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epa Research

Towards a Climate-neutral Land Sector by 2050

Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals (SeQUEsTER)

Authors: David Styles, Colm Duffy, Remi Prudhomme, George Bishop, Mary Ryan and Cathal O'Donoghue

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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Knowledge: Providing high quality, targeted and timely environmental data, information and assessment to inform decision making.

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1. Office of Environmental Sustainability
2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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Identifying pressures

Ireland's agriculture, forestry and other land use sector accounts for over 40% of national greenhouse gas emissions. The Climate Action and Low Carbon Development (Amendment) Act 2021 commits Ireland to reaching a legally binding target of net-zero emissions no later than 2050. While there are clear techno-economic pathways towards net-zero emissions within the energy and industrial sectors, there are no such pathways for the agriculture sector, where technical abatement options for emissions of nitrous oxide and methane are limited. Globally, it is assumed that land management will provide a net carbon sink to offset residual emissions from agriculture and other sectors. However, Ireland's land sector is a large net emitter of carbon dioxide (CO2) owing to large areas of drained organic soils and a low afforestation rate relative to the forest harvest rate. There is an urgent need to identify potential agriculture and land use configurations compatible with net zero. The SeQUEsTER project provides new insight into what those future land use mixes could look like.

Informing policy

SeQUEsTER provides new evidence to underpin strategic policymaking across agriculture, the environment and land use. The conclusions are relevant to policymakers, farmers, foresters, agri-food businesses and wider stakeholders in land management and food production. Key policy messages arising from the research include the following:

- Ongoing efforts to deploy ambitious emissions abatement across the agriculture sector are vital; however, the need to curtail milk and beef output cannot be avoided if climate neutrality is to be achieved.
- Delivery of ongoing bog restoration and plans for organic soil rewetting (water table management) will be critical to reducing very large (albeit uncertain) emissions from organic soils.
- The afforestation rate needs to be ramped up to at least 10 times the current rate, and 2.5 times the official policy target, in order to support large-scale milk and beef production within net-zero constraints in 2050.
- There is a need for coordinated policy across sectors to support both supply and demand of bio-based feedstocks for the bioeconomy, in a manner that incentivises positive land use change and diversification.

Developing solutions

SeQUEsTER uniquely applied a backcasting approach to identify what "solutions" to net zero could look like for the agriculture and land sector. This was necessary owing to the scale of the challenge and differs from approaches that extrapolate past trajectories forwards (and inevitably fail to identify net-zero compatible futures). The scale of systems transformations invoked in this modelling work indicate reversals or very steep accelerations in trends in land use and cattle numbers. Addressing this challenge is imperative to ensure the future viability of farms and agri-food exports. Strategic, long-term and cross-sectoral policymaking could realise multifaceted opportunities, linking farm diversification to downstream sectors