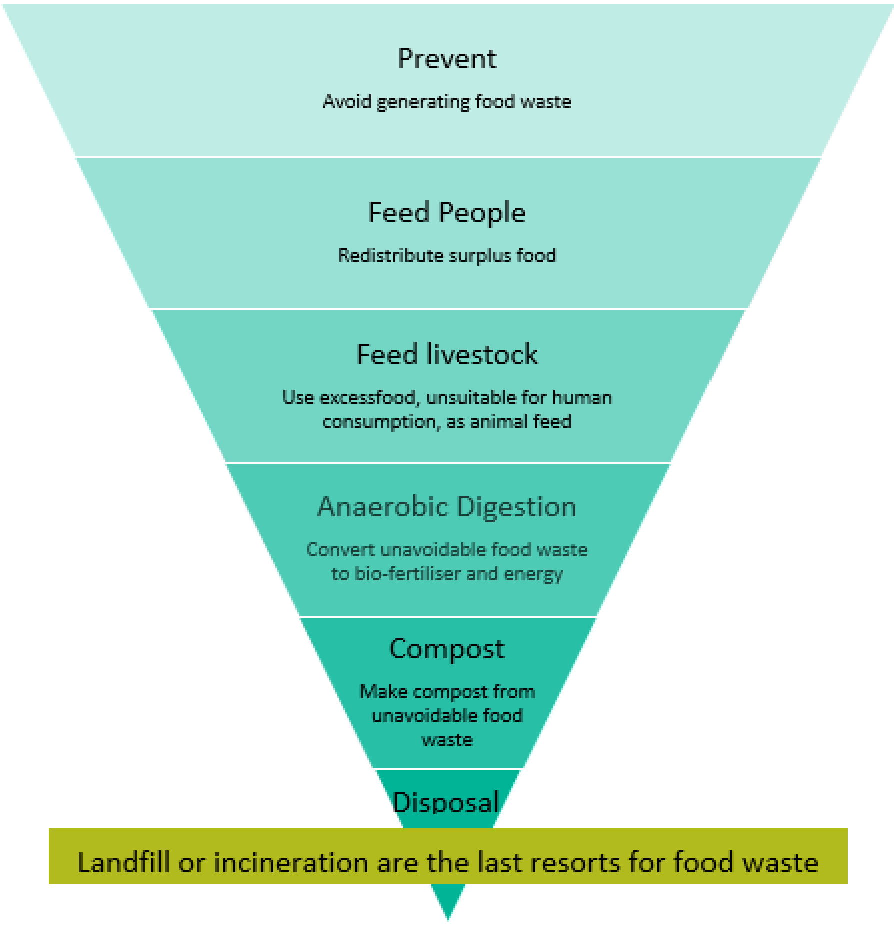
If it is separately collected, food waste can be processed in an anaerobic digestion (AD) plant to produce biogas, a mixture of methane and carbon dioxide. The biogas can then be used in two ways. It can be burnt in a boiler to produce heat or burnt in a combined heat and power (CHP) unit to generate heat and power. It can also be upgraded to biomethane by removing carbon dioxide. The biomethane can then be injected into the natural gas grid. If a grid connection is unavailable at the AD site, the biomethane can be injected into a pressurised container and trucked to a centralised gas grid injection point. It is also possible for the container of pressurised biomethane to transport it directly to an energy users site for use.

Waste regulations in Ireland have required the provision of a 'brown bin' for households to collect organic waste (food waste and garden waste) for several years, with exemptions for certain types of premises and some smaller population centres. Currently, only 43% of Irish households have a brown bin [29], but the recent waste strategy [24] has strengthened this commitment and widened the range of premises that organic waste must be collected. Brown bin use by householders has significantly increased over the last decade from 19,000 tonnes in 2008 to 137,000 tonnes in 2018. This has resulted in a decrease of food waste in the household residual waste bin. However, in 2018 there was still approximately 187,000 tonnes of food waste in the residual waste bin [29].

Commercial premises are also required to separate their food waste, which is collected separately. Despite this being required by legislation for a decade, a 2019 survey found that a third of premises still do not have a food waste bin [30].

National waste policy strategy sets out a food waste hierarchy that prioritises food waste prevention and management (*Figure 15)* [24]. After prevention and redistribution of surplus and excess food, the preferred option is AD, and then composting. At present most food waste goes to composting, but a large (90,000 tonne per year) AD plant using biogas to produce electricity has recently begun operation in Dublin.[11] A similar plant was proposed for near Cork, but has not yet come to fruition.[12]

Figure 15: The food waste hierarchy



Source: [29]

4.2.2 Availability and price

The quantity of food waste collected from households and commercial premises depends on them having a food waste bin and using it. The estimate in this report assumes that by 2023 all households and commercial premises will have a food waste bin. It also assumes that households and commercial premises put 70% of the food waste they generate into the food waste bin. All of the food waste collected is available as a feedstock for AD.

Composting is currently the preferred route for the management of food waste and is likely to be the primary determinate of current gate fees. The previous bioenergy report [6] estimated gate fees for brown bin waste at composting sites and AD sites. The gate fees for composting ranged between €70 and €80 per tonne based on data from [33] and [34]. For the two AD plants in operation at the time of that analysis, the gate fees ranged between €60 to €70/t [34]. AD sites that use food waste are common in the UK. Gate fees vary significantly from region to region across the UK, and there have been significant annual variations. The UK data shows that the gate fee is influenced by how much AD capacity is built in a region relative to food

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[11] https://www.energiagroup.com/renewables/huntstown-bioenergy/ . Commissioning of the plant was delayed by Covid, but the plant is now believed to be operational [31]

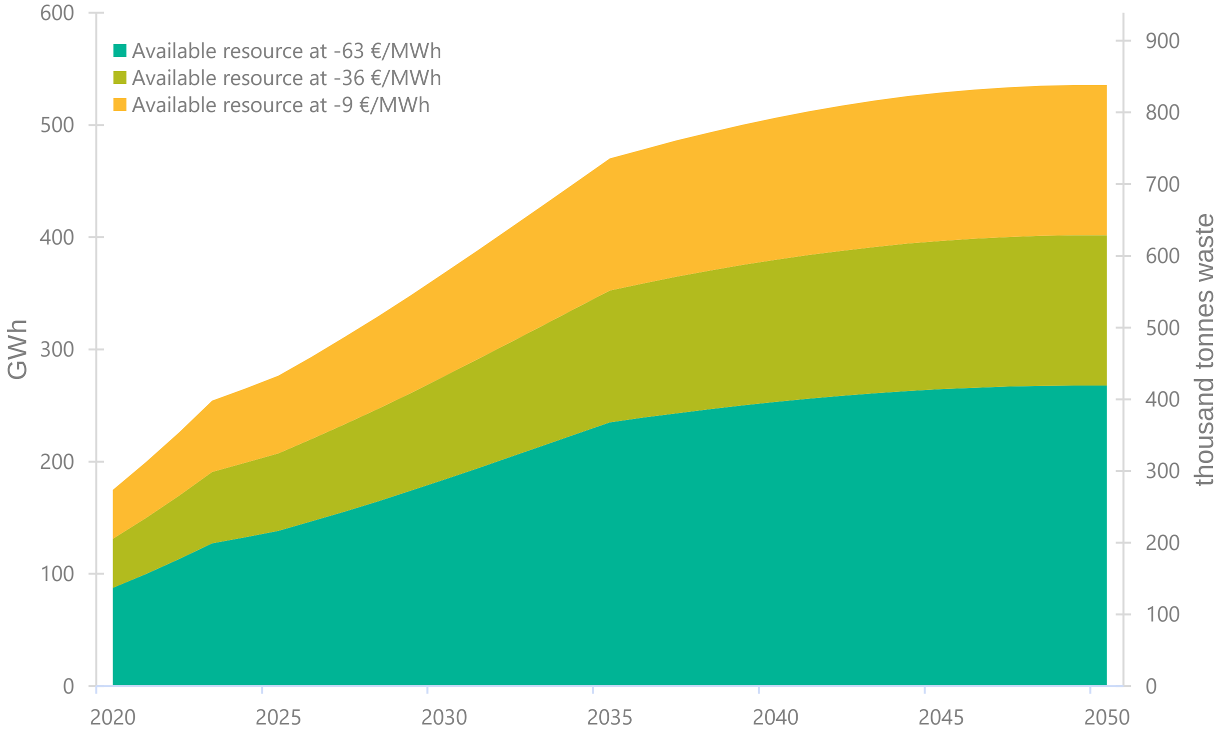
[12] https://www.irishexaminer.com/news/arid-20373440.html and [32]

waste produced there. The median value for all UK plants in 2020 [26] was £35/t (€40/t). However, the plants built since 2017 have had lower gate fees of £20/t (€23/t), potentially reflecting newer contracts. A typical value for regions charging lower gate fee is about £5/t (€6/t). A key assumption in this work assumes that as the AD industry develops in Ireland, gate fees were likely to be similar to those in the UK.

It is assumed that 50% of the resource is available at a gate fee of €40/t. A further 25% would be available at a gate fee of €23/t and the remaining 25% of the resource would be available at a gate fee of €5/t. These gate fees are equivalent to prices for the feedstock component of biogas costs, of -€63/MWh, -€36/MWh, and -€9/MWh, respectively.

The availability of food waste from the domestic and commercial sectors for bioenergy use is shown in *Figure 16*; a full data set is given in Appendix 1.

Figure 16: Availability of domestic and commercial food waste for bioenergy use (2020 – 2050)



4.3 Waste from the food processing industry

4.3.1 What is the resource and how can it be used?

Wastes and liquid effluents with a high organic content that arise from the processing of foods can also be processed in an anaerobic digestion (AD) plant to produce biogas, a mixture of methane and carbon dioxide. As described above the biogas can then be combusted to produce heat and/or power, or it can be upgraded to biomethane.

Wastes from food processing industries that have been identified as suitable for anaerobic digestion include milk processing waste and slaughterhouse waste. Milk processing for the production of ‘‘white products” (milk, yoghurt, and cream), "yellow products" (cheeses and butter), or "specialty products"(concentrates, powders) generates significant volumes of wastewater which requires treatment before it can be discharged. Anaerobic digestion of the waste water or of the sludges produced from treating the wastewater, can generate significant quantities of biogas. Animal slaughter produces solid waste from the digestive tract of slaughtered livestock (paunch), which can be used in AD, and large quantities of wastewater that requires treatment before discharge. Treatment of this wastewater can result in a sludge that is also suitable for AD [32].

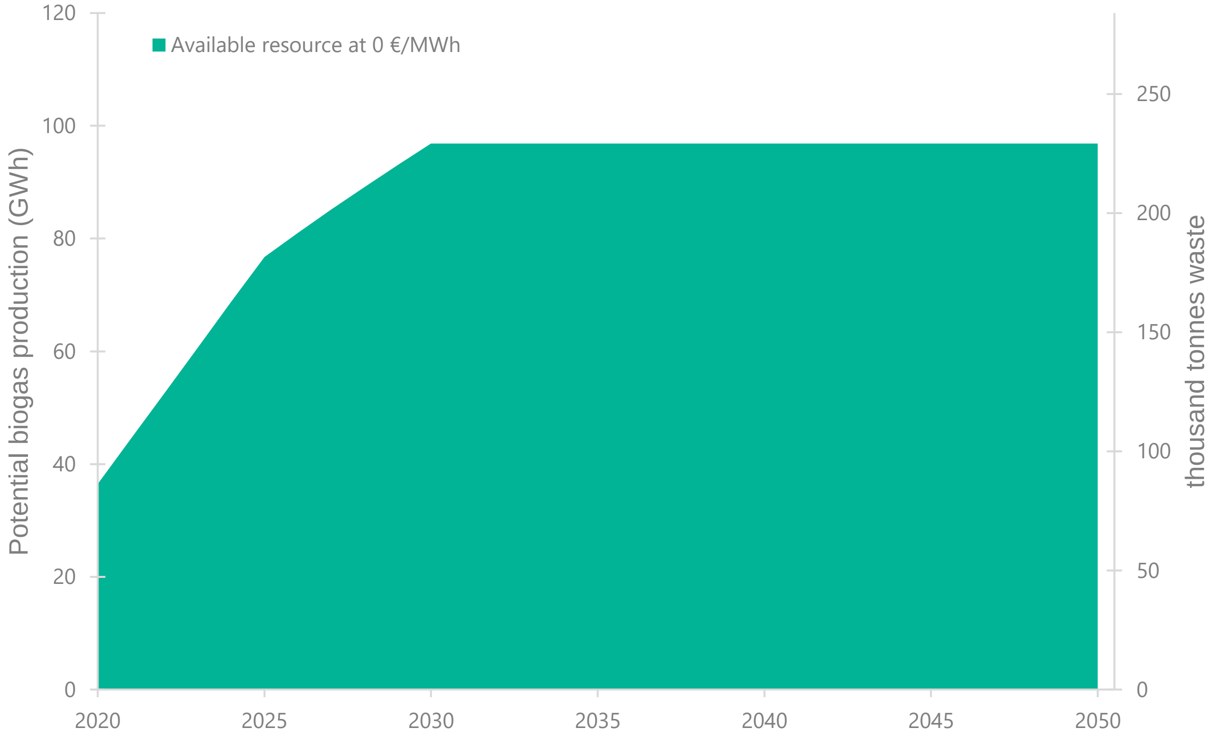
4.3.2 Availability and price

The most recent estimates of slaughter house waste and milk processing waste were published in 2016 and 2017 [35], [36]. They were based on retrieval and analysis of around 60 Annual Environmental Report (AER) returns submitted to the EPA in 2015. Updating of the data set through identification and retrieval of more up to date AERs for these facilities, plus any new facilities, was outside the scope of this study, and a more general approach is used to update the estimates. The quantities of waste generated in 2020 and beyond were estimated by multiplying estimates for quantities in 2015, by the forecast changes in the number of dairy cows (for milk processing waste) and in other cattle (for slaughterhouse waste). Changes in cattle numbers are as described in Section 3.1.2. Biomethane yields when the wastes are digested are assumed to be 38.4 m^3 CH_4/tonne for milk processing waste and 44.9 m^3 CH_4/tonne for slaughter house waste [36]. Not all sites might be suitable for the installation of an AD plant, particularly smaller sites where quantities of biogas generation would be lower. It was assumed that by 2030, all sites with a significant resource (greater than 1 GWh per year of potential biogas production) could potentially utilise the waste resource; these sites account for 85% of the total resource.

These wastes are typically disposed of by spreading on land or treating liquid effluents in a wastewater treatment plant before discharge to the sewer. The costs of these alternative waste management options vary by the type of waste, proximity to suitable land areas for spreading, and level of wastewater treatment required. AD facilities taking the waste might therefore charge a gate fee; previous estimates supplied by Gas Networks Ireland have suggested a level of €20/t[37]. However, it is likely that some sites producing these wastes would develop an on-site AD plant to treat the waste themselves, and in this case, a gate fee would not apply. As no detailed information on avoided waste disposal costs or potential gate fees was available, a conservative assumption is made here, that the resource is available at zero cost, €0/t.

The availability of waste from the food processing industry for bioenergy use is shown in *Figure 17*; a full data set is given in Appendix 1.

Figure 17: Availability of waste from food processing for bioenergy use (2020 – 2050)



4.4 Waste wood

4.4.1 What is the resource and how can it be used?

Waste wood (sometimes referred to as Post-Consumer Recycled Wood (PCRW)) arises from several different sources and is of differing quality. The quality of the wood determines the application it can be used for, which in turn influences its price. Four types of waste wood are potentially available:

- Commercial Packaging: arising from any commercial sector where wooden protective packaging or pallets are used. This wood is generally clean and has several other uses, including processing into animal bedding and mulches or as a feedstock for panel board production.
- Wood recovered from kerbside collections of waste from households: a mixture of wood that is generally domestic packaging of mixed quality.
- Civic Amenity collection: waste wood that is collected from household waste collection centres. Typical sources would be old wooden furniture. Most of this resource has been treated with paints or preservatives at some point.
- Construction and demolition: typically offcuts from wooden beams, doors or temporary wooden boarding. This wood is often a mixed combination of clean waste wood, waste wood that has been treated with paints or preservatives and MDF, which contains solvents.

Contaminated waste wood, containing paints or preservatives, must be combusted in plants that have advanced emission scrubbing equipment and comply with the Industrial Emissions Directive (2010/75/EU). This emission abatement equipment is an add-on to a typical combustion plant. It filters the exhaust (flue) gases to remove harmful particulates. The equipment is expensive to install and operate; it is usually associated with more stringent licensing requirements to ensure air quality targets are met. This equipment and licensing requirement results in additional costs to the plant operator and means that the price for contaminated wood is lower than for cleaner packaging wood waste.

4.4.2 Availability and price

Quantities of wood from different waste streams are based on data from waste reports, as shown in *Table 3*. Future quantities of waste are estimated from this data based on the growth in MSW assumed in Section 4.1. Although large quantities of wood are available from packaging waste, most of this goes towards material recovery, and only 15% (based on data on recovery rates) is assumed to be available for energy use. It is assumed that half of the waste wood in the MSW stream might be made available from energy use (for instnace through encouraging householders to separate out wood waste and take to civic amenity sites, or through separation and recovery of the wood at Materials Recovery Facility (MRF) plants).

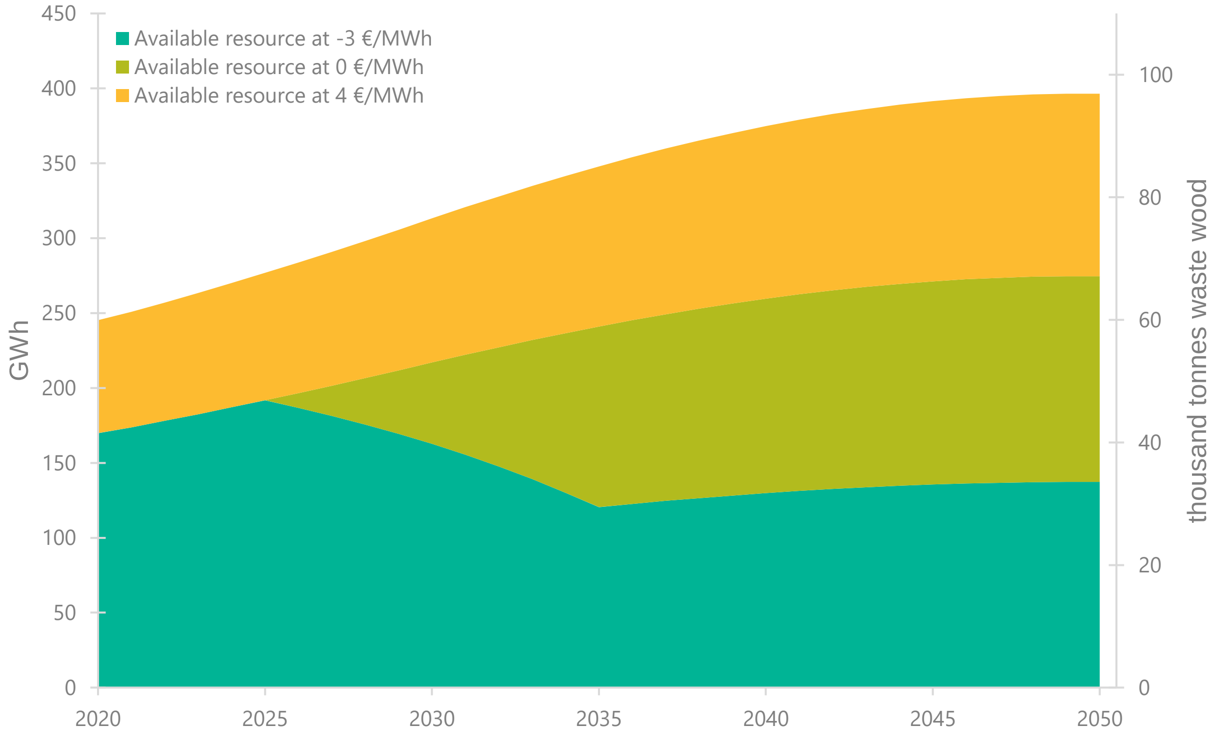
Table 3: Waste wood quantities

Source of waste wood	Latest year data available for	Quantity (tonnes)	Forecast quantity in 2020 (tonnes)	Source
Collected MSW	2016	13,840	15,380	[38], [39]
Civic amenity sites	2012	8.412	9,593	[40]
Packaging	2018	120,038	126,563	[21]
Construction & demolition waste	2018	23,068	24,322	[21]

Wood recyclers generally charge a gate fee for accepting low-grade waste wood. No data could be found on these gate fees in Ireland, but for the UK, an average gate fee for 2020 was €12.6/tonne (€3.1/MWh) [41], for example, those wishing to dispose of low-grade PCRW to the wood recycler may have to pay this fee for the recycler to accept it. In contrast, suppliers of high-grade clean wood could expect to receive a price from the recycler; an average price in 2020 in the UK was €14.8/tonne (3.6 €/MWh). The wood recycler's prices for then supplying the wood to an energy user will be higher than these gate fees. They must cover the costs of sorting the wood, removing contaminants, and chipping it. It is estimated that the wood is typically sold at about €60/t more than the price paid by the recycler.

The availability of waste wood for bioenergy use is shown in *Figure 18*; a complete data set is given in Appendix 1.

Figure 18: Availability of waste wood for bioenergy use (2020 – 2050)



4.5 Tallow

4.5.1 What is the resource and how can it be used?

Tallow is a by-product of meat processing, produced when offal and carcass/butchers' wastes are processed at rendering plants. Depending on the production method, it is classified into three categories, dictated by the Animal By-products Regulations:

- Category 1 can only be used for burning or fuel production
- Category 2 can be used for industrial applications
- Category 3 can be used for human contact (for instance in soaps and cosmetics).

Irish rendering plants produce Category 1 and Category 3 tallow.

The most common energy uses of tallow are as a heating fuel, often within the rendering industry itself, or for processing into biodiesel. To date, the rendering industry has made considerable use of tallow as a fuel. However, the annual use varies depending on how much the tallow is worth in other markets and oil fuel prices. When tallow prices are low, and oil prices are high, more tallow is used as a fuel.

4.5.2 Availability and price

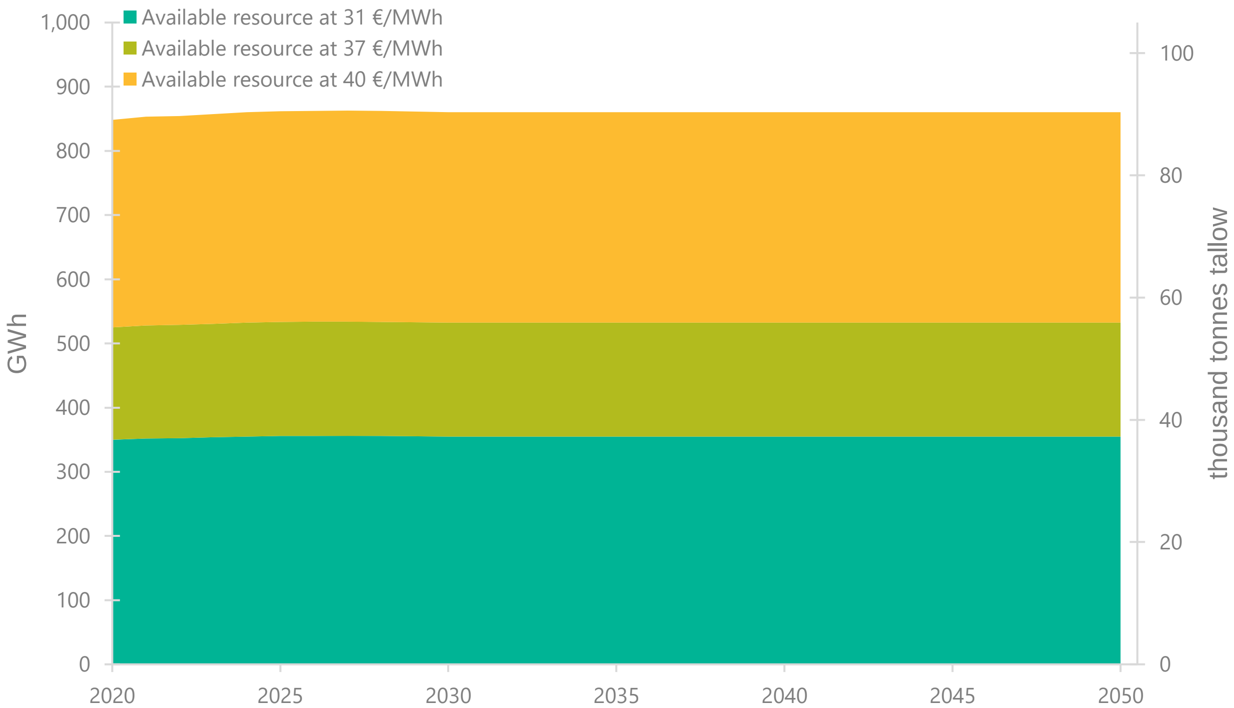
The resource was estimated using the same methodology as in the previous bioenergy study, which was based on a methodology used in an earlier detailed study of the tallow resource [42]. The methodology estimates that tallow production is based on the herd size, carcass weight, post-processing carcass material reaching the renderers and amount of tallow produced per tonne of carcass weight. As in the evaluation of pig and cattle slurry resources, forecasts of herd size to 2030 are taken from the projections made for Ireland's National Energy and Climate Plan [4]. Post-2030, no estimates are available, and the herd size is assumed to remain stable.

Approximately half of the tallow produced in Irish rendering plants is Category 1 tallow, which is high risk and can only be used as a fuel or biodiesel production. The remainder is Category 3 tallow, which is fit for human contact and can be used to produce oleochemicals for the pharmaceutical and cosmetics industry or pet food production, as well as for energy. Historically, about 38% of Category 3 tallow[13] has gone to non-energy uses. It is assumed that a similar proportion will go to non-energy uses in the future.

Data on tallow prices is difficult to acquire as tallow is not generally traded on the open market but as direct contracts between companies. One study examining prices in the UK suggested that, in the absence of subsidies, the price of Category 1 tallow is linked to fuel oil prices. Prices for Category 2 and 3 tallow reflect the trends in Category 1 tallow, plus the additional cost of segregation and processing [44]. The upper price of Category 3 tallow was thought to be linked to the lowest equivalent virgin plant oil, minus the transport costs and any import or export tariffs. Estimates of price used here are based on information from that study and data received from DAFM at the time of the previous bioenergy study [6].

The availability of tallow for bioenergy use is shown in *Figure 19*; a full data set is given in Appendix 1.

Figure 19: Availability of tallow for bioenergy use (2020 – 2050)



4.6 Used cooking oil

4.6.1 What is the resource and how can it be used?

Used Cooking Oil (UCO), also referred to as Recovered Vegetable Oil (RVO), or waste vegetable oil, can be collected, filtered and used as a feedstock to produce biodiesel. The primary sources of UCO are catering premises, food factories and households. There are commercial services that collect UCO from catering premises and food factories. Some companies supplying oil to catering companies offer an integrated service that includes a free collection of used oil. There is currently no collection of UCO from households in Ireland. In 2020 a total of 8.7 kt of Irish UCO were used to produce biodiesel supplied to the Irish market.[14]

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[13] Data from DAFM on uses of tallow in 2014 as cited in [43]

[14] Based on data from Biofuels Obligation Scheme sustainability statements for Ireland [45].

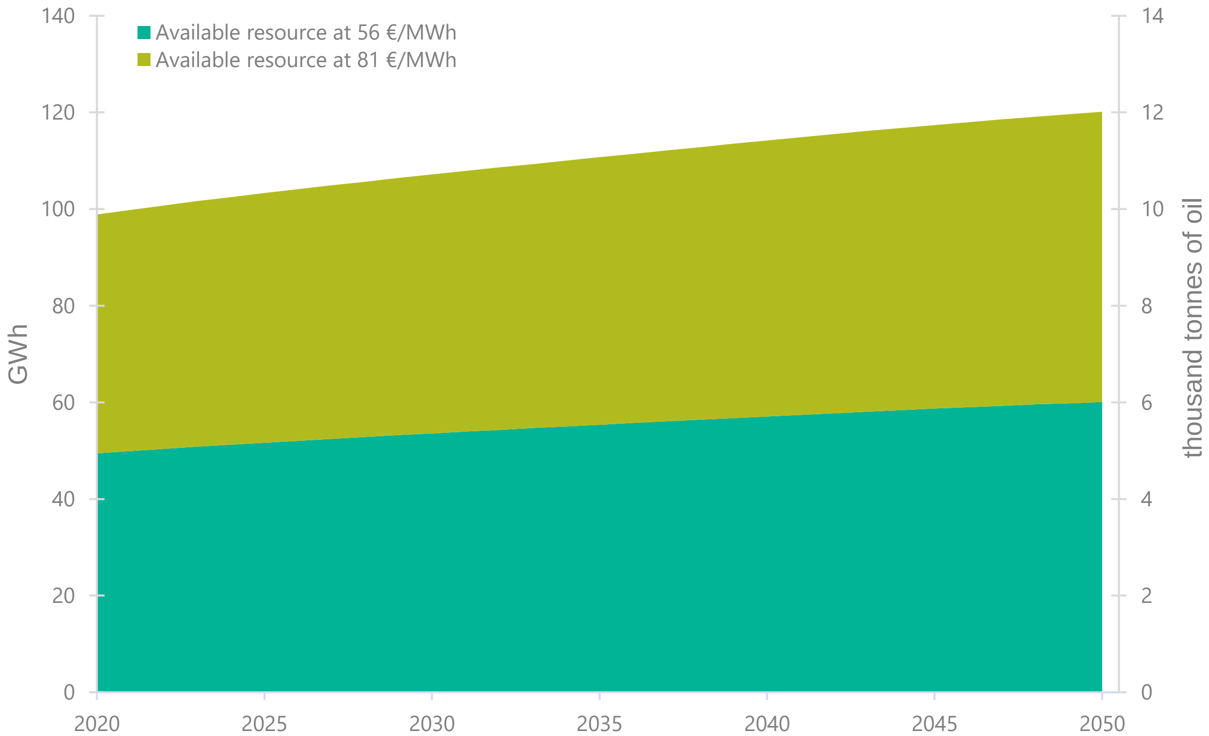
4.6.2 Availability and price

The amount of UCO which is potentially available for collection is estimated based on consumption per head, the recoverable fraction of this oil (70%) and forecasts of the Irish population. Legislation prevents UCO from being used in animal feed. Although a small proportion is used in the oleochemical industry, it is assumed here that all UCO collected is potentially available for energy purposes. As there is currently no household collection, it is assumed that only oil from catering premises and food factories (estimated to account for 57% of the resource) is collected. This gives a potential resource of 9.9 kt UCO in 2020. Almost all of this is used to produce biodiesel in Ireland. If household collection of UCO were to be implemented, then this could add another 9 kt UCO.

A literature review for the previous report suggested that price could fluctuate considerably and was affected by factors such as time of year. A review of the relevant studies suggests that UCO from catering premises would be available at between €558/tonne (€53/MWh) and €806/tonne (€81/MWh), with 50% of the resource available at each of these prices [46], [47]. A more recent (2019) UK study [48] found that UCO was trading at slightly lower prices than this, of £420 to £470/tonne (€480 to €530/tonne). However, a recent (2021) European study looking at UCO for biofuels production found that the price had fluctuated between 630 and 1200 €/tonne in recent years and assumed a typical price of €840/tonne [49]. Therefore, the prices assumed in the previous study were assumed to still represent the current price range that might be seen in Ireland.

The availability of used cooking oil for bioenergy use is shown in *Figure 20*; a full data set is given in Appendix 1.

Figure 20: Availability of used cooking oil for bioenergy use (2020 – 2050)



5 Bioenergy crops

One way for Ireland to significantly increase its bioenergy resources is to cultivate energy crops. These include crops such as:

- grass cultivated to supply Anaerobic Digestion (AD) plant that produces biomethane,
- miscanthus and short rotation coppice willow, which can be combusted in boilers and CHP plant to produce heat and/or power,
- starch and oil crops are used in refineries to produce transport biofuels.

Currently, only small quantities of perennial energy crops are grown and used for energy in Ireland. More recently, farmers have expressed significant interest in developing grass silage for AD. However, it is vital that any cultivation of energy crops is done sustainably and does not cause conflict with food and fodder production. This study evaluates how much land could be made available to cultivate energy crops without impacting other aspects of agricultural production. This was done for the two scenarios of future herd size. As discussed in 3.1.2, a 'Stable Herd' BAU scenario reflects current plans and projections for the Agriculture sector in Ireland. Also discussed is a hypothetical Land Use Change scenario under which the suckler herd declines in line with deep economy-wide emissions reduction targets. Then an evaluation of grass silage and perennial energy crop production, which might be possible on this land, is conducted, and how likely it was that farmers would make this transition.

5.1 Estimating availability of land for bioenergy crops

The farmed area in Ireland is about 4.5 million hectares (Mha), of which 92% is pasture and rough grazing [50]. The tillage area for crops such as cereals is 0.33 Mha (7% of the farmed area) but has been declining in recent years, with the cereal production area falling by 9% between 2015 and 2020 [15]. A further decline in the area devoted to food and fodder crops is considered undesirable from a food security perspective, and the recent Food Vision 2030 strategy proposes an expansion of tillage production. It is theoretically possible to grow an energy crop for AD as a break crop in an arable rotation,[15] thus avoiding a reduction in tillage area. For example, maize and grass could be grown for a year in between cereal crops to provide a feedstock for AD. In the case of maize, emissions associated with its cultivation are higher than for the AD feedstock considered in this study (a red clover/rye grass mix), which presents challenges for maize crops in meeting sustainability requirements. The GHG impacts an alternative supply of the product provided by the break crop usually in place would also need to be considered. In the case of grass, the cost of seeding a suitable red clover/ryegrass mix means that in order to keep the costs of the silage produced down, it would need to be left in for at least two years before being ploughed up, upsetting the arable rotation. For these reasons, it is assumed that no additional tillage land is available for conversion to the production of silage for AD or to perennial energy crops.

This means that land for bioenergy crops must come from grassland currently used for fodder cultivation. Such land could become available if the number of livestock grazing on the land reduces or if the productivity of the land is increased. In these circumstances, more grass is available, and the same number of livestock can be supported on a smaller land area. Section 5.1.1 describes how the potential areas of land that could be released through grassland productivity improvements were estimated.

Afforestation is also another important competing land use. The forest area in 2017 was 0.77 Mha, and current targets are to increase this to about 1.25 Mha, or 8% of the land area, by 2046. To achieve this, 8,000 ha per must be planted with new forest every year. In general, afforestation has broader land suitability than energy crops. However, given the afforestation ambition, it is also possible that forests may also be planted on grassland. The compatibility of land use for bioenergy crops with these targets is discussed further in Section 5.1.4.

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[15] Break crops, for example oil seed rape, are grown every few years on land used to grow cereals to prevent the builid up of pests and diseases.

5.1.1 Productivity increases

The amount of grass grown, and eaten by livestock per ha (known as grass utilisation) varies significantly between the most and least productive livestock farms. Increasing grass utilisation has been the subject of a campaign implemented by Teagasc, known as 'Grass 10' [51]. Its objectives include 10 grazings per paddock per year and for 10 tonnes of grass dry matter (DM) to be utilised from each ha of grassland. Measures to improve grass utilisation fall into two broad groups, improving grazing management which increases how much grass is utilised, and improving soil fertility, which increases the amount of grass grown per ha. Specific measures include:

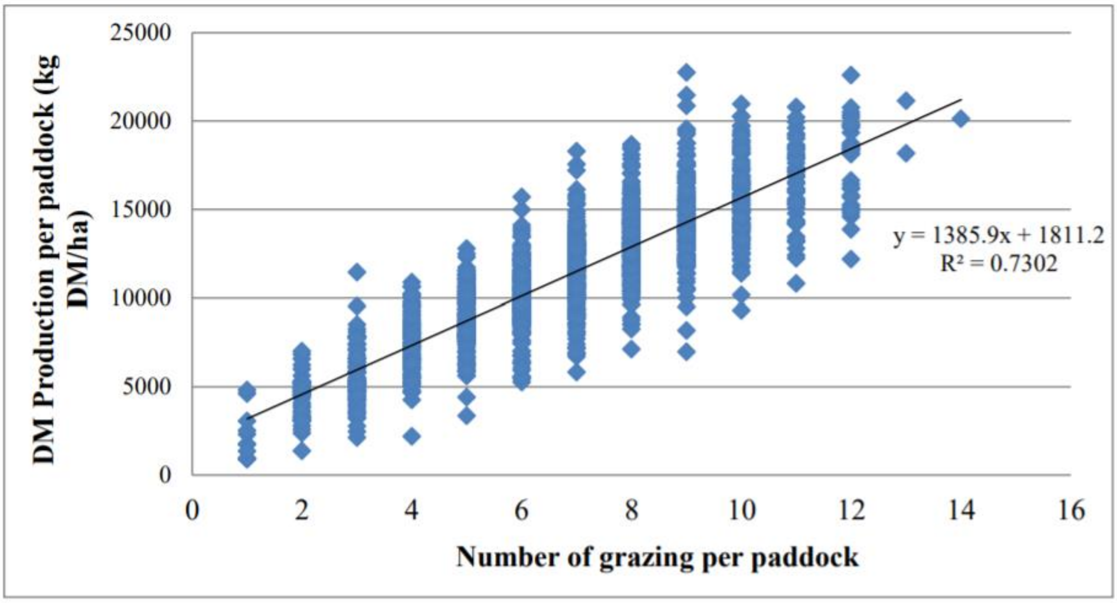
- *Rotational grazing*: achieving a high number of grazings per paddock per year. The most highly productive farms achieve more than 10 grazings per paddock per year [52]; productivity is increased because, when the number of grazings is increased, residency time for the cattle in a paddock is decreased, and this protects regrowth;
- *Good farm infrastructure:* paddock design and roadways, drainage; productivity is increased by the avoidance of damage (trampling) to pasture through cattle movements;
- *Precision grazing management:* grazing and cutting decisions made weekly based on weekly measurements of above-ground grass [52]; knowledge of grass growth in each paddock enables good planning of rotational grazing with benefits for grass quality and utilisation;
- *Maximising spring grazing* through early turnout and finishing the first rotation on time [53]; quality and utilisation of grass deteriorates if turnout is too late, and early spring grazing increases grass quality and utilisation in subsequent grazing rotations;
- *Optimising timing of autumn closure* [54]; achieving optimum grass cover at the time of autumn closure increases the supply of grass in early spring.

Measures to improve soil fertility include:

- Measuring Phosphate (P) and potassium (K) levels annually and ensuring that these are at optimum levels through the application of P and K [55], [56]; this ensures that growth is not limited by P and/or K supply;
- Monitoring soil pH and correcting, through, for example, the application of lime [57]; soil pH influences nutrient availability and, therefore, productivity;
- Increasing fertilisation with applications of nitrogen. While this option is likely to improve yield, it also leads to additional emissions from the soil of the greenhouse gas (GHG) nitrous oxide (N_2O). It could lead to the leaching of nitrogen into water courses [58].

It was considered likely that increasing grassland productivity and the number of rotational grazings per year would be achieved in conjunction with the other measures listed above. Therefore, a value for the potential productivity improvements that could be achieved for grazing land was estimated based on data from Teagasc from the PastureBase Ireland database [45]. PastureBase is a grassland management decision support tool for farmers, and also a mechanism to capture background data on farms, including grassland measurements. The data in PastureBase show a relationship between the number of grazings per paddock and DM yield per ha (*Figure 21*). Based on this dataset, the potential increase in DM yield, which could be achieved for grassland used for grazing by increasing the number of grazings per paddock was estimated (*Table 4*). This represents the increase (8.3 t DM/ha) that might be achieved for farms that have relatively poor grassland management, implementing a range of best practice measures. Some farms will have already implemented some of these measures, particularly in the dairy sector, and average productivity increases which could be achieved are therefore assumed to be lower (3.3 t DM/ha for dairy farms and 5.5 t DM/ha for beef farms.

Figure 21: Relationship between number of grazings and DM production



Source: Reproduced from [52]

Table 4: Productivity improvements assumed in modelling

Parameter	Central estimate (Range)	Notes
Assumptions for grazing		
Potential increase in the number of grazings for farms with lower productivity	6 (4-8)	Based on increasing grazings per paddock from 5 to 11
Maximum potential improvement in yield	8.3 (5.5-11) t DM/ha	
Fraction of farms measures applicable to and implemented on	Dairy: 40% Beef: 67%	Scope for remaining improvement assumed to be less on dairy farms than on beef farms
Average improvement in productivity across all farms	Dairy: 3.3 (2.2-4.4) t DM/ha Beef: 5.5 (2.7-7.4) t DM/ha	
Assumptions for land producing silage		
Potential increase from optimising P and K	1 t DM/ha	
Potential increase from improved management of pH	1.25 (1-1.5) t DM/ha	
Total maximum potential increase	2.25 (2-2.5) t DM/ha	
Percentage of potential increase achieved on average across all farms	Dairy: 40% Beef: 70%	More dairy farms are likely to have improved grazing management, so the scope for remaining improvement is lower on these farms.
Average improvement in productivity across all farms	Dairy 0.9 (0.8-1.0) t DM/ha Beef 1.6 (1.4-1.8) t DM/ha	

5.1.2 Land suitable for productivity measures and cultivation of bioenergy crops

Not all grassland areas are suitable for implementing productivity measures. Access constraints are important. Tractors and other machinery are needed to implement some of the measures, for example to build roadways, construct fencing, improve drainage, or apply nutrients. This may be infeasible on, for example, steep land. Environmental considerations also limit the applicability of some measures. Productivity improvements may be undesirable for biodiversity reasons in protected or environmentally sensitive areas as they can damage habitats. The cultivation and drainage of soils that have a high carbon content should also be avoided, as this can promote biological processes in the soil, which lead to a release to the atmosphere of the greenhouse gas carbon dioxide (CO_2).

Therefore, several exclusion criteria were identified to estimate areas where it would be feasible and environmentally acceptable to improve productivity. These are listed in *Table 5*.

Table 5: Exclusion criteria used to identify suitable land

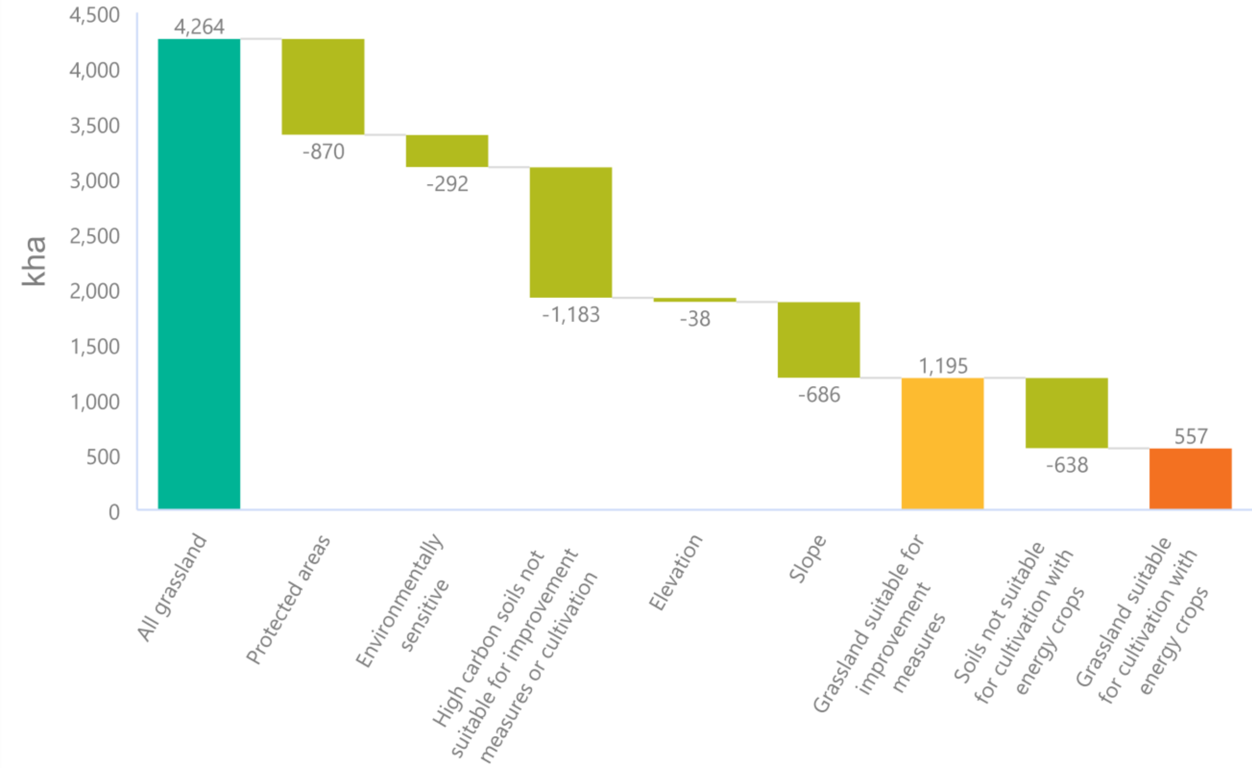
Exclusion criteria	Exclusion criteria	Note
Protected areas	Special Areas of Conservation, Special Protected Area, Natural Heritage Area, proposed Natural Heritage Area	Data on the location of areas from [59]
Environmentally sensitive area	Land parcels classified as Traditional Hay Meadow or Low Input Pasture	Data on the location of areas from LPIS data set
Soil types not suitable for productivity improvement measures	Soils with peaty topsoil, or potentially peaty topsoils, peats; (IFS codes 41 to 46 and 61 to 66)	As these are high carbon soils, their disturbance should be avoided as it may lead to carbon loss and release of CO_2. Improvement might also affect biodiversity on these soils.
Slope	>15%	Limit for machinery needed to carry out required operations [60]
Elevation	250 m	Expert judgement; higher areas likely to be wetter
Soil types not suitable for cultivation of silage for AD or other bioenergy crops	Soils with peaty topsoil, or potentially peaty topsoils, peats; (IFS codes 41 to 46 and 61 to 66) and soils that are poorly drained (IFS codes 31 to 34)	Poorly draining soils are excluded based on expert judgement related to the use of machinery for soil cultivation.

The Land Parcel Identification System (LPIS) database held by DAFM contains information on the use and location of each land parcel within a farm. The LPIS data is combined with other spatial data sets to identify areas of land suitable for improvement measures. The spatial data sets used are:

- protected areas from the National Parks and Wildlife Service [61],
- slope and elevation data sets from Ordnance Survey Ireland [62],
- and the national data set on soil type [62].

Together these allow the identification of the area considered suitable for improvement measures. In addition a further criterion (poor drainage) was applied to allow the area suitable for conversion to energy crops to be identified. *Figure* 22 shows the results of this modelling.

Figure 22: Impact of exclusion criteria on the suitability of land for improvement and conversion



The LPIS dataset allows the area of grassland on each farm in Ireland to be identified. The Animal Identification and Movement System (AIMS) held by DAFM provides data on the number of cattle of different types on each farm.[16] By combining the two data sets it is possible to identify the number and type of cattle on each farm with grassland. This allows each farm with grassland to be classified as either:

- Dairy: farms with only dairy cows, farms with more than five dairy cows together with other cattle
- Beef: farms with cattle but no more than five dairy cows
- Sheep: farms with grassland but no cattle

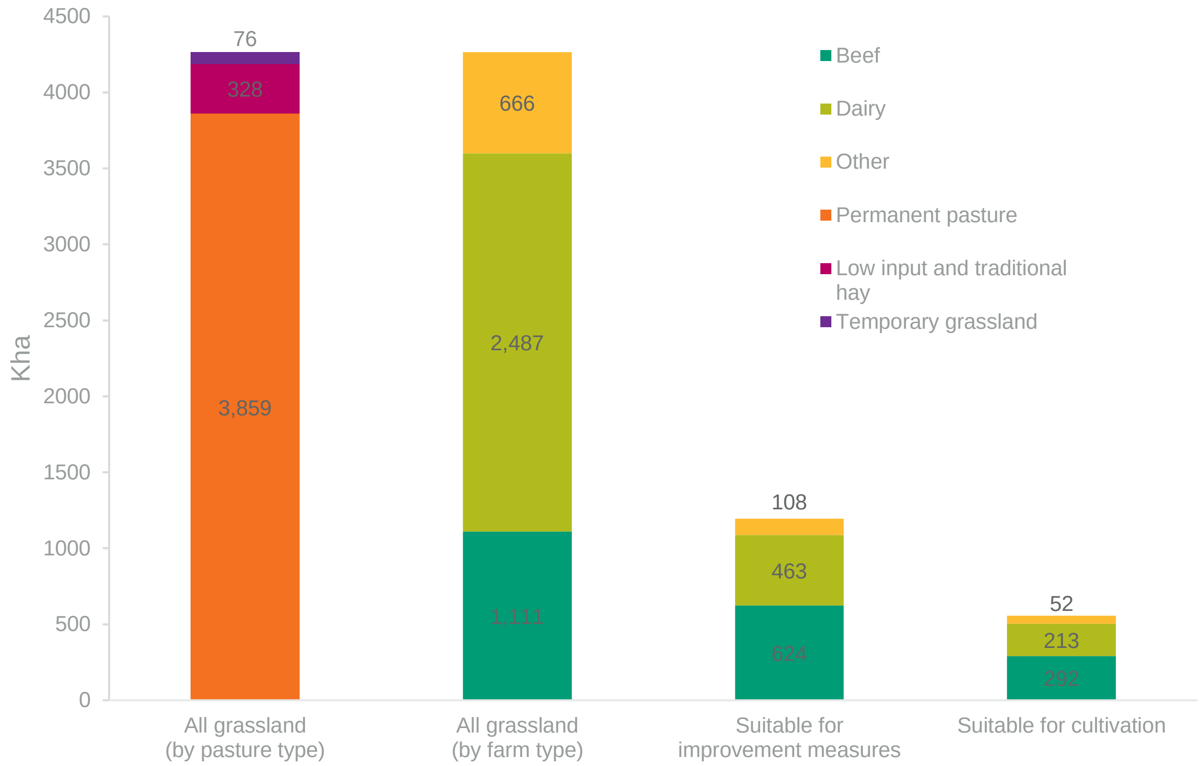
Combining the information from the two datasets also provides the necessary information on the potential supply of grass and demand for grass from livestock at the individual farm level. This is necessary in order to apply the methodology described in Section 5.1.3, which estimates how much land might actually become available for energy crop cultivation in the future when behavioural and economic factors are applied.

A breakdown of grassland area by type of farm is shown in *Figure 23*. The 'other' category in *Figure 23* includes sheep farms and a small number of farms that could not be classified as they were not present in both datasets.[17]

[16] The AIMS data includes the number of days various types of cattle were present on the farm ('livestock days'). Classifications used are dairy, suckler, cattle under 1 year, cattle 1 to 2 years, and cattle over two years. So for example three dairy cows present at the farm all year would be represented as 1095 (3 x 365) livestock days, and 10 cattle under 1 only present on the farm for one month in the year would be represented as 310 (10 x 31) livestock days.

[17] This is likely because the data sets were for two different years (2019 and 2020) and farm holding numbers (the linking identifier between the two data sets) changed for a small number of farms.

Figure 23: Grassland by classification in LPIS and by type of farm



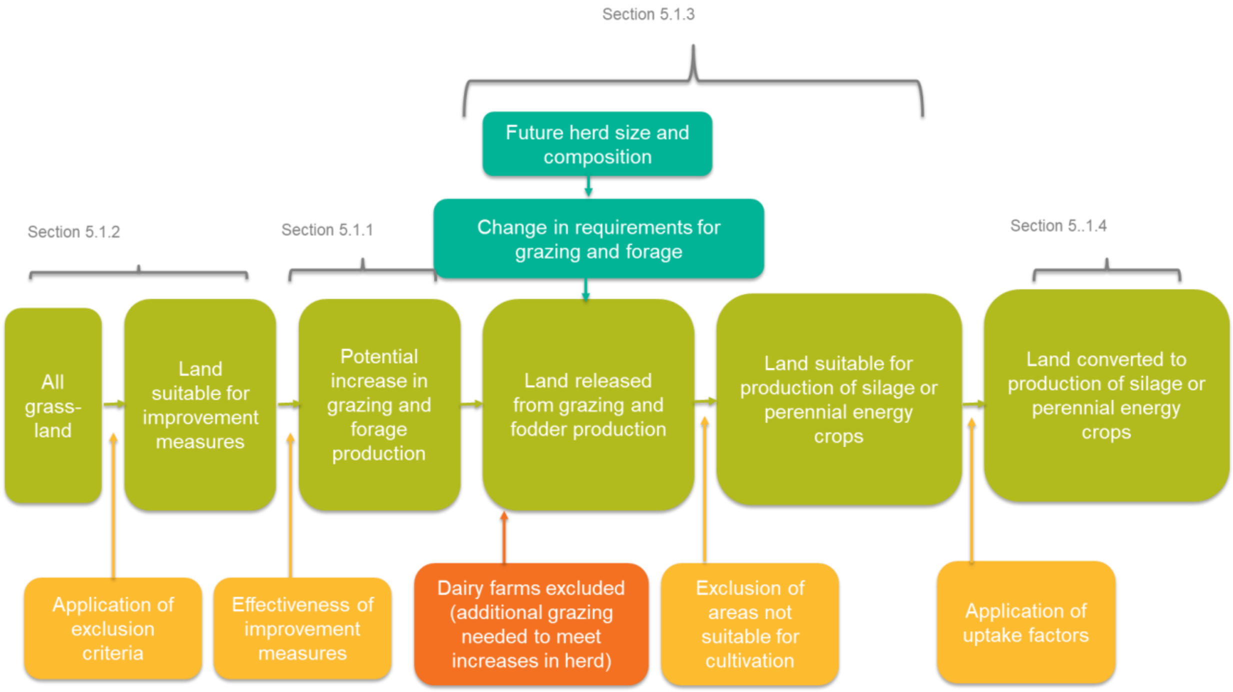
Note: other is mainly sheep but also includes a small number of farms where it was not possible to cross-reference data between AIMS and LPIS

5.1.3 Land which can be made available for energy crops

An overview of the methodology used to estimate the land which could be used to grow energy crops in the future is given in

Figure 24. A combination of the AIMS and LIPS spatial data sets means that information on the area of grassland and the number of cattle is available at the individual farm level. These can be used to examine, at the individual farm level, what livestock demands for grass for grazing and fodder are. Using forecasts of changes in the size of the national herd, the change in demand for grass in the future on each farm can be estimated. The methodology described in 5.1.2 above allows the area on an individual farm that is suitable for improvement to be identified, and by applying estimates of productivity improvement (as set out in Section 5.1.1) an estimate of additional grass which could be made available for livestock on each farm can be made. Combining these two estimates allows the amount of land on the farm which is not required to support livestock to be identified. A further assessment can then be made of whether this land would be suitable for growing energy crops. Each step is explained in more detail below.

Figure 24: Overview of methodology to estimate future uptake of energy crops



5.1.3.1 Future requirements for grazing and forage

As discussed in Section 3.1.2 two scenarios for changes in the size of the herd in 2030 were evaluated:

- Business as Usual (BAU) scenario – the 'Stable herd' projection forms the basis of the projections for greenhouse gas emissions from livestock in the National Climate and Energy Plan [4]. Under this scenario, the dairy herd increases by 10% by 2030, but the suckler herd reduces by 23%, giving an overall reduction in the national herd of 0.5%.
- A Land Use Change (LUC) scenario was created for input into the National Heat Study analysis for a 'Rapid Progress' scenario described in section 1.2. In this scenario, it is assumed that a desire to reduce livestock emissions from agriculture leads to a more significant reduction in the suckler herd, of 45% (about 440,000 head) by 2030, compared with that in the BAU stable herd projection. The dairy herd is assumed to show the same increase as in the BAU scenario. Overall, the national herd is reduced by almost 600,000 head (8.4%) to 6.5 million.

Predicting how the national level projections for herd size changes and silage use translate to individual farms is challenging. A myriad of economic, land and social factors will influence how these changes are implemented at the individual farm level. This analysis addresses this by making two simplifying assumptions. Firstly, it is assumed that each farm can currently supply both the grazing and silage requirements of its herd from grassland within the farm. This is a simplification of reality as some farms sell excess silage, and others buy some.

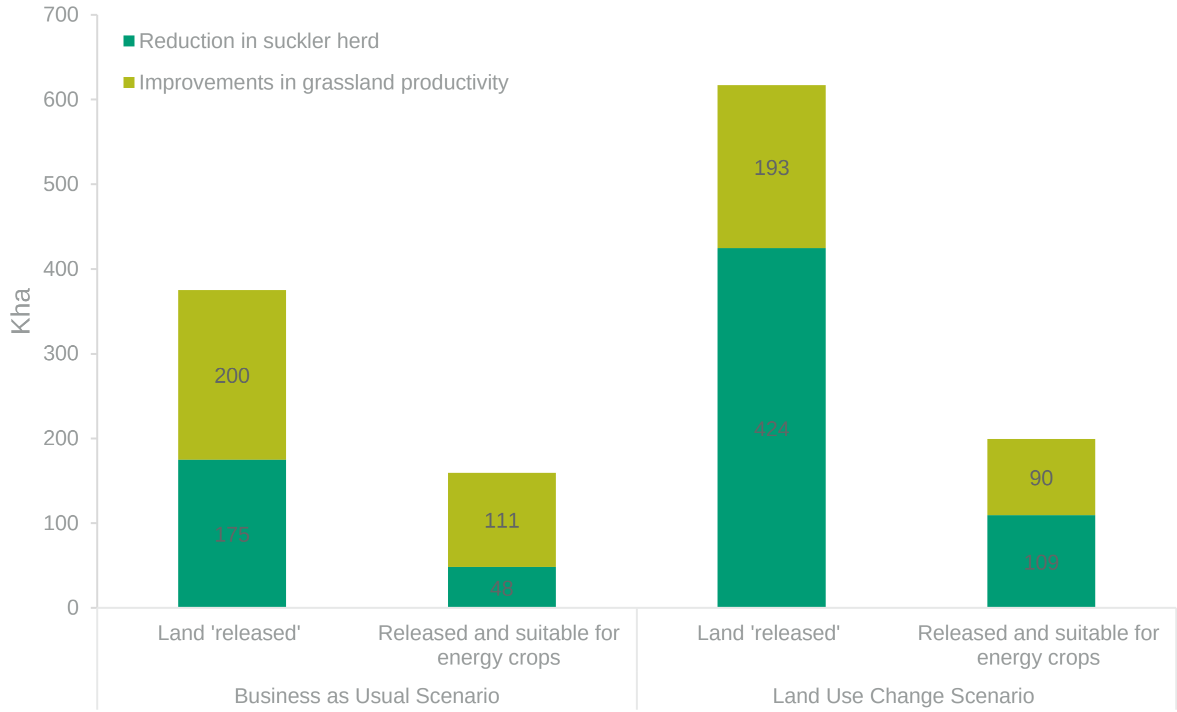
A second simplifying assumption is also applied to how the national herd size changes translate to individual farms. It is assumed that each farm type increases or reduces herd size in line with the national level changes. For example, in the BAU scenario, all beef farms reduce their suckler herd by 23%, and all dairy farms increase their herd by 10%. In reality, the distribution of the changes across individual farms will be influenced by a number of factors. For example, less profitable beef farms may reduce their herd by more than 23% and more profitable beef farms not reduce their herd at all. If less profitable or more profitable farms are clustered in particular geographical areas, then reductions in herd size could be higher or lower in some areas. Analysis of this aspect would require more detailed information on how typical profitability varies by farm type and location and was outside the scope of this study. However, while the impact of the simplifications at the individual farm level may be significant, the impact is much less for the national level estimates being produced here.

The herd size at a farm level is used to estimate the amount of land that would be required to meet grazing and fodder requirements in 2030, given the forecast change in the herd size, but assuming that the average productivity of grassland on the farm remains the same. The size and composition of the herd on each farm, and the nutritional requirements of different types of cattle in the herd are the key factors in the calculation. For beef farms where the herd size is forecast to decline, the smaller herd in 2030 can generally be accommodated on a smaller grassland area meaning some land can be released for other uses such as energy crops.

A second calculation was then made of additional land which could be released from grazing and silage production if the productivity improvements discussed in Section 5.1.1 are implemented. These productivity improvements were only applied on grassland areas within the farm that met the criteria set out in Section 5.1.2. The total area of land which can be released from production was then compared on a farm by farm basis with the area of land identified as suitable for cultivation for energy crops (either a mixed ryegrass and red clover sward for use as an AD feedstock or perennial energy crops). It was found that on dairy farms the extra grazing and fodder requirements from the expansion of the dairy herd were generally in balance with the extra grass that could be supplied from the productivity improvements. This means that the dairy farms do not need to expand in size but will need to continue to use all of their grassland to support larger herd. It was therefore concluded that energy crops would not likely to be grown on dairy farms. For beef farms however the smaller herd on the farm in the future, and the additional grass which could be grown due to productivity improvements meant that not all of the grassland on the farm would be required to support the farm herd in the future. This land no longer required to support the herd could be released from beef production and, if it has suitable characteristics used to grow energy crops.

It is estimated (*Figure 25*) that in the Business as Usual 'Stable Herd' scenario, reductions in the suckler herd and improvements in grassland productivity could allow 375 kha of grassland to be released from beef production by 2030. Under the 'Land Use Change' scenario where the suckler herd sees further reductions, this rises to 617 kha. The spatial mapping process outlined in Section 5.1.2 was used to identify the area suitable for recultivation with energy crops on each farm. By comparing this with the area of land released from beef farming, it was possible to estimate how much of the released land is suitable for recultivation with energy crops. Under the BAU stable herd scenario, 160 kha of released land on beef farms is suitable for recultivation with energy crops and under the Land Use Change scenario, 199 kha.

Figure 25: Land released from beef farming in 2030



5.1.4 Compatibility with forestry targets

The forest area in 2017 was 0.77 Mha. Current targets are to increase this to about 1.25 Mha, or 8% of the land area, by 2046, by planting 8,290 ha per year. This target is currently not being achieved, and planting has declined in recent years from just over 6,000 ha per year in 2016 to 2,434 ha in 2020 [63]. If the targets were to be achieved, then this would require planting of 248 kha by 2050.

A 2016 report [64] examined the potential for forestry expansion and found around 3.75 Mha that could be suitable for afforestation (*Table 6*); of which 1.3 Mha was marginal agricultural land, predominantly improved grassland. This suggests that there is enough suitable land for the afforestation targets to be achieved. However, the estimates need to be refined by considering where afforestation ambitions compete with other land use options.

Table 6: Area of land with potential for forestry expansion

Type of land		kha	% of suitable land
Productive agricultural land	Grassland/arable	2,336	62%
	Wet grassland	88	2%
	Unenclosed/other	25	1%
	Total productive land	2,449	65%
Marginal agricultural land	Improved grassland	991	26%
	Wet grassland	156	4%
	Unenclosed /other	154	4%
	Total marginal land	1,302	35%
All land	Total suitable land	3,750	100%

Source: [64]

A complete analysis of land-use change patterns is outside the scope of this report, but a high-level analysis suggests that the levels of conversion of grassland for grazing and fodder to bioenergy crops are compatible with achieving the forestry targets. As shown in *Figure 26* the area of grassland which could be released from beef production under the LUC scenario, but is not considered suitable for bioenergy crops is significantly higher than the land required to meet the afforestation target. This land was considered unsuitable because the soils were classified as having poor drainage and may well be suitable for forestry. There will also be areas of unenclosed land suitable for forestry (estimated as 170 kha in *Table 6*), which were not considered in the grassland analysis described above. Finally, as discussed in Section 5.2.3.2, not all of the land identified as released and suitable is assumed to be converted to bioenergy crops, thus increasing the amount of land which could be available for afforestation. These additional factors mean that even under a LUC scenario, it should still be possible to meet afforestation targets alongside a substantial energy crop resource. However, further research into how these two objectives could be integrated into a cohesive land-use change policy or plan would be useful.

Figure 26: Land which could be released from beef production compared to afforestation target

5.2 Grass silage

5.2.1 Background

Biomethane produced from grass silage via Anaerobic Digestion has significant technical potential. Previous work by Ricardo for SEAI [65] and by KPMG for the Renewable Gas Forum of Ireland (RGFI) [66] suggested that 6 to 7 TWh could be available, much of it from grass silage. This has driven significant interest in grass silage as an AD feedstock in Ireland from the energy and agricultural sectors.

However, this technical biomethane potential must be refined to account for environmental, sustainability and economic constraints. The sustainability of the production is a critical consideration. When all emissions associated with the grass silage production, other inputs to the AD process, and any methane leakage are taken into account, there must be significant greenhouse gas (GHG) savings compared to the natural gas the biomethane will replace. It is also important to ensure that additional silage for AD is produced sustainably and does not cause other undesirable environmental impacts such as loss of biodiversity or the intensification of other farming activities resulting in increased GHG emissions. The assessment of the resource presented here is therefore based on identifying grassland, which could be released from grazing or fodder production and converted to production of grass silage for AD without causing additional negative environmental impacts.

The recast of the European Renewable Energy Directive (REDII) [67] aims to ensure that bioenergy production is done sustainably. It sets out several sustainability criteria that bioenergy should meet. These include a minimum GHG saving that should be achieved, together with a methodology for calculating the GHG savings. A key benchmark is the percentage of GHG emissions saved through the use of bioenergy. Specific upstream emissions for the cultivation, harvesting, transport and processing of energy crops into fuel are added together and compared to similar upstream emissions for fossil fuel. A saving of 70% must be achieved by AD sites coming into operation before 2026. Post-2026, a saving of 80%, compared to a fossil fuel counterfactual factor, must be achieved by heat produced from biomethane. A previous SEAI report on the sustainability of bioenergy options showed that biomethane produced solely from grass silage would not meet the savings threshold [68]. However, when the grass feedstock is used together with cattle slurry, the 70% benchmark can be met. The REDII methodology gives a 'credit' for the GHG emissions avoided by not having to store slurry, which offsets the upstream emissions from grass silage. Section 5.2.6 discusses in more detail the GHG emissions and savings associated with co-digestion of silage and slurry.

Slurry has a high water content, which means that the biogas produced per tonne is relatively low. This low energy density means that it is neither cost-efficient nor energy efficient to transport it long distances to an AD plant. Previous work has suggested that slurry should not typically be transported more than 5 to 10 km, although techniques to dewater slurry before transport can help to increase these distances. While silage has a higher energy density than slurry, it is still expensive and inefficient to transport long distances. Therefore, it is essential to consider where these resources are located and if there is enough of each within the same catchment areas. Mapping them allows this interaction to be better understood, and whether there are areas where there is not enough slurry available to mix with grass to ensure that sustainability requirements are met[18]. The mapping of the slurry resource was discussed in Section 3.1.2, and the mapping of silage is described in Section 5.2.3 below.

Energy is not the only potential use for biomass. It is important to consider whether other, higher-value options are available for biomass or whether a cascading use principle can be applied. This would see high-value materials extracted first, and only those lower value residual products would be used for bioenergy. This option has been explored for grass silage in other work, and a small-scale grass biorefinery has been developed and demonstrated in Ireland [69].[19] This approach, which allows both feed and bioenergy requirements to be met, is not considered here, as it fell outside the scope of the study. However, as the concept is developed further and more data becomes available on the costs and performance of the biorefinery, this could be a useful additional option to explore.

5.2.2 What is the resource and how can it be used?

As discussed in Section 2, some grassland in Ireland is currently under-utilised, and improving grassland productivity could allow some grassland to be used to produce grass silage for energy purposes.

Grass silage has high moisture content and is best suited to energy production by using AD to produce biogas. Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2), which can be combusted in a boiler to supply heat or in a gas engine to produce electricity and heat. Alternatively, the biogas can be upgraded

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[18] The mapping exercise gives a good overview of the likely distribution of silage and slurry and can be used to identify areas which are likely to have good resource availability. Any potential AD plant would however need to do a more detailed local assessment. The distances over which it may be cost-effective to transport silage or slurry will vary depending on local road infrastructure, and it may be economic to transport silage from areas where there is little slurry to neighbouring areas where greater quantities of slurry are available.

[19] Fresh grass is converted to a press cake which is a feed for cattle, a protein concentrate, which can be used as a monogastric feed, fructo-oligosaccharides which can be used for feed or in the food industry and a nutrient rich whey which can be used as a fertiliser or as a feedstock for AD.

to pure biomethane (by removing the CO_2 and other impurities) and injected into the natural gas grid or used directly as a vehicle fuel. As discussed above, to meet sustainability requirements, the grass silage must be co-digested with cattle or pig slurries. Domestic or commercial food waste or industrial food processing waste could also be added. Such AD plant could range from small scale on-farm systems to larger centralised AD systems shared between several farms.

5.2.3 Availability

The estimation of the land areas that might be suitable for growing energy crops without compromising existing farming activities was described in Section 5.1.3. In order to estimate the amount of silage for AD that could be produced on these areas of land, two further aspects were defined: the cultivation system and yield for silage production, and the likelihood that farmers use released land for cultivation of silage rather than other activities such as land rental, or to diversify farm income.

5.2.3.1 Technical potential

Significant contributions to the GHG emissions associated with silage production arise from the nutrient requirements of the crop. The application of nitrogen (N) to the land leads to emissions of the GHG nitrous oxide (N_2O) from the soil. However, it also results in higher grass yields, and the yield achieved is also crucial in determining emissions per tonne of silage. Soil GHG emissions can be reduced by minimising N inputs while maintaining a satisfactory yield. This can be achieved through, for example, the choice of grass species with a lower N requirement and by ensuring that other nutrient levels in the soil (such as potassium and phosphorous) are at optimum levels to maximise soil fertility and grass yield.

The manufacture of N and other chemical fertilisers has a large carbon footprint, so using organic fertilisers to replace synthetic chemical fertilisers can also help to reduce emissions. The digestate from the AD plant is typically used to provide nutrients instead of synthetic fertilisers. However, some of the GHG benefits of reduced fertiliser emissions from using organic N is offset by increased soil N_2O emissions due to the need to apply more organic N than synthetic N. This is because the N in digestate is less available to plants than synthetic N, so more N must be applied to ensure the same level of availability and uptake by the plant. This leads to additional N_2O emissions. [20] The key to reducing GHG emissions from silage production is thus to minimise the N requirement necessary to achieve a satisfactory yield.

A solution being explored to achieve this is the use of a hybrid ryegrass/red clover sward, where N requirements are reduced due to the nitrogen-fixing characteristic of red clover. Experimental work at Devenish Farms to explore this option was used as a basis for modelling the potential yield which would be achieved and the inputs which might be required. The work suggests that a yield of at least 13 t of dry matter (DM) per ha could be achieved; this is equivalent to a silage yield of 52 t fresh matter (FM)/ha assuming a DM content for the silage of 25%. The nitrogen requirements of the hybrid/red clover grass sward are estimated to be 90 kg N/ha [70], under half of that required for a standard ryegrass sward (195 kg N/ha) [71]. Modelling of the AD process for this study suggests that the N for the hybrid ryegrass/red clover sward, together with a substantial proportion of the phosphate and potassium requirements, could be supplied by digestate from the AD plant, enabling recycling of nutrients and reduction of GHG emissions. The GHG emissions associated with biogas production from silage are explored further in Section 5.2.6.

It is estimated that each tonne of dry matter of silage could produce 550 Nm^3 of biogas[21] with a methane content of 55%, so 303 Nm^3 of biomethane, or 3.09 MWh/t . The maximum biomethane production which could be achieved from silage for AD given the estimates of released land suitable for recultivation discussed in Section 2 are shown in *Table 7*. This highlights the critical role of grassland productivity improvements in

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[20] This offsetting effect does not occur when synthetic phosphorous (P) and potassium (K) and are replaced with P and K from organic fertilisers as despite having a lower availability their application does not lead to any GHG emissions from the soil.

[21] A wide range of values for the biogas yield from silage exists in the literature, for example [72] quotes a range of 500 to 715 Nm3/t of dry matter and a range of [73] 570 to 715 Nm3/t DM. A relatively conservative estimate of 550 Nm3/t is assumed here.

releasing land for silage production for AD, as under the BAU scenario (see section 5.1.3), this accounts for over two-thirds (70%) of potential production. The additional reduction in the suckler herd assumed in the LUC scenario leads to an increase in total potential production of just over a third (37%).

Table 7: Technical potential for biogas production from silage for AD

	Unit	**Business as Usual**			**Land Use Change**		
		Change in herd size	Productivity improve-ments	Total	Change in herd size	Productivity improve-ments	Total
Area released	kha	175	200	375	424	193	617
Released area suitable for silage for AD	kha	48	111	160	109	90	199
Technical potential for production of silage	Mt DM	0.63	1.45	2.08	1.42	1.17	2.59
Technical potential for biogas from silage	GWh	1,946	4,475	6,421	4,399	3,606	8,005

The potential location of this production on a 5km grid square basis is shown in *Figure 27*. As discussed above, due to the relatively low energy density of silage, an AD plant is likely to need to source feedstocks from within a relatively small radius. The exact size of this will depend on a detailed local cost assessment, but some typical values can be applied. For example, a minimum size for an agriculturally based AD plant, upgrading biomethane for injection into the gas grid, might be 20 GWh [66]. For this size plant, and assuming that the grass silage is mixed in an AD plant with 50% by weight slurry, which will add an additional 15% of biogas production capacity, then:

- If transport of feedstocks is restricted to a very short distance to minimise transport costs, and feedstocks must be sourced from within a 10 km by 10 km area,[22] the plant would need to be located where there are four adjacent grid squares, each with a resource of greater than 4 GWh, any of the blue colours on the maps, are required.
- If transport of feedstocks is economic over a longer distance and the feedstock production area is expanded to a 20 km by 20 km grid square, then each of the grid squares needs to have a resource of greater than 1 GWh, any of the darker green or blue squares on the map.

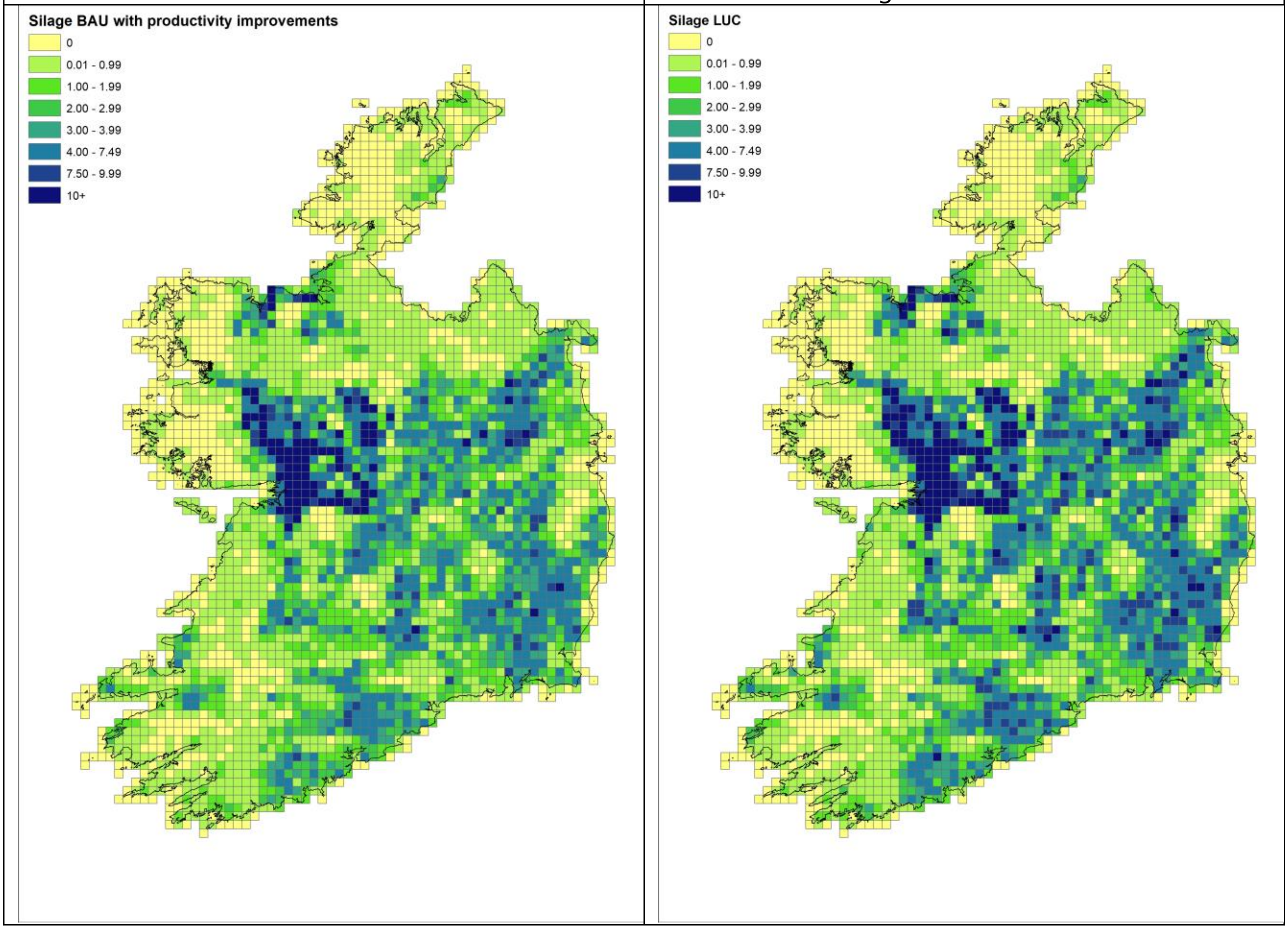
Examination of the map suggests that the resource density could be high enough over large parts of Ireland, provided an appropriate slurry resource is available, which modelling (Section 3.1) suggests it would be. Areas with a greater resource density could support multiple or larger plants.

While the maps give a good indication of regions that may have a high resource density, any proposed plant would need to have a more detailed, site-specific feasibility study. The methodology for estimating the resource and hence the maps are based on average values, for example for grassland productivity and average changes in herd size, and the particular details and responses of individual farms may vary from this. Similarly, the distances that feedstocks could need to be transported will depend on the road network, not just the straight line distance, and this will affect the economics and design of any particular plant.

[22] Note distances here are as the crow flies; the feasibility of any particular plant would need to take into account actual road transport distances and a number of other factors.

Figure 27: Location of the potential production of silage for AD (in GWh of biogas production) given land released under BAU and LUC scenario (5km grid square)

Business as Usual	Land use Change Scenario



5.2.3.2 Realisable potential

While production of silage for fodder is common practice on farms, production of silage as an AD feedstock will have additional requirements, such as possibly requiring grass reseeding with a low N input sward, and engagement with sustainability reporting requirements (for instance recording inputs and fuel use for the purposes of GHG intensity calculations). Where land is available for growing silage only, if grassland productivity improvements are made, then there is also a need to first implement those improvements. It was the view of the advisory group for the project, that barriers or hidden opportunity costs such as these would mean that not all farmers would wish to transition into producing silage for AD. This could particularly be the case where only relatively small areas of suitable land are released from livestock production or where farmers farm on a part-time basis, which is relatively common in the beef sector.[23] In lieu of any data on which to base estimates of the proportion of farmers who would move into silage production for AD, the assumptions in *Table 8* were agreed with the advisory group. These 'uptake' figures could be heavily influenced in practice by the price offered for silage, and general policies and trends in the agricultural sector.

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[23] Just under half of farmers do not have farming as their sole occupation, many of these are beef farmers https://www.cso.ie/en/releasesandpublications/ep/p-fss/farmstructuresurvey2016/da/foli/; Accessed 19/08/2021.

Table 8: Assumed likelihood that a farm will produce silage for AD

Released suitable area on farm (ha)	<5 ha	5 -10 ha	10 - 20 ha	>20 ha
Likelihood if land released due to reduction in herd size	50%	67%	85%	100%
Likelihood if grassland productivity improvements required to release land	0%	25%	75%	100%

The impact of applying these assumptions to the estimates of land available to generate values of the 'realisable' potential for conversion to silage for AD is shown in *Figure 28*. The quantities of biogas associated with this realisable potential, which it is assumed could be achieved by 2030, are shown in *Table 9*. As projections for herd size are not made by DAFM for the period after 2030, due to the high level of uncertainty in agricultural markets worldwide, resource availability is assumed to remain at 2030 levels post 2030. In practice, some of the biogas produced will be used at the AD plant itself, to provide heat to the digester, or for pasteurisation and a small amount will be lost through fugitive emissions. The exact quantity used at the plant will depend on the design of the AD plant, and whether the biogas is used to provide heat and/or power for the plant, and whether the biogas is upgraded to biomethane, but typically the quantity of biogas which is available for energy for export from the plant will be under 90% of the biogas yield shown in *Table 9*.

Figure 28: Impact of 'likelihood' factors for uptake on areas used to produce silage for AD

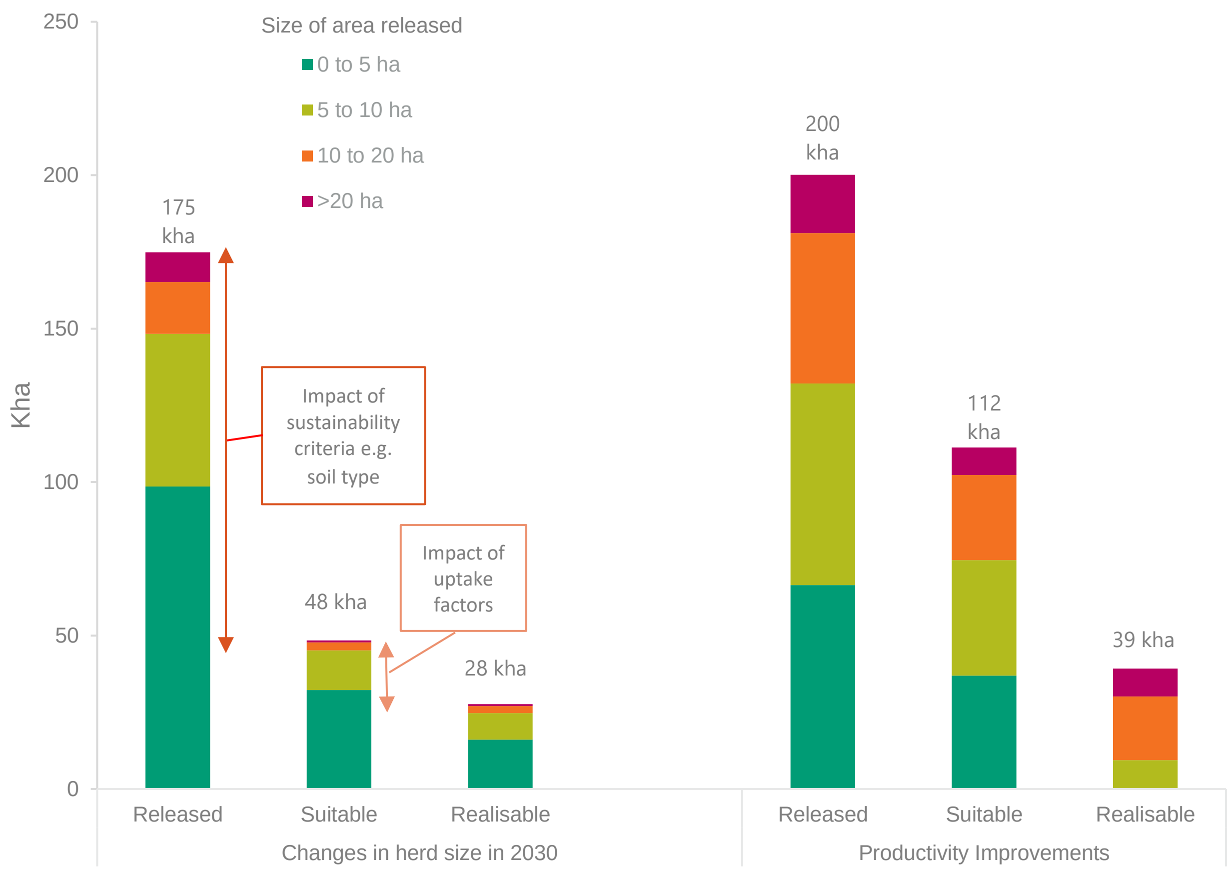


Table 9: Realisable potential for biogas production from silage for AD by 2030

	Unit	Busines as Usual			Land Use Change		
		Change in herd size	Productivity improve-ments	Total	Change in herd size	Productivity improve-ments	Total
'Realisable' area converted to silage for AD	kha	28	39	67	71	31	103
Realisable potential for production of silage	kt DM/yr	359	510	868	928	405	1,333
Realisable potential for biogas from silage	GWh/yr	1,109	1,576	2,685	2,869	1,252	4,121

5.2.4 Price

A production cost for grass silage was estimated by Teagasc[24] based on the inputs and farming operations required. It was assumed that the sward is reseeded at least every five years to ensure that a high yield is maintained, as high yielding varieties of both ryegrass and red clover can have limited persistence. Costs for farming operations were based on contractor costs from [74], and the cost of inputs (fertilisers, lime, herbicides and seeds) from the Central Statistics Office and suppliers' websites. This production cost estimate allows only for direct variable costs incurred by the farmer, who for the operation to be profitable will also need to recoup other indirect and overhead costs. An estimate of this was based on the gross margin typically achieved by farms, as this reflects the difference between the income a farm receives per ha and direct variable costs. For silage produced on land which is released due to a reduction in the suckler herd, this was based on the average gross margin achieved for cattle rearing in 2019 excluding basic payments of €520/ha [75]; for comparison, this is slightly higher than rental values for grazing/silage which are €435/ha to €512/ha. For silage produced on land released due to grassland productivity improvements, it was assumed that the gross margin would need to be 20% higher to reflect some of the additional costs and management time required to implement the required measures. Costs are shown in *Table 10*, per tonne of silage, and also per MWh of biogas produced from the silage; these values reflect only the contribution of the feedstock cost to the biogas and does not include conversion costs.

Table 10: Costs of producing silage for AD

	€/ha	€/t DM	€/t FM	€/MWh of biogas
Silage grown on land released due to smaller herd size				
Production cost	1,914	147	37	
Gross margin	520	40	10	
Total price	2,434	187	47	61
Silage grown on land released due to productivity improvements				
Production cost	1,914	147	37	
Gross margin	624	48	12	
Total price	2,538	195	49	63

[24] Personal Communication. Dominika Krol, Teagasc, 19/01/2021

5.2.5 Co-digestion of grass silage with slurry

As discussed in Section 5.2.1 RED II requires that a minimum GHG saving is achieved by biomethane and calculations using the methodology specified in RED II clearly show that these savings cannot be achieved by an AD plant only using grass silage as the feedstock. When manures or slurries are used in an AD plant the methodology gives a credit for the GHG emissions avoided by not having to store the slurry. Hence digesting slurry with grass silage reduces the calculated emissions, allowing biomethane from the AD to meet the GHG saving criteria. *Figure 29* shows the impact that co-digesting slurry has on the average GHG emissions per unit of heat that could be produced from the biomethane and compares these to the maximum GHG emissions per unit of heat permitted under RED II. The values in the figure are based on the cultivation of a hybrid ryegrass/red clover sward, which would minimise N inputs, assuming fertilisation with either a mixture of synthetic nitrogen fertiliser and digestate from the AD plant or just relying on digestate from the AD plant. This shows that at least 50% of the feedstock to the digester (by weight of fresh matter) will need to be slurry if the AD plant is to meet the 2026 GHG savings limit for heat set in RED II. An AD plant beginning to operate before this could meet the relevant limit with a lower proportion of slurry. It is likely that AD operators will wish to minimise the amount of slurry added to the plant as it has a much lower biogas potential than silage. For example, for a plant digesting equal quantities of silage and slurry, the silage will produce around 85% of the biogas produced in the plant. In estimating the amount of biogas that could be produced by co-digesting grass silage and slurry it is therefore assumed that slurry forms 50% by mass of the feedstocks for the AD plant.

Figure 29: Impact of co-digestion of slurry with grass silage on GHG emissions

Source: Calculations by Ricardo using REDII methodology as implemented in [68]

The GHG saving methodology specified in RED II is intended to aid the governance of renewable energy production. As such, the methodology relates directly to the production of the feedstock, the AD process, and the upgrading process required to produce biomethane for injection to the grid. The methodology does not, apart from avoided emissions from slurry storage and spreading, consider any wider impacts in the agricultural sector or economy that might result. These wider impacts were investigated in the study and are reported in Section 5.2.6.

5.2.5.1 Availability and price

Table 11 shows that the slurry resource estimate in Section 3.1.2 is significantly higher than the potential silage resource indicating that 50% co-digestion should be possible.

Table 11: Comparison silage and slurry resource in 2030

	BAU (stable herd) scenario (million tonnes)	Land Use Change scenario (million tonnes)
Technical potential – slurry	32	29
Technical potential – silage	8.3	10.4
Realisable potential - silage	3.5	5.3

Note: Quantities are in tonnes of fresh matter as would be input to the digester and are based on a dry matter content of 25% for silage and 7% for slurry

However, as discussed earlier, the high liquid content of slurry means that it is not desirable to transport it long distances, so it is important that the silage and slurry resource are located close to each other. The spatial mapping was undertaken of the slurry and the silage resources indicate that the geographical locations are relatively well matched (*Figure 30*). The maps show the quantity of biogas that each resource could produce and a 50/50 mix of silage and slurry means that for every 1 GWh of biogas produced from silage, about 0.15 GWh of biogas would be produced from slurry. So, for an AD plant to be sited at a location where there are lime green squares on the silage map (which represents potential biogas production from silage of 1 to 1.99 GWh per year with the 5 km grid square), the same location would need to have grid squares on the slurry map which have a biogas potential of 0.15 to 0.29 GWh per year (indicated by lime green - 0.15 – 0.29 in the graph legend) or higher.

An idea of regions where AD plant might be located based on this resource mapping can be gained from the maps, although any individual plant would need to do its own resource assessment. An agricultural AD plant using a silage/slurry mix might be expected to produce around 20 GWh of biogas per year. If feedstocks were all to be obtained with a small radius of the plant (5 to 10 km) this would require 4 adjacent grid squares where the silage potential is greater than about 4.3 GWh and slurry is greater than about 0.6 GWh (any of the shades of blue squares on the maps). If the radius for delivering feedstocks to the plant was greater (20 to 40 km) then a plant could be located where there are 16 adjacent grid squares where biogas production from silage is greater than 1 GWh and biogas production from slurry is greater than 0.15 GWh (squares coloured lime green, dark green or one of the shades of blue). In areas where there is a high resource density, indicated by the darker blue grid squares, AD plant could be larger, or a number of plants could be located relatively close together. The maps indicate that, in general, availability of slurry for co-digestion is unlikely to be a limiting factor in the development of silage/slurry AD plants. The only region where slurry quantities might not match potential silage production are some parts of Galway.

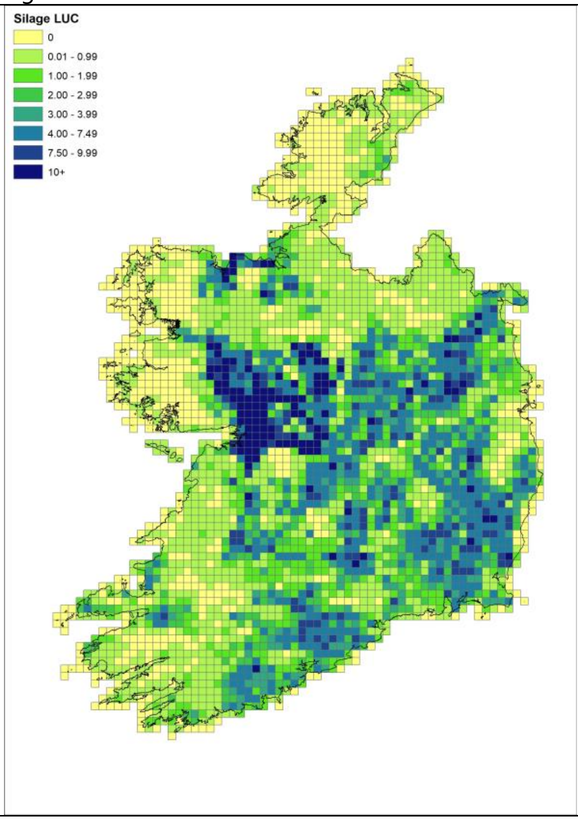
It is assumed that cattle slurry would be available at no cost, and the price for silage has been estimated to be 47 to 49 €/t (*Table 10*). Co-digesting these feedstocks in a 50/50 mix would give an average price of 23.5 to 24.5 €/t, or a contribution to biomethane production costs of 53 to 55 €/MWh.[25] The overall availability and price of biogas under the stable herd and land use change scenarios are shown in *Figure 31* and *Figure 32,* respectively. The resource is assumed to become available from 2023 and as projections of herd size are only available for the period to 2030, the herd and hence the resource is assumed to remain at 2030 levels until 2050.

[25] Note that while the average cost of feedstocks is halved when 50% slurry is co-digested, the reduction in the contribution of feedstock costs to biomethane production costs is much smaller due to the much lower biogas yields achieved per tonne of slurry.

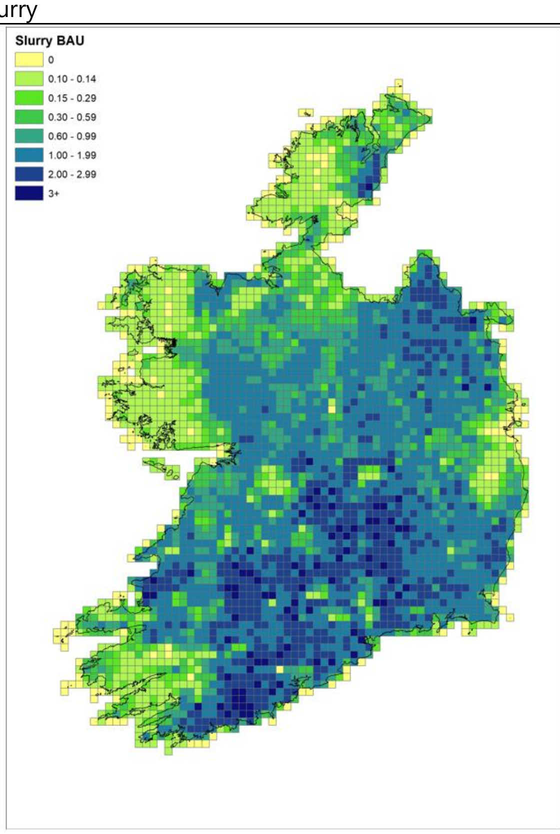
Figure 30: Location of slurry and silage resource under the 'stable herd' and LUC scenarios (in GWh of biogas production for each 5km grid square)

Business as Usual (Stable Herd) Scenario

Silage

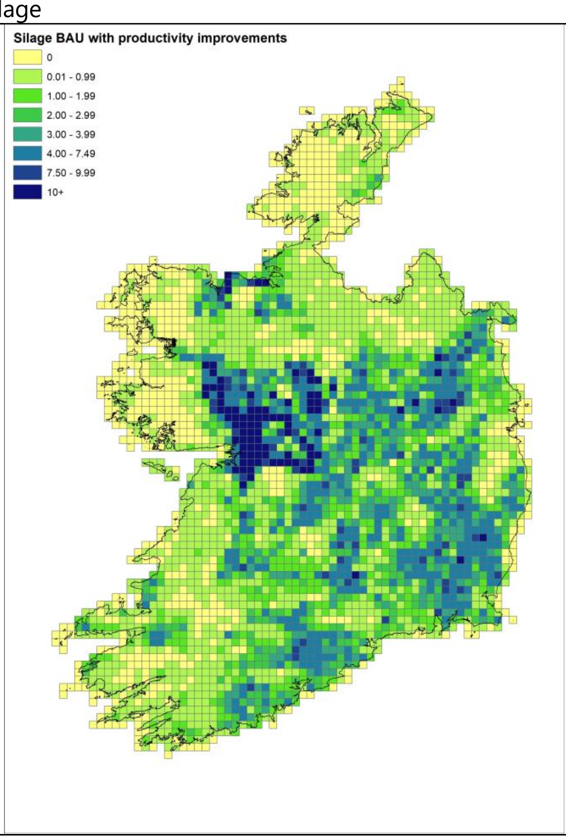


Slurry



Land use Change Scenario

Silage



Slurry

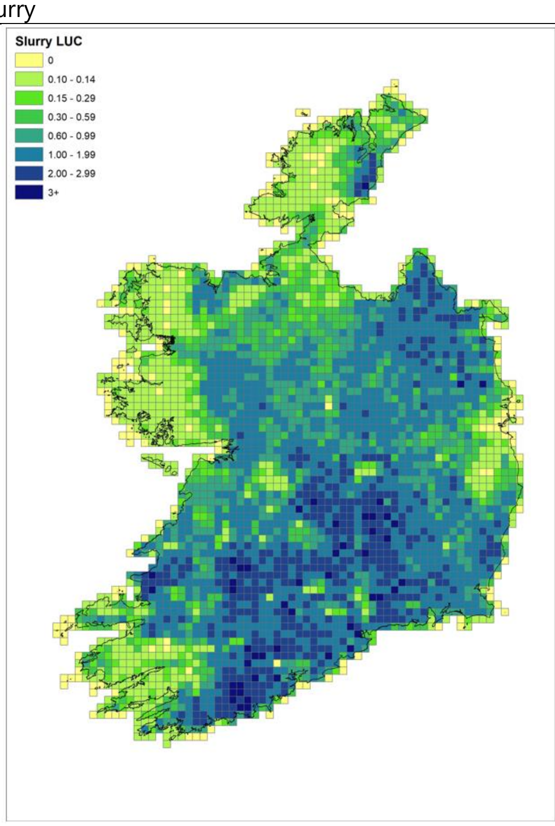


Figure 31: Availability of silage and slurry feedstock 50/50 mix for use in AD plant under the stable herd scenario (2020-2050)

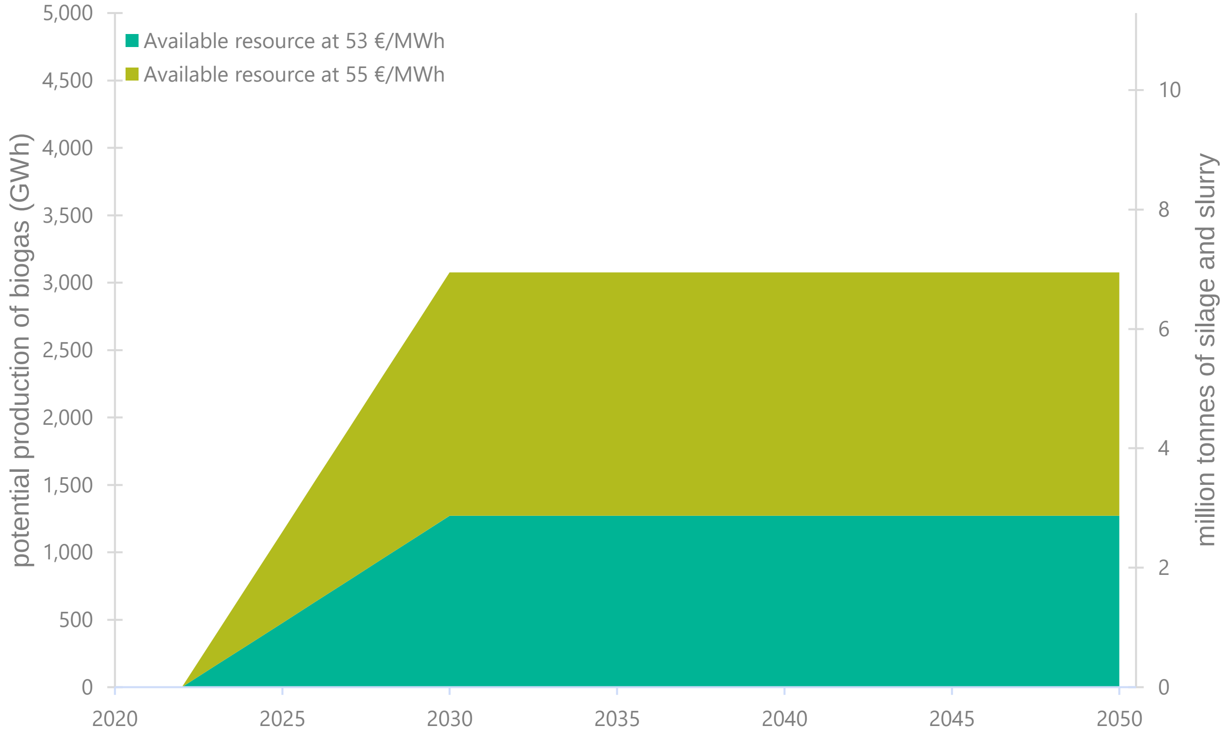
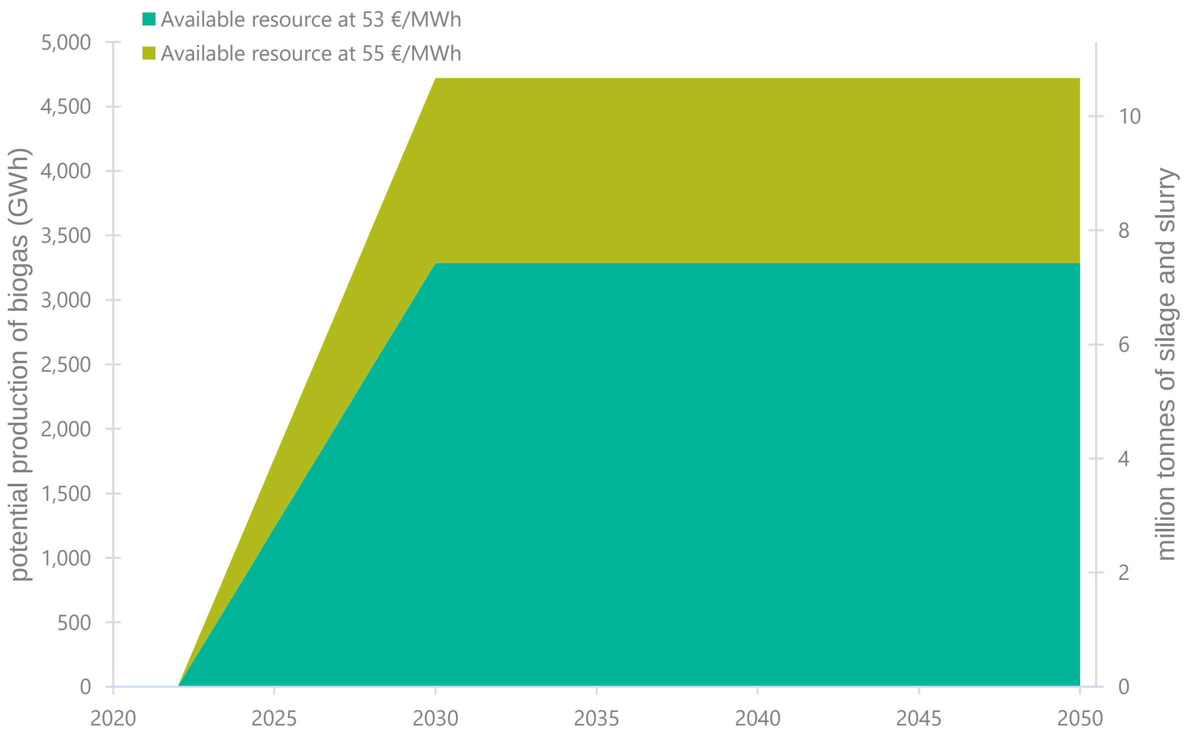


Figure 32: Availability of silage and slurry feedstock 50/50 mix for use in AD plant under the land use change scenario (2020-2050)



5.2.6 Sustainability considerations

As described earlier, REDII sets out a methodology for calculating GHG emissions from biomethane production and minimum GHG savings which are required to be achieved. The methodology is focused on the inputs, energy and emissions associated with producing the feedstock, transporting it to the AD plant, and the emissions and energy use associated with operating the AD plant and biogas upgrading unit. Apart from considering emissions from avoided slurry use in the AD plant rather than storing it, the methodology does not consider other wider impacts from the establishment of a grass silage/slurry AD plant *(Figure 33*). A wider LCA was therefore carried out to include these wider impacts:

- Typically slurry is stored and then spread on grassland in the spring. Using the slurry in the AD plant means that emissions associated with slurry storage are avoided, as are the emissions of nitrous oxide (N_2O) from the soil, associated with spreading the slurry. However, slurry contains nutrients that help to fertilise the grassland, and if it is not spread, then some spreading of synthetic fertilisers are necessary. There will be emissions associated with producing these fertilisers and soil N_2O emissions associated with the application of any synthetic N fertilisers that replace slurry.

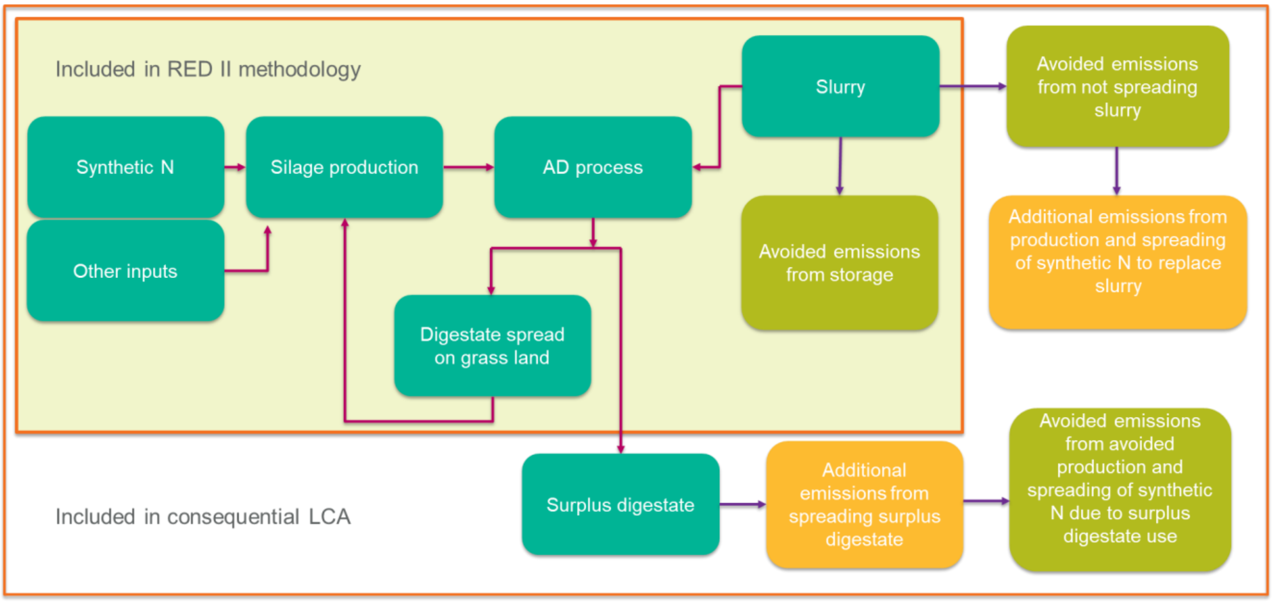
- A mass and nutrient balance for the AD plant shows that more digestate is produced than is needed to meet the nitrogen requirements of the hybrid rye/red clover sward that is grown to feed the AD plant. This means that there is surplus digestate that can be used to fertilise other land. There will be soil emissions associated with spreading the digestate, but also avoided emissions from the production and spreading of the synthetic fertilisers it replaces.

A wider LCA was therefore carried out to examine in a more holistic way to determine what the overall impact on GHG emissions of a grass silage/slurry plant would be. As well as including the additional effects set out above, and in *Figure 33*, wherever possible it used emission factors that were as representative as possible of the Irish situation and consistent with emissions factors used in the Irish National GHG Inventory. These included:

- Replacing the 'credit' for avoided slurry storage in the REDII methodology with an estimate of the emissions avoided based on factors used in the national GHG inventory for pit storage, the most common form of slurry storage in Ireland.
- Replacing the soil N_2O emissions factors used in previous calculations of sustainability, which were based on international default factors, with emissions specific to Ireland.

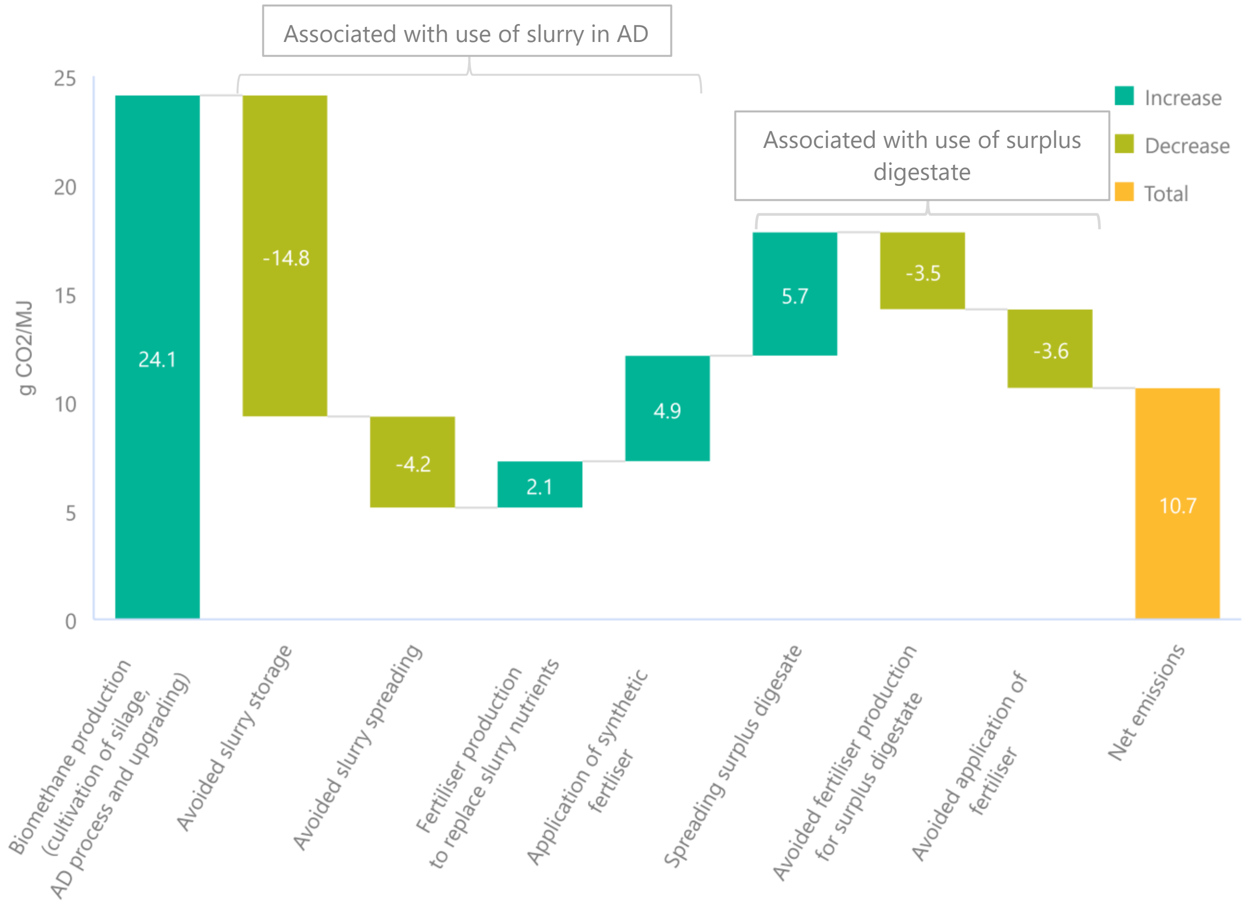
The AD plant is assumed to meet best practice standards and in particular, to have closed storage of digestate. This means that off-gases from the closed storage are circulated back to the AD/biogas upgrading plant so that there are no fugitive emissions of methane from the stored digestate.

Figure 33: Boundaries of REDII GHG methodology and of wider consequential LCA in this study



The results of the wider LCA shown in *Figure 34* indicate that the net GHG emissions from an AD plant using a 50/50 silage slurry mix where all nitrogen inputs for the grass silage are provided by digestate would be 10.7 g CO2/MJ biomethane produced. This is equivalent to 12.8 g CO_2/MJ heat, which is lower than the value calculated using the REDII methodology in Section 5.2.5 of 14.7 g CO_2/MJ. The lower estimate is mainly due to the avoided emissions from avoided slurry storage being greater in the LCA conducted here; as discussed above the estimate of avoided emissions from avoided slurry storage are based on emissions factors used by the EPA in compiling the national greenhouse gas inventory. Including other consequential effects in the LCA leads to a small increase (about 14%) in the estimate of net emissions.

Figure 34: Results from wider LCA for GHG emissions per MJ of biomethane produced



5.3 Perennial Energy crops

5.3.1 What is the resource and how can it be used?

Perennial energy crops suitable for cultivation in Ireland are Miscanthus (a woody rhizomatous grass) and willow grown using a short rotation coppice (SRC) technique. These crops can be grown on arable land or reasonable quality permanent pasture. The planting, cultivation and harvesting of these crops requires specialised equipment, techniques and planting material. Establishment requires intensive effort and agrochemical input, but thereafter perennial crops require less input in agrochemicals and labour than annual crops. Once planted they take up to four years to reach maturity, after which they are harvested at regular intervals - typically every year for Miscanthus and every four years for willow SRC. After about 20 to 25 years the crop is removed and replanted, and then the harvesting cycle begins again.

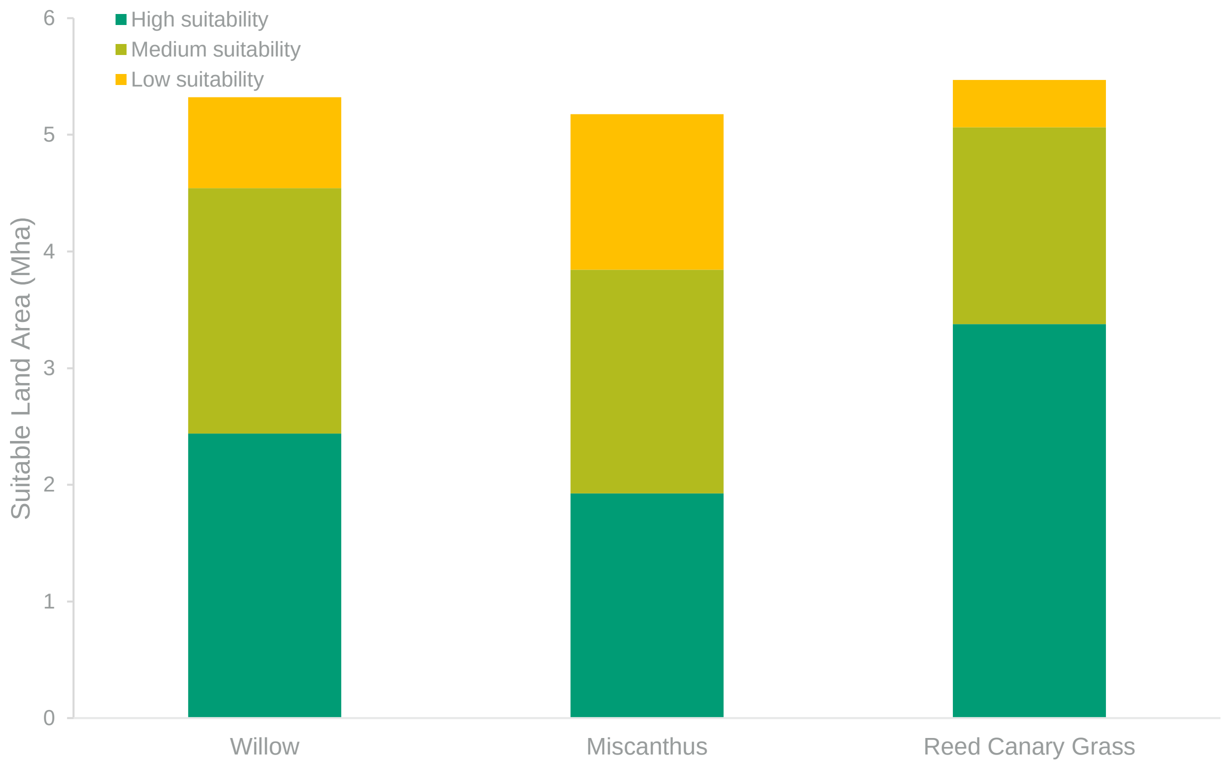
Wood from SRC is suitable for use in small scale boilers to produce space, water and process heat, it can also be combusted to produce electricity in a purpose built plant, or can be used in a combined heat and power (CHP) unit to produce both heat and electricity. SRC can also be co-fired in existing power plants in Ireland. Miscanthus however, while suitable for combustion in purpose designed plant, cannot be co-fired in the existing peat fired power plant in Ireland due to its chlorine content. It could, however, be used as a feedstock for new bioenergy power plant. If combined with carbon capture and storage (CCS), the latter would result in negative emissions and help contribute to Ireland's ambition to reach net zero. Wood from SRC and Miscanthus may also be converted into renewable transport fuels by using advanced techniques that are currently at the demonstration stage in Europe and the USA.

Only small areas of energy crops have been planted to date and this has declined in recent years; from 939 ha of SRC and 2,414 ha of Miscanthus in 2015 [6] to 278 ha of SRC and 593 ha of Miscanthus in 2020.[26] Although willow is only harvested every four years, when the quantities harvested are averaged out over this four year period, it typically delivers the same yield as Miscanthus, which is harvested every year. Both crops are capable of yielding about 10 oven dried tonnes per ha per year (odt/ha/y), so the quantities currently planted could produce about 8,700 odt annually, equivalent to 44 GWh.

5.3.2 Availability and price

Previous spatial mapping work by SEAI used soil, topographical and climatic data to look at the suitability of land for growing perennial energy crops.[27] Reed Canary grass was included in the analysis as it is more similar to other crops farmers currently grow, so might be adopted more quickly. However, its yield is significantly lower than either SRC willow or Miscanthus and it is unlikely to be as profitable for farmers and is not considered further here. As *Figure 35* shows, large areas (about 2 Mha) were considered highly suitable for either SRC willow or miscanthus, a finding borne out in a separate mapping exercise carried out using the MISCANFOR model to support recent work funded by the EPA on the potential for negative emissions technologies in Ireland [76]. The modelling suggests that in general, willow would be better suited to parts of Ireland with a cooler, wetter climate, but that for regions particularly suited to Miscanthus, like the southeast, very high yields could be achieved for Miscanthus.

Figure 35: Areas determined by spatial mapping to be suitable for perennial energy crops



Source: Previous bioenergy GIS modelling by SEAI[27]

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[26] Based on Land Parcel Information System data for 2020 provided by DAFM

[27] For more information or data on the previous GIS bioenergy modelling, please contact SEAI.

Both studies considered only the suitability of land and not its availability.[28] As discussed earlier in Section 5.1, land for growing energy crops would need to be made available from the pool of land currently used for other agricultural activities. The estimate of the potential energy crop resource, therefore, makes use of the estimates of land availability derived in Section 5.1.3, and the uptake factors detailed in Section 5.2.3.2. The criteria used to determine the suitability of land for perennial energy crops closely matches the criteria used to determine the suitability of the land to grow silage. This means that the estimates of land likely to be converted, which are derived in Section 5.2.3.2, are therefore also relevant for perennial energy crops. The estimates of the resource for grass silage and perennial energy crops are therefore unlikely to both be achieved in full. This aspect was taken into account in the overall resource scenarios constructed for the wider modelling done in the Heat Study, and details of the bioenergy resource scenarios constructed are given in Section 7.1.

The total area assumed to be available for growing perennial energy crops by 2030 is, as for grass silage, 67 kha under the stable herd scenario, and 103 kha under the land use change scenario. Growing either Miscanthus or SRC willow requires a specialised supply chain; for example, to cultivate and provide Miscanthus rhizomes or willow slips for planting, and specialised planting and harvesting equipment. The low rate of planting to date in Ireland means that this supply chain is underdeveloped and will take time to progress. It is therefore assumed that the rate at which planting can be expanded is limited, and the new area planted in any one year can be no more than 25% greater than the area planted in the previous year. The availability of the resource under the stable herd and land-use change scenario are shown in *Figure 36* and *Figure 37*, respectively. Based on assumptions in the previous SEAI spatial modelling, the modelling undertaken in [76], and discussions with Teagasc, it is assumed that areas already planted are achieving 10 odt/ha/year, but that by 2025 new areas planted can achieve 11 odt/ha/year. It is also assumed that as breeding produces improved cultivars, yields will steadily rise, increasing by 0.12 odt/ha/year to 14 odt/ha/year for areas planted in 2050. Plantations are assumed to be replanted at the end of their productive life. The areas planted are likely to be a mix of Miscanthus and SRC willow depending on which crop is the most suitable for any particular location and the market that exists for each type of energy crop.

[28] The SEAI spatial modelling did exclude unavailable areas such as urban areas, water bodies and protected areas, such as those designated as national parks

Figure 36: Availability of perennial energy crops under the stable herd scenario (2020 to 2050)

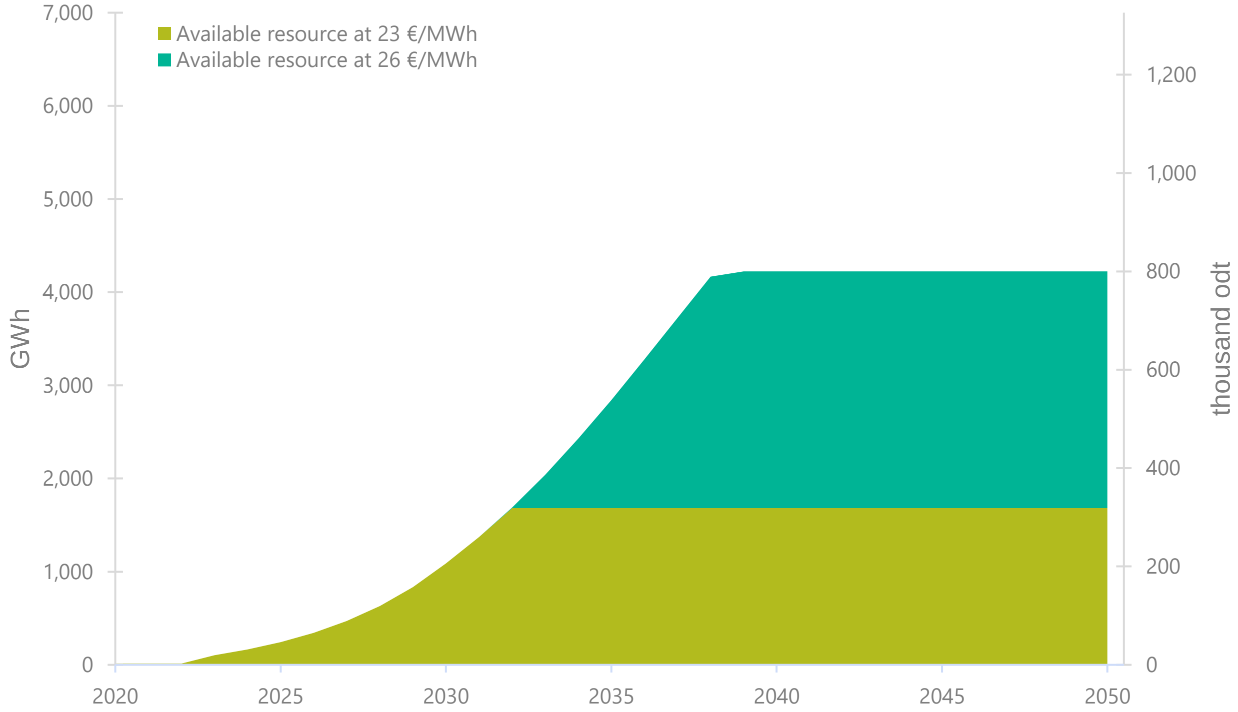
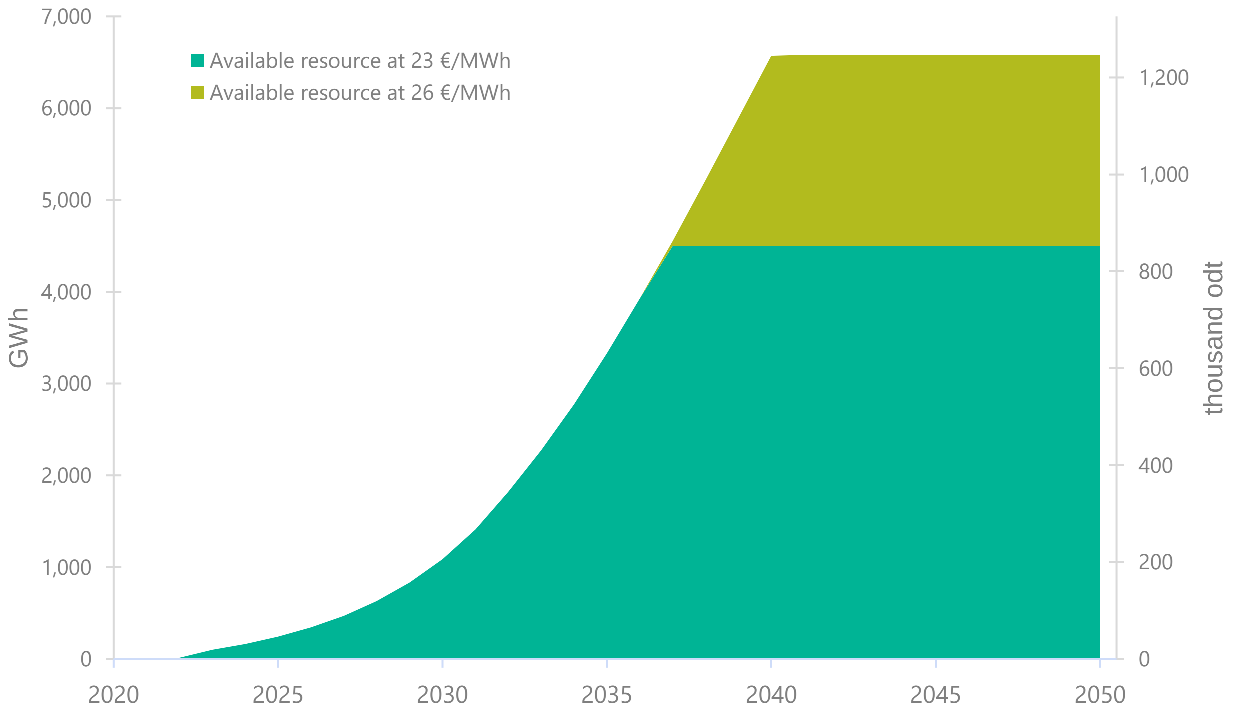


Figure 37: Availability of perennial energy crops under the land use change scenario (2020 to 2050)



The cost of producing perennial energy crops is based on a detailed costing produced recently for the UK [77]; a discount rate of 5% was used in evaluating costs and yields across the lifetime of the plantation. As discussed in Section 5.2.4 this production cost estimate allows only for direct variable costs incurred by the farmer, who, for the operation to be profitable, will also need to recoup other indirect and overhead costs. As for grass silage an estimate of this was based on the gross margin typically achieved by farms, as this reflects the difference between the income a farm receives per hectare and direct variable costs. This leads to the costs for energy crops shown in *Table 12*.

Table 12: Costs of producing perennial energy crops

	€/ha	€/odt	€/MWh
Energy crops grown on land released due to smaller herd size			
Production cost	**6,420**	**56**	**11**
Gross margin	7,534	66	13
Total price	**13,954**	**122**	**23**
Energy crops grown on land released due to productivity improvements			
Production cost	6,420	56	11
Gross margin	9,041	79	15
Total price	15,461	136	26

5.4 Starch and oil crops for transport biofuels

5.4.1 What is the resource and how can it be used?

Conventional arable crops can be used as feedstocks for biofuels. Starch crops such as wheat can be fermented to produce bioethanol (a substitute for petrol), and oil from oil seed rape (OSR) can be converted to Fatty Acid Methyl Ester (FAME) biodiesel or hydrotreated in a refinery to produce hydrotreated vegetable oil (HVO). Both wheat and oil seed rape are currently grown in Ireland but are used for food and fodder or exported; none is used for biofuels production domestically. There is demand for biofuels in Ireland – the Biofuels Obligation Scheme requires fuel suppliers to ensure that not less than 11 litres in every 100 litres of road transport fuel is biofuel [78]. This is mainly met through imports of biofuels. Ireland imports all of its bioethanol, and 87% of FAME; domestic FAME production uses UCO and tallow as feedstocks [45].

Any new biofuels production in Ireland from wheat or OSR would also have to meet the sustainability requirements set out in the recast of the Renewable Energy Directive (RED II) [67]. These specify that for any new biofuels production facility starting operation from 1 January 2021, the biofuel produced must achieve GHG savings of at least 65% and must meet with other sustainability criteria intended to prevent land use change. The Directive also sets a 'crop cap' limiting the amount of biofuels produced from feed and fodder crops that may be supplied.[29] Typical GHG savings values from RED II for bioethanol from cereals and biodiesel from OSR are 47%,[30] suggesting that it could be challenging for any new production plant to meet the limits set in RED II.

5.4.2 Availability and price

Additional production of these crops for the energy market could be achieved using the equipment, techniques, and expertise already available on arable farms, but depends on the availability of suitable land, possible competition with food uses of the crops and the security and profitability of the energy market for these crops. As already discussed, the arable area in Ireland has shrunk in recent years and it seems unlikely that additional land would be available for biofuels production. Furthermore, as indicated above, the sustainability of such fuels could be poor. It is therefore assumed that no wheat or OSR production for use as biofuel feedstock is likely.

[29] This shall be no more than one percentage point higher than the share of such fuels in the final consumption of energy in the road and rail transport sectors in 2020 in that Member State, with a maximum of 7% of final consumption of energy in the road and rail transport sectors in that Member State.

[30] For bioethanol, based on typical values for cereals other than maize as stated in [67] and assuming use of natural gas as a process fuel. Using a renewable fuel such as forest residues could allow savings close to 70%.

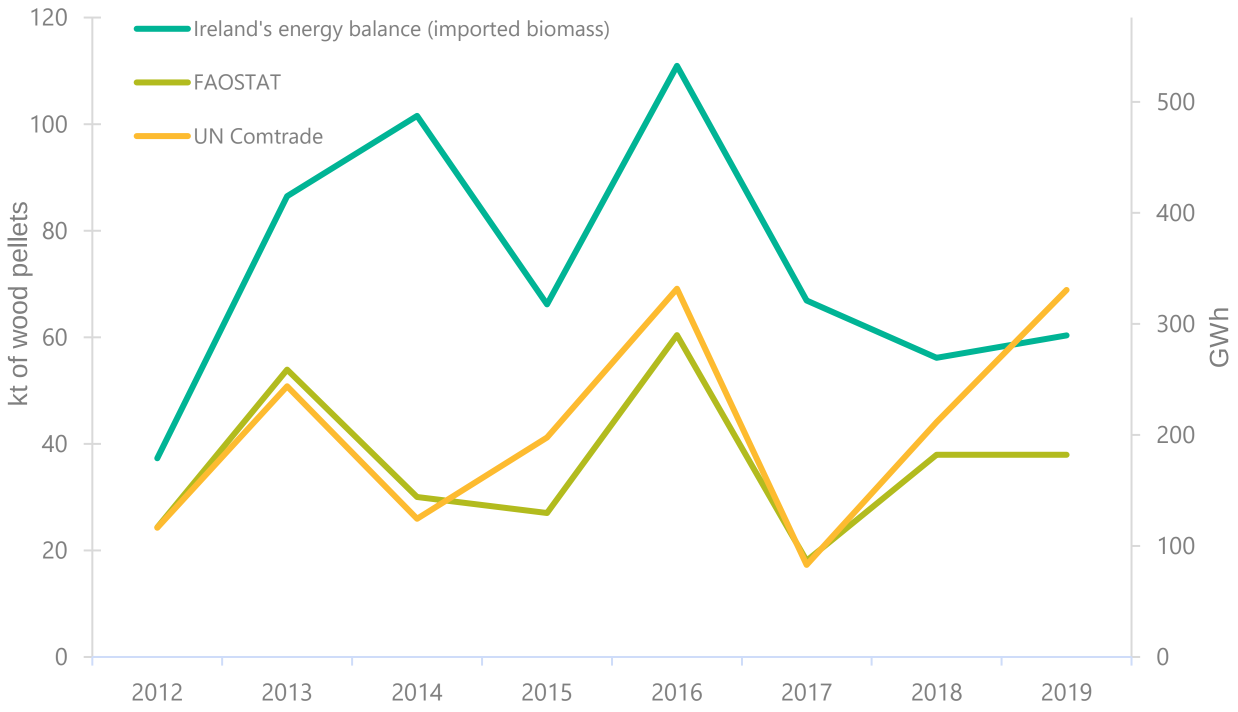
6 Imported resources

6.1 Wood pellets

6.1.1 Current imports of wood pellets

Estimates of wood pellets imported into Ireland are available from a number of sources, Ireland's Energy Balance, the Food and Agricultural Organisation's dataset (FAOSTAT) on Forestry Trade Flows [79] and the United Nations (UN) database on trade statistics (UN Comtrade) [80]. The data (*Figure 38*) suggests that Ireland currently imports around 60 to 70 kt of wood pellets but those levels fluctuate considerably year on year, and have been as low as 17 kt. UN Comtrade data and FAOSTAT also suggest that there is some export of pellets of about 20 to 30 kt in recent years mainly to the UK.

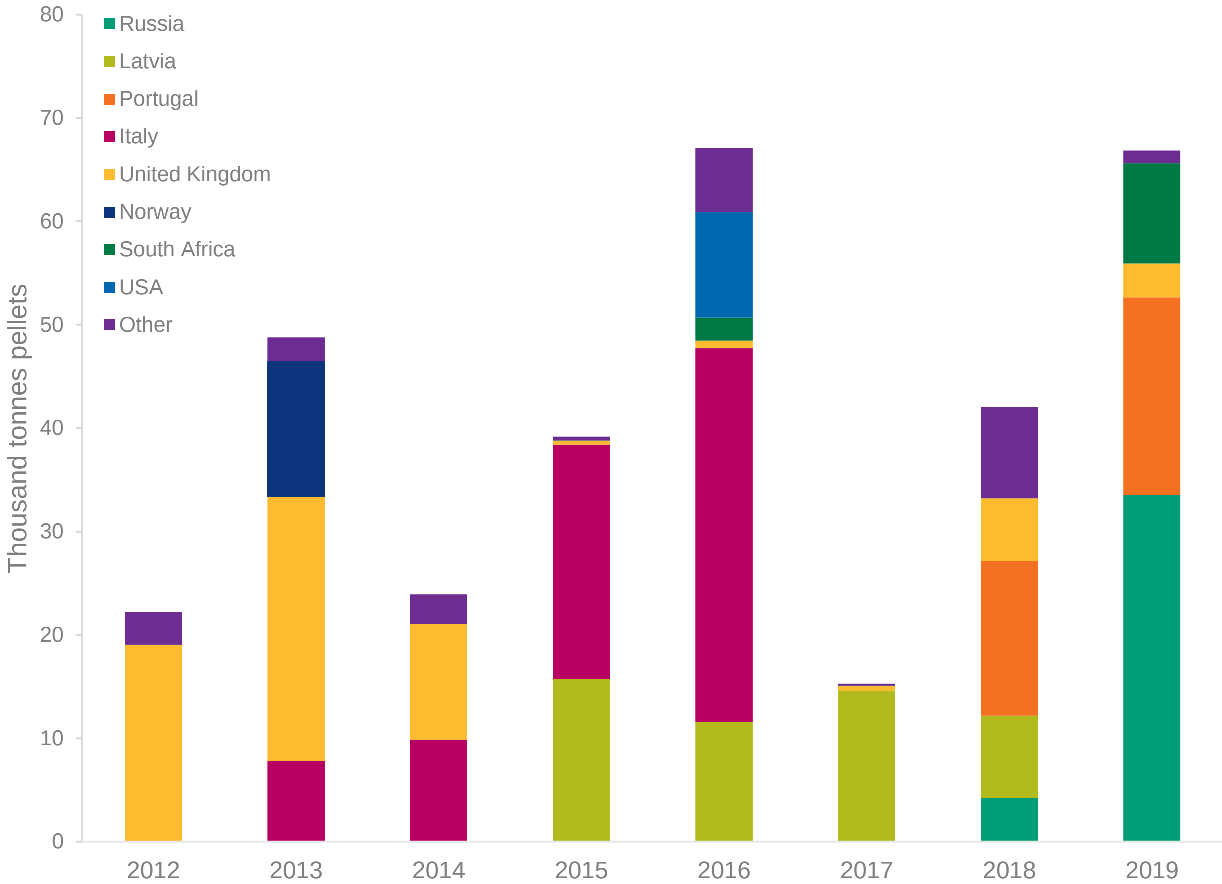
Figure 38: Imports of wood pellets to Ireland



Note: Values from Ireland's energy balance are for all imported biomass so may include other forms of biomass as well as wood pellets.

The origins of imported wood pellets have also varied substantially over time. Historically Italy and the UK were significant suppliers, but more recently Latvia, Russia and Portugal have become significant (*Figure 39*); 2019 also saw the import of pellets from South Africa.

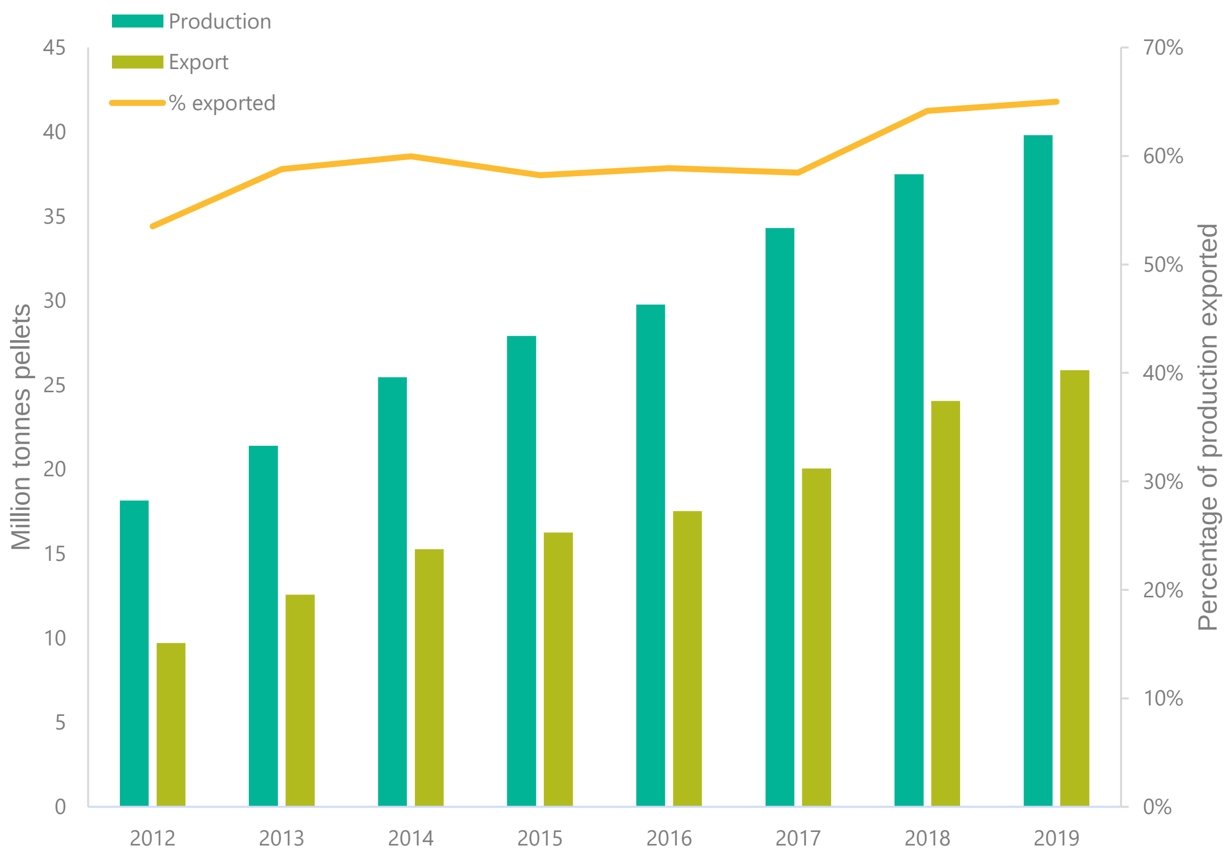
Figure 39: Origin of wood pellets imported to Ireland



Source: UN Comtrade [80]

Globally, production of pellets has increased substantially in recent years, showing a 12% year on year growth (*Figure 40*). The quantities traded have increased at an even higher rate (15% per year) and in 2019, 65% of production was exported. Production and export are concentrated in relatively few countries – the top five ranked countries accounted for 47% of global production and 57% of exports (*Table 13*). Europe is a large regional producer of pellets. Imports to Ireland accounted for 0.034% of pellets traded globally and 0.021% of global pellet production. The UK was the world's largest importer of biomass in 2018, mainly due to use in the Drax power station. UK imports are predominantly from the US (63%), with the remainder mainly coming from Canada (19%) and Latvia (9%).

Figure 40: Global production and trade in wood pellets



Source: FAOSTAT

Table 13: Global pellet production and trade in 2018

Production		Net export		Net import	
Country	**Mt**	**Country**	**Mt**	**Country**	**Mt**
World	36.6	World	24.0	World	23.2
		Top 5 ranked countries			
USA	7.5	USA	5.8	UK	8.0
Canada	3.0	Canada	2.6	Rep. of Korea	3.4
Germany	2.5	Viet Nam	2.5	Denmark	2.6
Viet Nam	2.4	Russia	1.5	Italy	2.2
Sweden	1.6	Latvia	1.4	Belgium	1.1
		Ireland			
Ireland	0.038	Ireland	nil	Ireland	0.008
Rank	46th			Rank	20th
% of global production	0.1%			% of global imports	0.03%

Source: Produced using data from FAOSTAT

6.1.2 Potential future imports of wood pellets

Any increased imports of wood pellets will need to be achieved in a way that ensures only sustainably produced pellets are imported and they meet the relevant legislative requirements set out in REDII [67]. These include criteria to ensure that forestry products are not taken from primary forests, forests with a high biodiversity value or protected areas and that the wood is harvested in a sustainable and legal way. In addition, the pellets, after taking account of the emissions associated with their production, processing and transport produced, must deliver minimum GHG savings when used for energy production. From 2026, when more stringent GHG criteria will apply, then the upstream GHG emissions associated with wood pellets must be less than 47.4 kg CO_2/MWh of energy contained in the pellet when used in electricity production and 49 kg CO_2/MWh when used in heat production.[31] Using typical values for the carbon intensity of forestry operations, pellet production, and transport and shipping distances:

- Pellets exported from the Baltics (such as Latvia), Portugal, and North-West Russia should all meet the 2026 sustainability criteria comfortably.
- Due to the longer shipping distances involved, the carbon footprint for pellets exported from the south-east of the USA and western Canada is higher, but for cases where pelleting plant are located close to the exporting port and are not transported significant distances by road, then it should be possible to meet the sustainability criteria.
- Pellets imported from destinations further afield (for instance South Africa) are highly unlikely to be able to meet the criteria.

It is possible that in the longer term, decarbonisation of transport options, and densification techniques, like torrefaction, could help to lower the carbon footprint of pellet production and transport, but in the short to medium term, imports may need to be restricted to countries where the transport distances are shorter. The use of Carbon Capture and Storage (CCS) on plants combusting wood pellets would give a credit for the carbon stored in the GHG savings calculation specified in RED II. This means that such plant could still comply with the criteria when using pellets imported from further afield, however from the perspective of reducing GHG emissions globally, transport distances should be minimised to ensure the greatest reduction in emissions.

Pellets are traded on the open market, but larger users will often develop long term bi-lateral contracts to ensure security of supply and reduce risks regarding prices. In developing estimates of the potential availability of pellets for import to Ireland, both pellets which might be traded on the open market and are therefore available for purchase by both small-scale users through pellet distributors who manage importation, and pellets which might be purchased directly by larger-scale users are considered.

Increasing demand for wood pellets worldwide is likely to mean additional harvesting to meet supply; however, this mustn't breach annual sustainable harvesting levels and cause a loss in the carbon stock of forests. Together with Forest Research, Ricardo has previously developed a model of global forestry which estimates the potential sustainable harvest from all countries and also considers the ability of that country to meet other sustainability requirements. These are combined to estimate potential increases in the production of wood and from this the fraction of wood that might be available for use as bioenergy. The model was used to inform estimates for the UK's climate change committee on the future availability of biomass from forests. Using this model, potential additional production in the two countries most likely to be a source for imports to Ireland, the US and the EU, based both on current import patterns and the sustainability greenhouse gas analysis conducted, were estimated. In the case of the US, it is considered that there is substantial potential to increase sustainable harvesting levels, and that harvesting of wood suitable for pellet production could double by 2050. In the case of the EU however, annual harvesting levels are already close to sustainable levels and growth of only around 10% is forecast by 2050. Russia was also examined as a

[31] Assuming conversion efficiencies of 36% for electricity and 85% for heat

potential source but in this case the modelling shows that harvesting levels are already potentially above what might be considered sustainable. Russia was therefore not considered as a potential source of imports.

The EU is already a major export market for US pellets, and while this may decline in the future as use of bioenergy in the US and neighbouring regions increases, it is considered likely, that in 2050, 70% of US exports still come to the EU. Competition for wood pellets exported from the US, and also for additional production within the EU from EU countries is likely to depend on a number of factors. These include the domestic forestry resource, energy demand within a country, and the role that countries see biomass as having in looking to achieve Net Zero. A key determining factor in this respect may be the desire to use Bioenergy CCS (BECCS) as this generates negative emissions, which can be useful for offsetting emissions from hard to decarbonise sectors such as agriculture. Ireland has a particularly high contribution from the agricultural sector in its national GHG emissions, and accounted for 5.1% of EU agricultural emissions in 2021. It, therefore, seems likely that Ireland could have a strong demand for imports. It was therefore assumed that over time Ireland's share of US exports and additional production in the EU, rises, reaching 6% by 2050. [32]

As discussed above, the use of BECCS means that use of pellets with slightly higher transport-related emissions could still meet the sustainability criteria in RED II. A further tranche of pellet imports from countries with longer transport distances (Brazil and South Africa) was therefore identified. The same methodology as above was used to estimate firstly potential sustainable increases in harvesting in these countries, and assumptions about the proportion of exports coming to the EU from these countries, and the proportion of those EU imports coming to Ireland. In the longer term, it is considered that there could be substantial competition of these imports and in 2050. Ireland is only assumed to get 0.3% of total exports from these countries.

Finally, the possibility of imports of pelleted energy crops rather than pellets based on sawmill residues or small roundwood) was considered. This used estimates of global land availability to consider how perennial energy crops might develop in relevant regions of the world,[33] and that a small fraction of this around 0.1% might be available for import to Ireland.

Figure 41 shows the potential quantity of wood pellets that could be available for import into Ireland. Managing such levels of imports is likely to require further development of infrastructure at ports. This has been successfully achieved in the UK, which in 2009 had imports of 45 kt (around the current level of Irish imports) and by 2019 had increased this to 8,697 kt, with most of the increase being utilised by the previously coal-fired Drax power station. The increase was accompanied by the development of port infrastructure, mainly the conversion of jetties designed for coal handling to wood pellets and the installation of unloaders, conveyors and storage silos. Ports undergoing development included:

- Immingham: £135 million investment delivering 50,000 tonnes storage, and a throughput of up to 6 Mt per year,
- Liverpool: £85 million investment delivering 99,000 tonnes storage, and a throughput of up to 3 Mt per year,
- Tyne and Hull

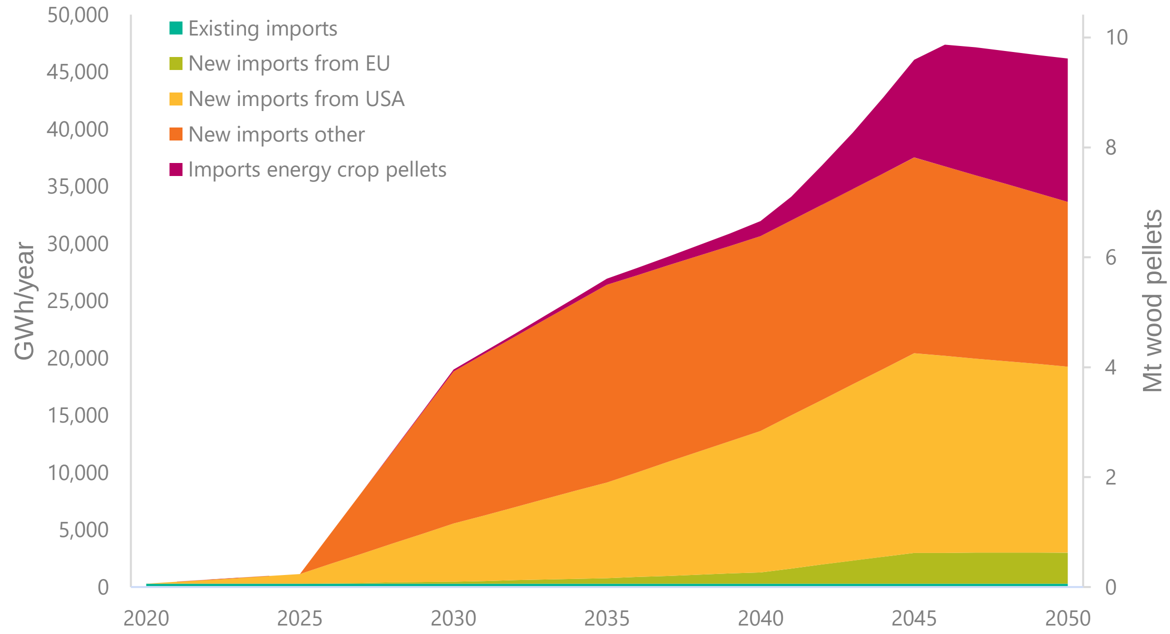
In Ireland, the main ports for dry bulk imports are Dublin, Shannon - Foynes (which is also where the Moneypoint power and coal unloading infrastructure is located) and Cork, and in 2020, 15.6 Mt of dry bulk goods were imported. Moneypoint has previously imported up to 1.7 Mt of coal, but these fell by about 1 Mt due to the lower running hours seen by the Moneypoint power station in recent years and will cease when it closes fully in 2025. The Foyne port management company foresees that in the longer term facilities there

[32] Based on the facts that Ireland accounts for 1% of primary energy consumption in the EU and 5% of agricultural emission which might drive demand for biomass for BECCs.

[33] Estimates of land availability are based on those from the IMAGE Integrated Assessment Model as used in the UK and Global Bioenergy Resource Model (https://www.gov.uk/government/publications/uk-and-global-bioenergy-resource-model)

could be improved to allow an increase from 10 Mt to 20 Mt. Dublin port's plans include an increase in throughput to 3.5 Mt in 2040 partly driven by imports of biomass for power generation. Overall this suggests that imports of the substantial quantities of biomass shown in *Figure 41* could be accommodated if investments were made to develop infrastructure at ports and onward distribution infrastructure.

Figure 41: Potential quantities of wood pellets available for import to Ireland



Prices estimated for imported pellets are given in *Table 14*.

Table 14: Estimated prices for imported pellets

Type	€/tonne	€/MWh	Basis
Existing imports	167	34.7	Existing analysis for SEAI on price of imported pellets [11]
New imports from Europe	167	34.7	Existing analysis for SEAI on price of imported pellets [11]
New imports from USA	155	32.3	Review of pellet prices from variety of sources
New imports other	176	36.6	Based on cost of imports from USA with allowance for increased road transport and shipping distance
Imports energy crop pellets	194	40.3	Based on costs of new imports with an allowance for increased costs of energy crop production compared to use of forestry thinnings or sawmill residues

6.2 BioLPG

6.2.1 What is the resource and how can it be used?

BioLPG is a direct substitute for conventional fossil fuel derived LPG and can be an easy way for existing LPG users to decarbonise their heat production. BioLPG is currently produced from the off-gases generated when vegetable oils and used cooking oil are hydrotreated to produce Hydrotreated Vegetable Oils (HVO) a drop in replacement for diesel in road transport. It is also possible to produce BioLPG by gasifying solid waste or biomass to syngas and converting this via the Fisher-Tropsch process to Dimethyl Ester (DME)[34] and then to BioLPG. This technology is not yet commercialised; estimates are based on assessing current and future HVO production in Europe, and how much BioLPG might be generated from this.

It is estimated that Ireland currently uses about 42 t of BioLPG; this is imported from Neste's HVO production facility at Rotterdam and is about 0.1% of the 40,000 t per year production at the site. There are currently a number of other HVO production facilities in Europe and total production capacity is almost triple that of the Neste Rotterdam plant [81]; recovery of BioLPG from off-gases at these production plant could lead to an additional 72,000 t of bio LPG production in the EU. It is forecast that planned developments of HVO production plant globally could lead to the production of a further 100,000 tonnes of BioLPG [82]. Not all of this will be in Europe, and not all may come to fruition, so it is assumed that by 2030 an additional 10,300 t of bioLPG might be produced in the EU giving total production of 122,360 t of bioLPG. Ireland currently accounts for about 1% of LPG use in the EU, [35] it is assumed that 1% of this could be available to Ireland in 2030 (1,224 tonnes (15,516 GWh)). This is over seven times the current consumption of LPG in Ireland for energy uses (2,097GWh) [5] suggesting that full substitution of LPG with bioLPG should be possible.

Upstream GHG emissions from bioLPG production will be the same as those of the HVO it is coproduced with; these are dependent on the feedstock oil used for the HVO production. BioLPG produced where used cooking oil is the feedstock for HVO should meet the REDII 2026 limit for heat, but other virgin oil feedstocks would not. The current commercial HVO and BioLPG production feedstock mix includes palm oil which in addition to having relatively high GHG emissions associated directly with its production has also been identified as having a high indirect land-use change (ILUC) impact [81]. BioLPG produced from HVO using palm oil as a feedstock is therefore particularly undesirable from a sustainability perspective. It will be important to ensure that bioLPG has the same robust sustainability governance as other forms of bioenergy.

The price premium for bioLPG over conventional LPG was examined previously [83] for SEAI in 2017. Calor Gas who were about to start importing bioLPG indicated that it would be sold at a premium to cover the cost of transportation from Rotterdam, and the mass balance system necessary to allow tracking of the bioLPG. As such, it would be a flat rate across all consumers. Based on this information received previously from Calor, the current prices of conventional LPG (from [84]) and assuming that bioLPG's current exemption from carbon tax is maintained, estimated prices for bioLPG shown in *Table 15*.

Table 15: Estimated prices for bioLPG

	€/MWh (excluding VAT)
Commercial cylinders	141
Bulk LPG (0 to 3 tonnes)	103
Bulk LPG (3.1 to 40 tonnes)	92

[34] DME could also be blended with LPG at up to about 20% with no need to make changes to heating equipment

[35] Based on data from Eurostat energy database Table 'Supply, transformation and consumption of oil and petroleum products [nrg_cb_oil]'

7 Summary of resource availability

7.1 Resource availability under the modelling scenarios

For most of the resources, a single estimate of future availability has been made. However, in the case of grass silage and perennial energy crops, two estimates of future availability were made to illustrate the impact that future changes in the size of the national herd may have on land available to grow these crops. Two scenarios were examined, a business as usual 'Stable Herd' scenario where the dairy herd increases but the sucker herd decreases which gives a very small overall reduction in herd size, and a Land Use Change scenario where it is assumed that a desire to reduce livestock emissions from agriculture leads to a more significant reduction in the suckler herd. As discussed earlier, the land which could be released from grazing and fodder production under the two scenarios, due both to changes in the national herd and to improvements in grassland management to improve grassland productivity, can be used to either cultivate grass silage as a feedstock for AD, or to cultivate perennial energy crops. The future availability of these two crops, therefore, depends both on the herd scenario and which crop it is assumed is cultivated. As outlined in Section 1.2, the overall modelling work conducted as part of the National Heat Study examines four scenarios that reach net-zero emissions in the heat sector by 2050 and a business as usual Baseline. The choices made to represent the availability of grass silage and energy crops under each of the scenarios are shown in *Table 16*, and are consistent with the overall narrative for each of the scenarios.

Table 16: Alignment of resource estimated for energy crops with modelling scenarios

	Baseline (Business as Usual)	Decarbonised Gas	High Electrification	Balanced	Rapid Progress
Theme	No drive to increase production of energy crops	Maximise grass silage and biomethane production	Maximise perennial energy crops	Mix of grass silage and energy crops	Maximise grass silage and biomethane production
Herd scenario	Stable Herd	Stable Herd	Stable Herd	Stable Herd	Land Use Change
Use of land 'released' due to changes in herd	Grass silage	Grass silage	Perennial energy crops	50% grass silage 50% perennial energy crops	Grass silage
Use of land 'released' due to improvements in productivity of grazing land	No assumed increase in productivity so no additional land released	Grass silage	Perennial energy crops	50% grass silage 50% perennial energy crops	Grass silage

Figure 42 shows the development of the domestic bioenergy resource over time under each of the scenarios, and *Figure 43* a breakdown of the contribution of each bioenergy resource in 2020, 2030 and 2050. A full set of results is given in Appendix 1.

The domestic bioenergy resources considered in this study are estimated to amount to 6.5 TWh in 2020, about 4% of primary energy supply. Just over two-thirds (4.4 TWh) of these resources were utilised for bioenergy in 2020,[36] suggesting that bioenergy use could be increased significantly at present. In addition to these domestic resources, about 2 TWh of imported bioenergy was used, of which three quarters was liquid

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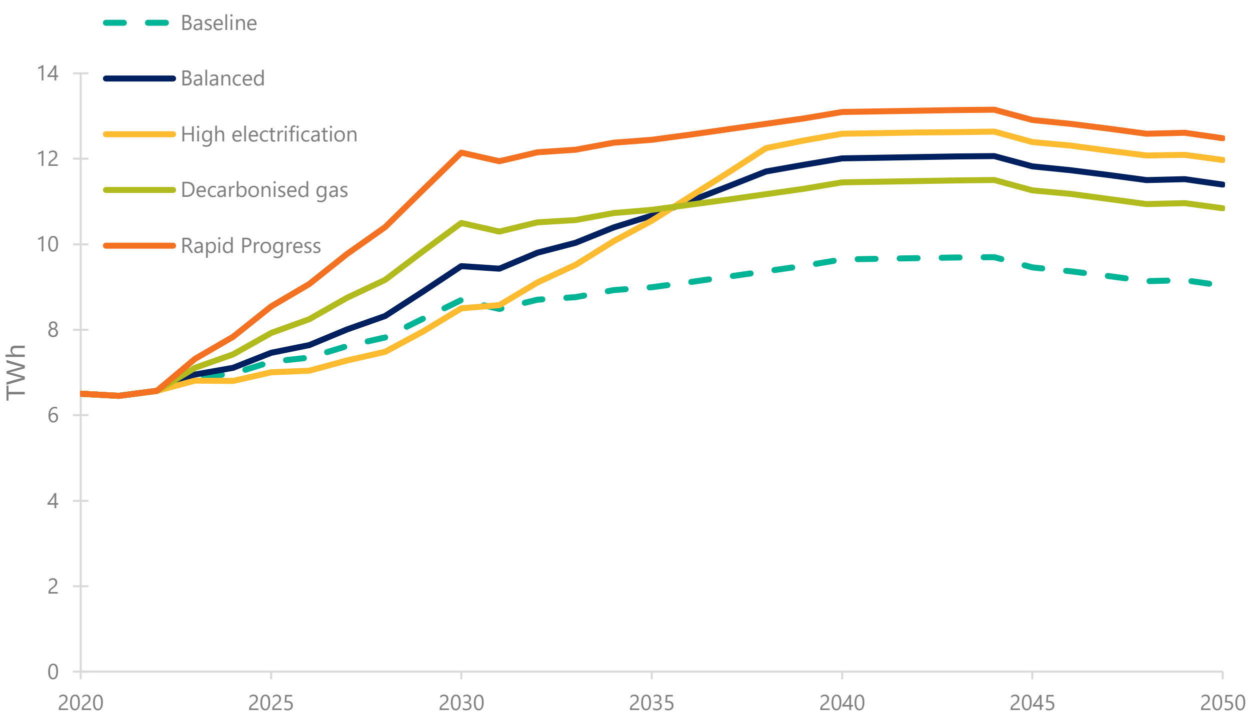
[36] An additional 0.4 TWh of biogas from sources not considered in this study (landfills and AD of sewage sludge) were also used in 2020 [3].

biofuels for transport with the remainder being wood pellets for co-firing in power stations and for biomass boilers.

Figure 42: Total domestic bioenergy resource under the five modelling scenarios



By 2030, the potential bioenergy resources could increase by around a third in the Baseline scenario, with most of the increase coming from:

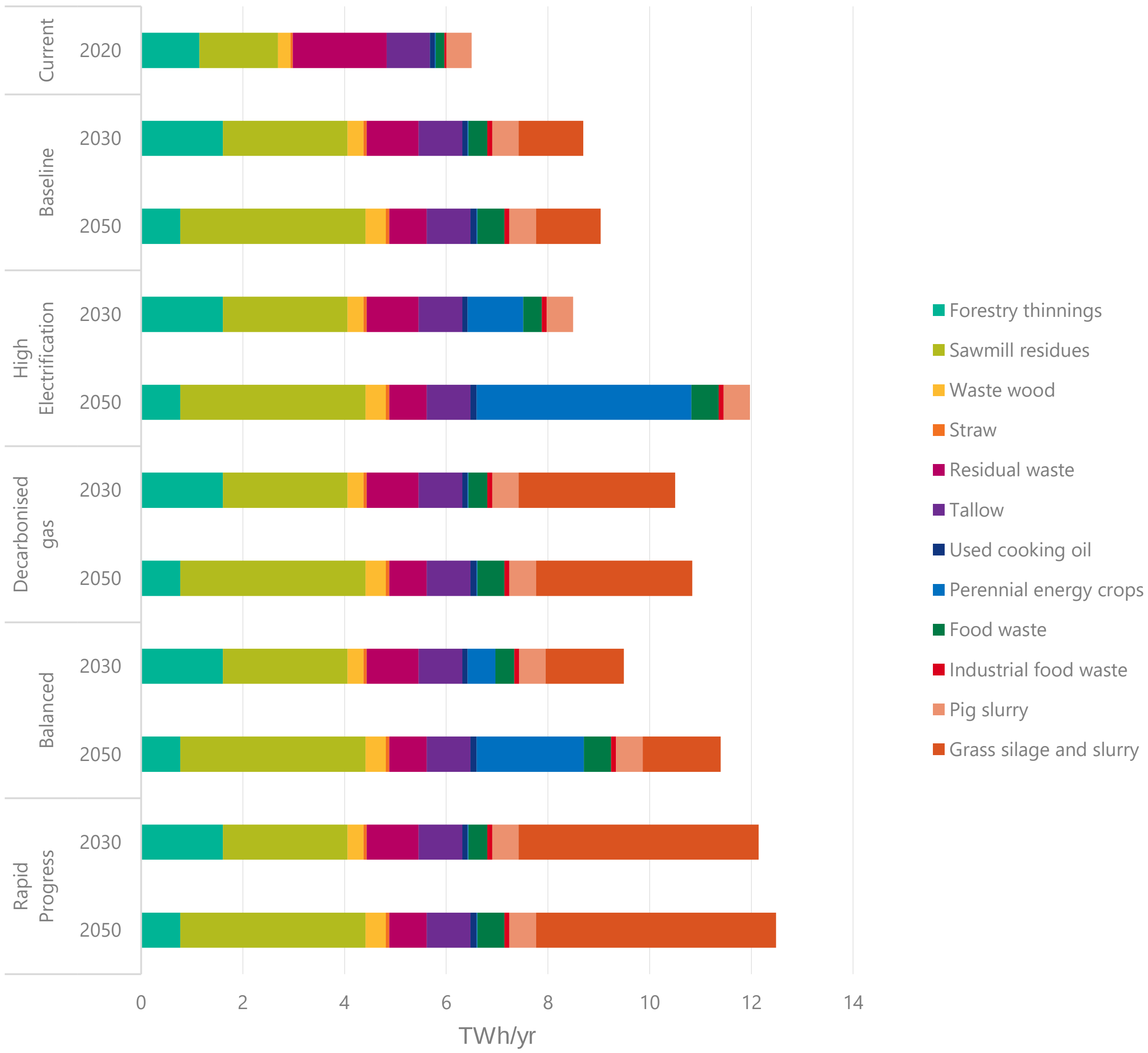
- Grass silage grown for AD on land is no longer needed for grazing and fodder as the suckler herd declines
- An increase in sawmill residues as more sawlogs are harvested and processed
- More small roundwood from thinnings and increased harvesting operations.

There are also small increases in the amount of food waste from domestic and commercial premises, as the separate collection of these resources improves, and larger quantities of wastes from slaughter houses and milk processing are assumed to be available. There is, however, a decline in the amount of residual waste as recycling and separate collection of food waste are assumed to increase.

In the period 2030 to 2050, the accessible bioenergy resource is forecast to increase by another 5%, due mainly to further increases in sawmill residues and, to a lesser extent, further increases in food waste collection. However, quantities of small round wood available for bioenergy decline and quantities of residual waste fall further, so that the overall increase is relatively small.

As described earlier, the Decarbonised Gas scenario assumes that efforts are made to ensure that grassland productivity and utilisation are increased, allowing more land to be freed up to produce grass silage. This increases resources by 1.8 TWh per year by 2030 compared to the Baseline. The Rapid Progress scenario explores the impact of a more significant reduction in the suckler herd, and in this scenario, the additional land, which is then available to grow grass silage for AD, leads to an extra 1.6 TWh compared to the Decarbonised Gas scenario in 2030 (3.4 TWh more than the Baseline).

Figure 43: Breakdown of domestic bioenergy resource under the five modelling scenarios



The High Electrification scenario explores the possibility of using land released from beef production for perennial energy crops rather than grass for AD in the Decarbonised Gas scenario. Due to the time needed to establish the supply chain for energy crops and to roll out their planting, the resource from these crops in 2030 is relatively limited (1.1 TWh), but by 2050 they are able to deliver 4.2 TWh, giving an overall increase in the bioenergy resource of 3.4TWh. This scenario has the highest overall resource in primary energy terms, in other words the energy content of the resources. This is because the energy content of the perennial energy crops which can be grown on a hectare of land is (based on the assumptions used in modelling) greater than that of the silage produced. The contribution of the bioenergy resources grown on that land to final energy demand will depend on how the resource is used and associated losses due to further processing of the resource and conversion losses. Some examples for use of the two resources for heat are shown in *Table 17*. However, the contribution that a particular bioenergy resource will make to the energy system is also affected by a number of other factors, such as its cost and how this compares to alternative fuels.

Table 17: Energy produced from a hectare of land used for perennial energy crops and grass for AD

Parameter	Unit	SRC willow chips	SRC willow pellets	Grass silage
Crop yield	odt/ha/yr (SRC); tDM/ha/yr (grass)	10	10	13
Energy content of crop	MWh/odt (SRC); MWh biomethane/t DM (grass)	5.3	5.3	3.1
Finished fuel produced*	MWh fuel/ha	52.8	47.6	34.9
Heat delivered	MWh heat/ha	44.9	40.4	29.7

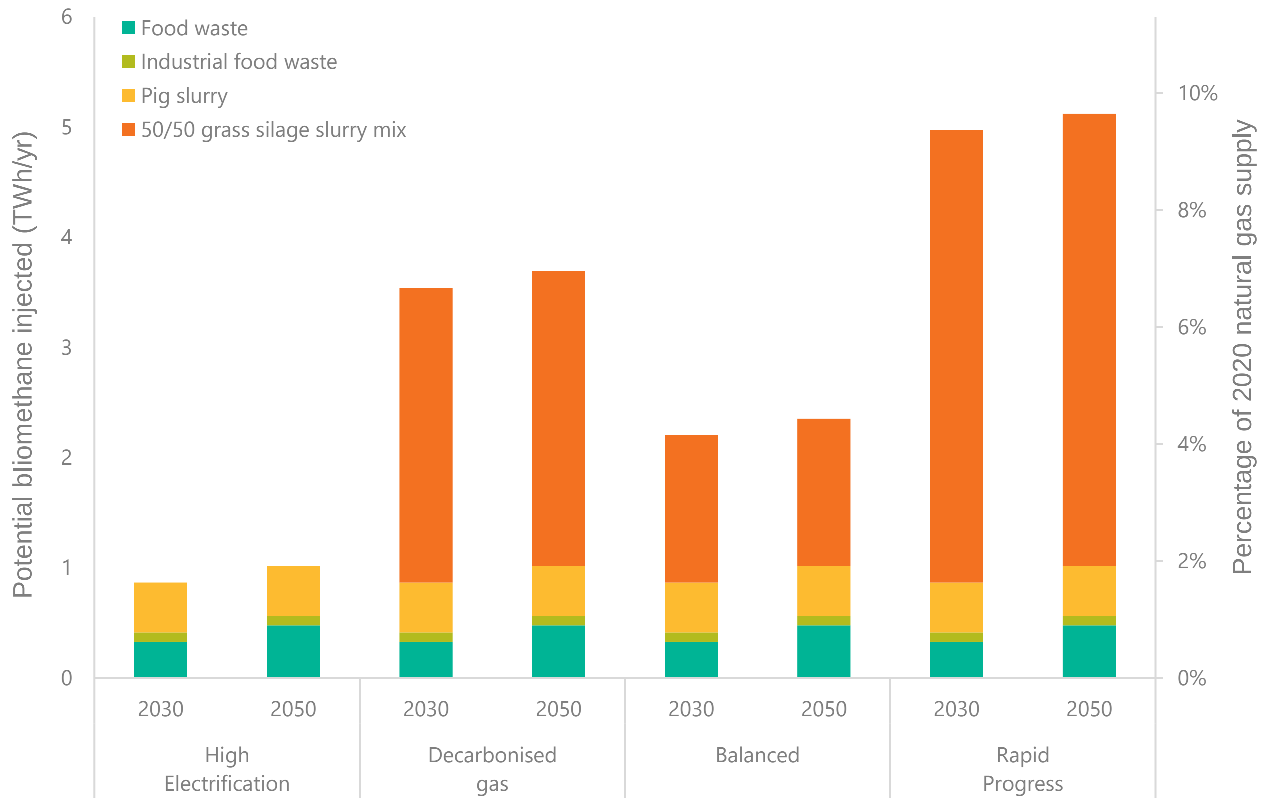
* including emissions associated with producing the feedstock into a fuel and accounting for any losses during processing

Finally, the Balanced scenario assumes that there is a role for both perennial energy crops and biomethane produced from AD of grass within the energy system. It assumes that half the land released from beef farming is used for grass silage and half for perennial energy crops. As in the High Electrification scenario, the slower roll out of energy crops than silage for AD means that the increase in total resources to 2030 of 3 TWh is lower than in the Decarbonised Gas scenario. By 2050 though, the perennial energy crop potential is fully realised and the total accessible resource is 11.4 TWh – midway between the resources in the High Electrification and Decarbonised Gas scenario.

Given the interest in using biomethane to decarbonise the gas grid, the potential contribution that resources suitable for AD could make to gas supply are shown separately in *Figure 44*. The values for each of the resources shown in *Figure 43*, are the energy content of the biogas each resource could produce in an anaerobic digester. However, the AD plant will require heat and power to operate and there are further power requirements for upgrading the biogas to biomethane. It is common practice to supply this heat and power by using some of the biogas that is produced. This own use is typically about 11 to 13% of total biogas production, reducing the amount of biomethane that is available for injection. *Figure 44* shows the amount of biomethane that could be injected, taking account of this own use, so values are lower than those shown in *Figure 43*. To set the quantities in context, they are compared to natural gas supplied in 2020. In the High Electrification scenario, where only waste resources are available, biomethane injection is equivalent to 1.95% of natural gas supplied in 2020. As discussed earlier, in the Decarbonised Gas scenario, land made available due to a reduction in the beef herd and improvements in the productivity of grassland is assumed to be used to grow a red clover/ryegrass mix for silage for AD. This resource increases the biomethane injected to 8% of the current gas supply. Under the Rapid Progress scenario, where further reductions in beef farming allow more switching into the production of this AD feedstock, the potential contribution rises to 11%. In the future, requirements for gas may diminish due for example, to the electrification of heating or the use of hydrogen. Consequently, biomethane could form a higher proportion of gas in the grid. Alternatively, it could be containerised and used at industrial sites not currently connected to the grid. These aspects are explored further in other parts of the Heat Study, Low Carbon Gases for Heat.[37]

[37] SEAI, 'Low Carbon Gases for Heat: Potential, Costs, and Deployment Options in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Low-Carbon-Gases-for-Heat.pdf

Figure 44: Potential for biomethane injection



7.2 Cost of resources

Figure 45 shows cost supply curves for the Balanced scenario for 2030 and 2050. These show the amount of resources that can be supplied at a particular cost. The costs are for the resource itself, and in most cases, they do not fully represent the cost for the feedstock that will be seen by the end user.[38] For example, in the case of forestry resources and perennial energy crops, these are the cost of the resource at the 'farm gate' or 'forest road' and do not include the costs of any processing such as chipping[39] or pelleting, or the costs of distributing chips and pellets to end users. In the case of resources used to produce biogas, the costs are for the feedstock only and do not include the costs of operating the AD plant to produce biogas from the resource. The attractiveness of a resource to an end user may also be affected by the ease and efficiency with which it can be converted into heat or power. These additional costs and factors are modelled and accounted for in other parts of the Heat Study, where an end user perspective is modelled. The cost curves do, however provide an initial view of the relative cost of resources.

In the Balanced scenario shown in *Figure 45*, about 2.3 TWh (just under a quarter of total resources in 2030) are wastes that are available at zero or negative cost, for example, the waste producer will pay to have the waste managed. A further 4.2 TWh (4.5 TWh by 2050) of by-products and residues, including forestry thinnings, sawmill residues and straw, are available at a relatively low cost of under 2 c/kWh (€20/MWh). Perennial energy crops have a slightly higher cost than this, of 23 to 26 €/MWh, and biogas from a grass silage/slurry mix an even higher cost of 53 to 55 €/MWh. However, as discussed above, these costs do not include conversion and processing costs, so care should be taken in comparing them directly.

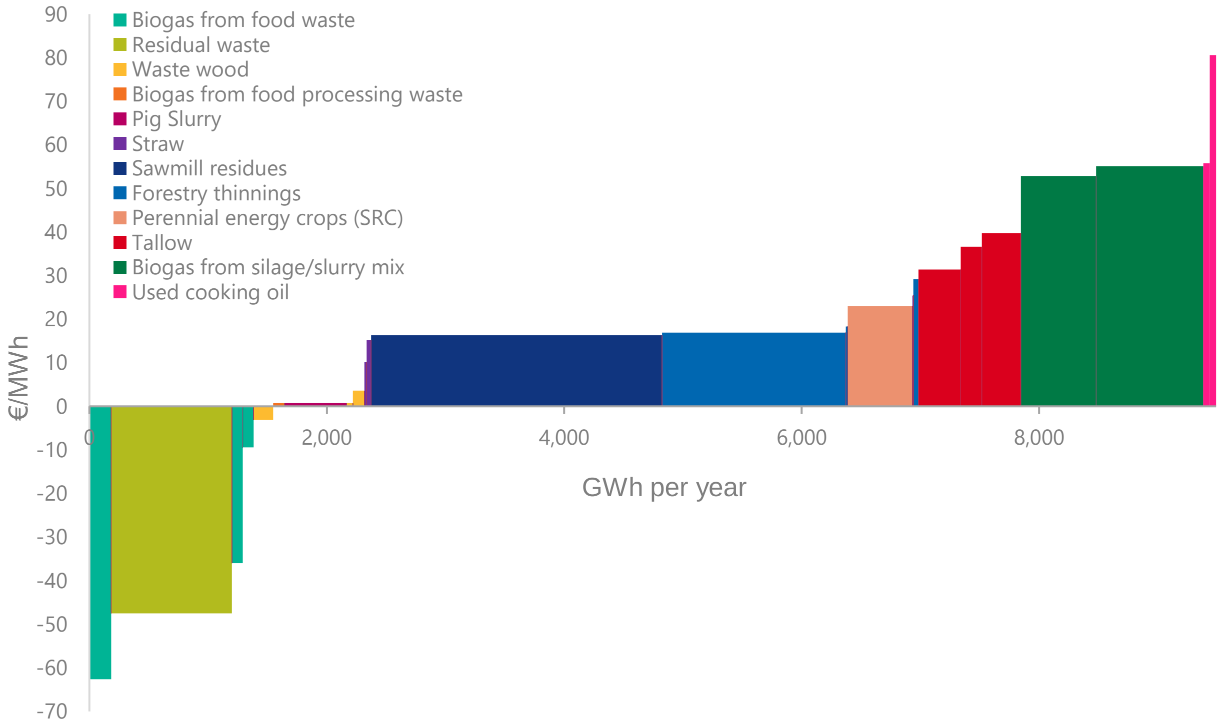
[38] An exception is the biogenic component of residual waste where this is based on the gate fee that would be paid by an energy from waste plant.

[39] Some harvesting techniques for SRC willow include chipping as part of harvesting.

Cost supply curves for the other scenarios for 2050 are shown in *Figure 46*.

Figure 45: Resource cost supply curves for Balanced Scenario in 2030 and 2050

2030



2050

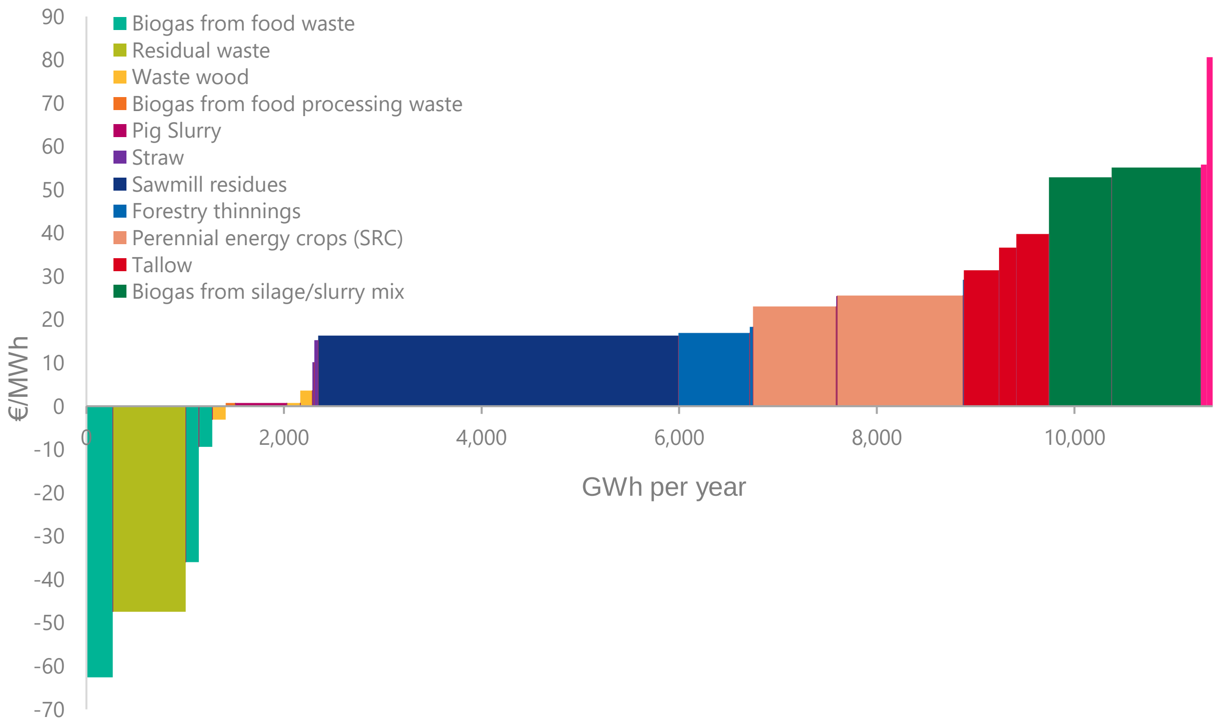
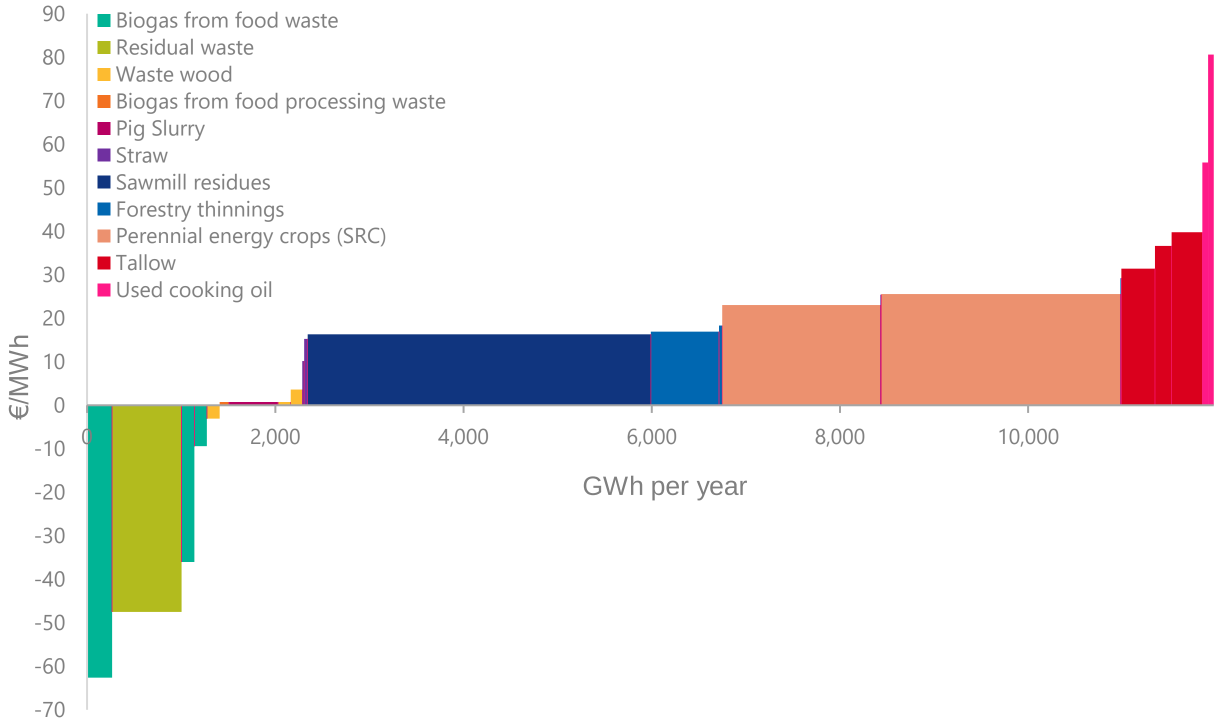
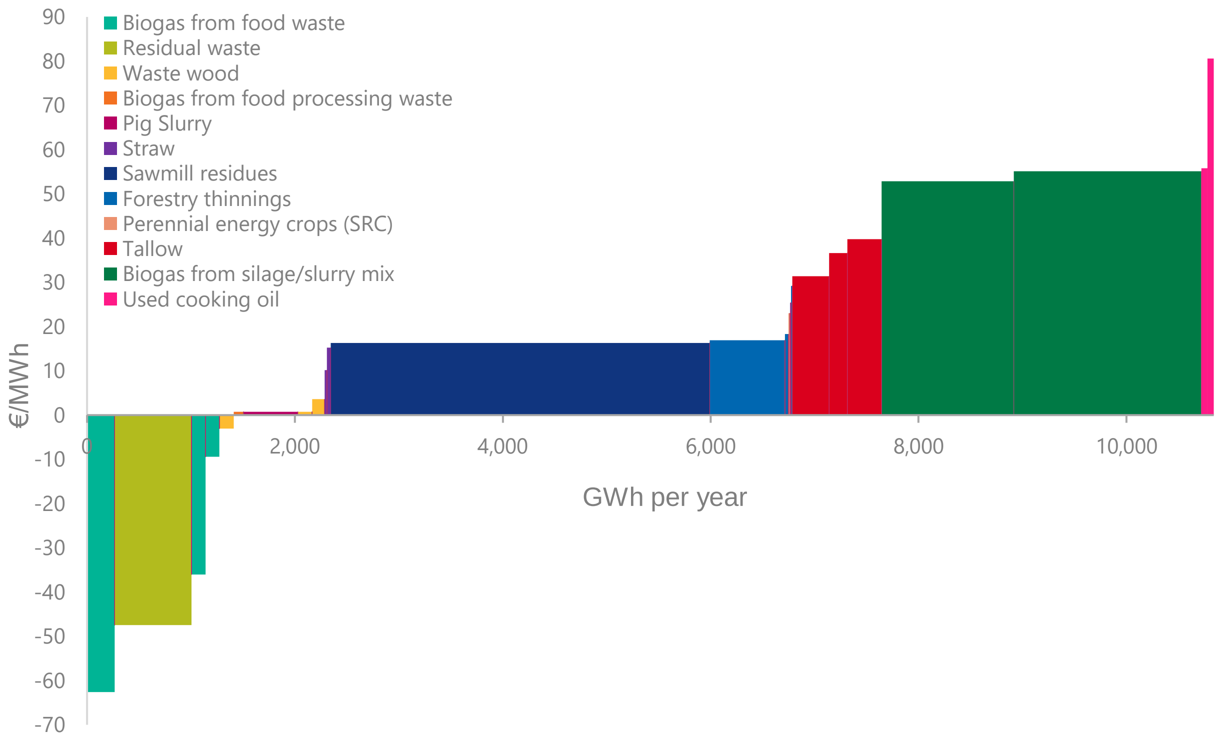


Figure 46: Cost supply curves for other scenarios for 2050

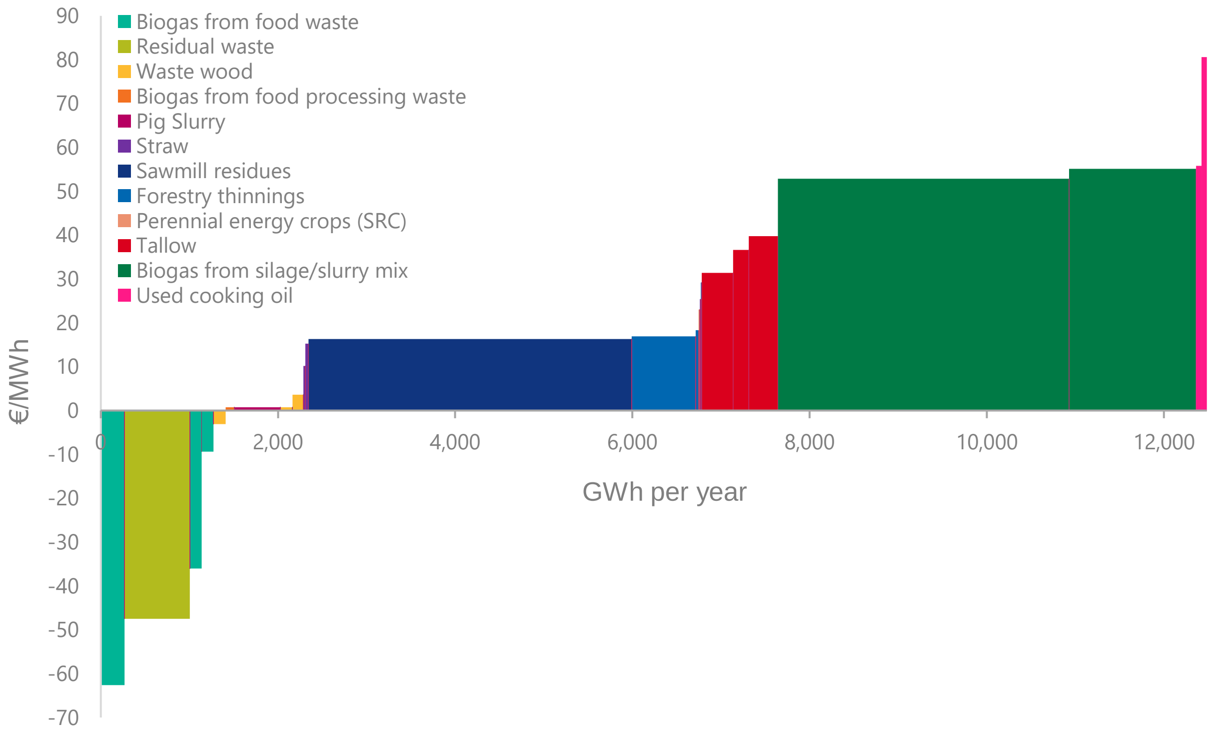
High Electrification



Decarbonised Gas



Rapid Progress



7.3 Sustainability of resources

In developing the estimates of accessible resources, care was taken to ensure that only resources which could be produced in a sustainable way were included. This included consideration of upstream greenhouse gas emissions, for example, those associated with cultivation, and also the need to avoid other negative environmental impacts. The recast of the Renewable Energy Directive (RED II) specifies that biogas/biomethane heat, electricity and liquid biofuels produced at installations must deliver a minimum level of GHG savings compared to typical fossil fuels. It also sets other sustainability criteria to ensure that bioresources do not come from land with high biodiversity or high carbon stock or are sourced in a way that is likely to cause indirect land use change.

In the case of wastes and residues used for bioenergy, the only greenhouse gas emissions that need to be considered are those associated with any additional activities to collect and process the waste or residue for use as bioenergy feedstock.[40] However, from a broader sustainability perspective, it is important to ensure that using the waste for bioenergy does not act as a counter-incentive in preventing waste generation in the first place or discouraging implementation of options higher up the waste hierarchy such as reuse or recycling. These aspects were incorporated in this study when estimating residual waste arising by considering actions to reduce waste generation and ensuring that recycling targets were met.

Some wastes and residues already have an existing end use, for example, forestry thinnings and sawmill residues are used in the panel board industry. Diverting resources away from such competing uses may have knock-on effects that lead to additional greenhouse gas emissions from having to produce an alternative material to supply the competing use. This study has assumed that other uses are still supplied, ensuring that bioenergy use does not cause such indirect effects. Finally, in the case of residues such as straw, and forestry harvesting residues it can be important that some material is left in the forest or ploughed back in to the field to ensure that soil quality is maintained. This has been allowed for in the resource estimates.

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[40] This reflects the assumption that the primary activity would have occurred anyway, and that it should bear the carbon footprint of the production process.

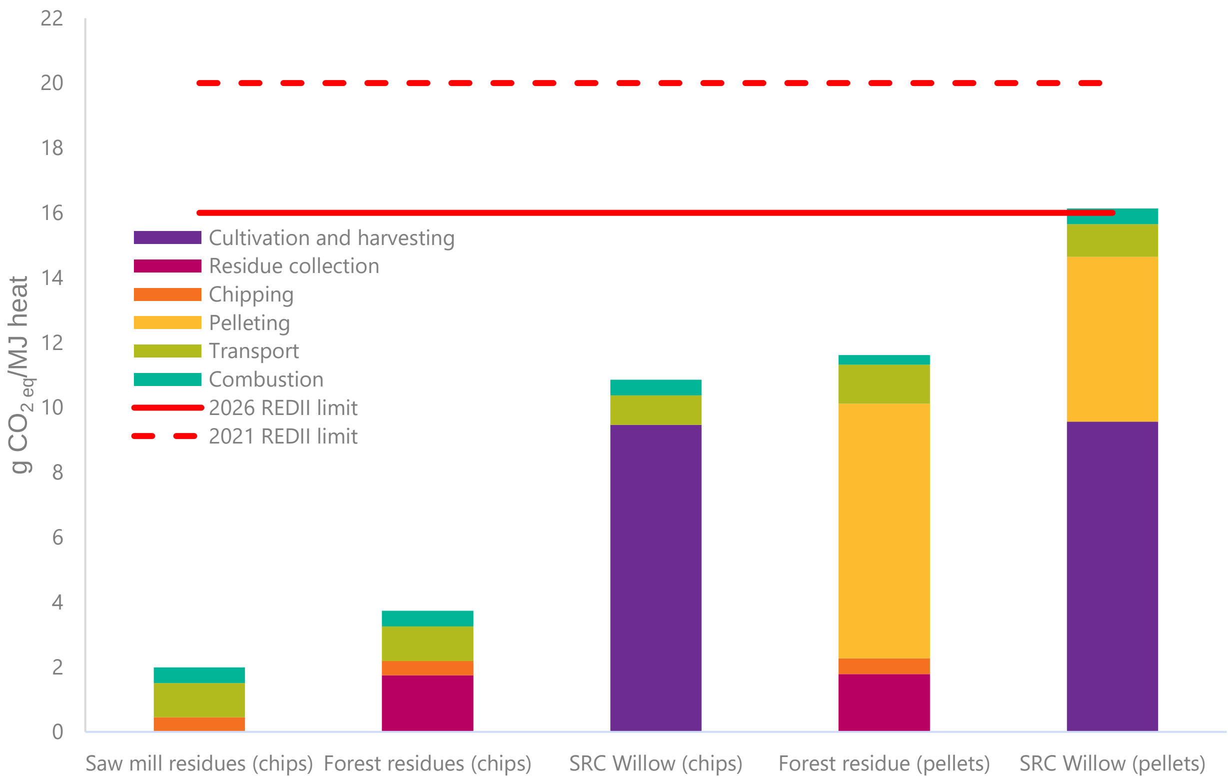
The overall impact on GHG emissions from the use of forestry products for bioenergy has been the subject of much discussion. This study only considered small round wood, which is extracted when the forest is thinned or is produced at final harvesting of the forest for high value, larger saw logs so that bioenergy use is not a driver for additional harvesting. The removal of timber from a forest is accounted for in Ireland's national greenhouse gas inventory as a reduction in the carbon stock provided by forests. For wood which then ends up in products (such as sawlogs), this is considered to still form a carbon pool for some years, and this is allowed for in the inventory. For wood that is burnt, this is regarded as an immediate loss to the carbon stock. At a national level, sustainable forest management means that only as much wood is harvested in a year as is replaced by new growth. It is assumed that this is the case for Ireland so that use of forest thinnings for bioenergy does not cause a net reduction in the forest carbon stock.

The resources with the highest greenhouse gas emissions are typically crops, because of the fuel needed to cultivate them, the carbon footprint of inputs such as fertilisers, and the GHG emissions from the soil that are associated with the application of nitrogenous fertilisers. The resource estimates developed here for silage as an AD feedstock are based on cultivating a red clover/ryegrass mix where the nitrogen-fixing properties of the red clover minimise the need for nitrogenous fertilisers and hence reduces GHG emissions. As discussed in Section 5.2.6, even using this grass mix which has a lower nitrogen requirement than a monoculture of ryegrass, the silage must be mixed with slurry when it is used to produce biogas to make sure that the GHG savings specified in RED II are met. Perennial energy crops, such as SRC willow, typically require no or very little fertiliser application, so emissions associated with their cultivation are much lower. The resource estimates made in this study also exclude cultivation on land that is environmentally sensitive, has a high biodiversity value, or has soils with high organic carbon; the latter are excluded as cultivation of such soils to grow energy crops might lead to oxidation of some of the carbon, and additional emissions of the GHG CO_2.

Figure 47 shows GHG emissions per unit of heat for a selection of domestic resources. The estimates include emissions associated with any further processing of the feedstock and its distribution to the end user, and trace emissions of the non-CO_2 GHGs when the fuel is combusted as these are all aspects that must be considered when considering compliance with the greenhouse gas savings specified in RED II. Emissions from sawmill residues are low, as there are no emissions associated with its production, and it is easily collected. Emissions from forestry residues are slightly higher due to the energy expended in collecting the residues, and those from SRC willow higher again due to the emissions associated with cultivation and harvesting. Waste wood is likely to have emissions similar to those from forestry residues. In all cases heat produced from these materials when they are chipped comfortably meets the more stringent criteria in RED II for heat produced in installations starting operation from 2026. The energy required for pelleting adds substantially to emissions, and emissions from pelleted energy crops do not quite meet the more stringent REDII criteria, but only small improvements, for example in yield or minimising emissions from pelleting and transport would be necessary to ensure that it did. Similar calculations for imported wood pellets suggest that pellets imported from Europe (the Baltics or Portugal) would easily meet the RED II 2026 limit, but that pellets imported from the South East US, would be close to the limit. BioLPG is a co-product from the production of hydrotreated vegetable oil (HVO), a biofuel which is a substitute for fossil diesel. BioLPG thus has upstream emissions similar to the HVO, and these are dependent on the feedstock oil used for the HVO production. BioLPG produced where used cooking oil is the feedstock for HVO should meet the REDII 2026 limit for heat, but other virgin oil feedstocks would not. It will be important to ensure that bioLPG has the same robust sustainability governance as other forms of bioenergy.

As discussed earlier, the different modelling scenarios explore the impact of using available agricultural land for either a perennial energy crop, SRC willow, and an annual energy crop, silage from a red clover/ryegrass mix. Energy production is higher in scenarios where SRC willow is grown due to its higher energy density per hectare (*Table 17*). *Table 18* compares the GHG emissions associated with heat produced from these two crops. Values are shown for a calculation consistent with the methodology specified in RED II, and also when adopting a wider boundary which takes into account other impacts in the agricultural sector from using grass silage for AD (see section 5.2.6 for more details).[41] The GHG emission savings which can be achieved from using a hectare of land for either crop is then calculated, using the energy produced per ha from *Table 17* and assuming that the heat displaced has a carbon intensity of 80 g CO_2/MJ, which is the value specified in RED II for calculating GHG savings from heat production. GHG savings are higher when SRC willow is grown particularly if it can be used in a chipped form.

Figure 47: GHG emissions from domestic and imported bioenergy resources



Source: Based on data used in [68]; adjusted for SRC to yields assumed in resource assessment.

The sustainability criteria and greenhouse gas savings specified in RED II have been used as a benchmark in this study for ensuring that the resource assessment only considers sustainable resources. However, the criteria in RED II only applies to larger installations.[42] To ensure that all future bioenergy use in Ireland is sustainable could therefore require additional national legislation (such as beyond direct transposition of the Directive) to ensure compliance of smaller installations as well. Application of the sustainability and greenhouse gas emissions saving criteria to smaller installations in national legislation is permitted by the Directive.

[41] In both cases it is assumed that there is no overall change in soil carbon from cultivating either of the crops.

[42] Above 20 MW thermal input for solid and liquid biomass fuels and 2 MW for gaseous biomass fuels.

Table 18: Comparison of GHG emissions for heat produced from energy crops

Basis of emissions calculation	Unit	SRC willow chips	SRC willow pellets	Grass silage	Grass silage/slurry mix (50/50)
GHG emissions from production of heat					
RED II	g $CO_{2\ eq}$/MJ heat	10.9	16.1	31.6	15.1
Wider LCA	g $CO_{2\ eq}$/MJ heat	10.9	16.1	30.7	12.8
GHG savings from production of heat (using REDII comparator of 80 g CO_2 eq/MJ heat)					
RED II	g $CO_{2\ eq}$/MJ heat	69.1	63.9	48.4	64.9
Wider LCA	g $CO_{2\ eq}$/MJ heat	69.1	63.9	49.3	67.2
RED II	t $CO_{2\ eq}$ /ha	11.2	9.3	5.2	8.0
Wider LCA	t $CO_{2\ eq}$ /ha	11.2	9.3	5.3	8.2

Appendix 1 Resource availability data

Table A1: Availability and price for resources where availability does not change by scenario

Feedstock	Price	2020	2025	2030	2035	2040	2045	2050
	€/MWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Forestry thinnings	29	59	62	43	22	11	11	11
Forestry thinnings	18	0	3	14	22	34	34	34
Forestry thinnings	17	1,088	1,340	1,549	1,512	1,415	1,163	723
Sawmill residues	16	1,544	1,989	2,451	3,001	3,648	3,648	3,648
Straw	25	7	0	10	10	10	10	10
Straw	15	26	0	37	37	37	37	37
Straw	10	14	0	20	20	20	20	20
Pig slurry	0	500	506	521	521	521	521	521
Residual waste	-47	1,846	1,262	1,018	680	712	732	737
Waste wood	4	75	85	96	107	115	120	122
Waste wood	0	0	0	54	120	130	136	137
Waste wood	-3	170	192	163	120	130	136	137
Industrial food waste	0	36	77	97	97	97	97	97
Food waste	-9	44	69	92	118	127	132	134
Food waste	-36	44	69	92	118	127	132	134
Food waste	-63	87	138	184	235	253	264	268
Used cooking oil	56	49	52	54	55	57	59	60
Used cooking oil	81	49	52	54	55	57	59	60
Tallow	40	323	328	328	328	328	328	328
Tallow	37	175	178	177	177	177	177	177
Tallow	31	350	356	355	355	355	355	355

Table A2: Availability and price of 50/50 silage/slurry mix

Scenario	Price	2020	2025	2030	2035	2040	2045	2050
	€/MWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Baseline	52.9	0	477	1,271	1,271	1,271	1,271	1,271
Baseline	55.1	0	0	0	0	0	0	0
Decarbonised Gas	52.9	0	477	1,271	1,271	1,271	1,271	1,271
Decarbonised Gas	55.1	0	677	1,805	1,805	1,805	1,805	1,805
High Electrification	52.9	0	0	0	0	0	0	0
High Electrification	55.1	0	0	0	0	0	0	0
Balanced	52.9	0	238	635	635	635	635	635
Balanced	55.1	0	339	903	903	903	903	903
Rapid Progress	52.9	0	1,233	3,287	3,287	3,287	3,287	3,287
Rapid Progress	55.1	0	538	1,434	1,434	1,434	1,434	1,434

Table A2: Availability and price of Willow Short Rotation Coppice

Scenario	Price	2020	2025	2030	2035	2040	2045	2050
	€/MWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
Baseline	23.0	15	15	15	15	15	15	15
Baseline	25.6	0	0	0	0	0	0	0
Decarbonised Gas	23.0	15	15	15	15	15	15	15
Decarbonised Gas	25.6	0	0	0	0	0	0	0
High Electrification	23.0	15	245	1,089	1,682	1,682	1,682	1,682
High Electrification	25.6	0	0	0	1,159	2,541	2,541	2,541
Balanced	23.0	15	122	545	841	841	841	841
Balanced	25.6	0	0	0	580	1,270	1,270	1,270
Rapid Progress	23.0	15	15	15	15	15	15	15
Rapid Progress	25.6	0	0	0	0	0	0	0

Glossary

Acronym	Description
AD	Anaerobic digestion
AIMS	Animal Identification and Movement System
COFORD	Council for Forest Research and Development
DAFM	Department of Agriculture, Food and the Marine
DM	Dry matter
EfW	Energy from Waste
GHG	Greenhouse gases
LPIS	Land Parcel Identification System
RDF	Refuse Derived Fuel
MSW	Municipal Solid Waste
WtE	Waste to Energy
CO_2	Carbon dioxide (a greenhouse gas)
N_2O	Nitrous oxide (a greenhouse gas)

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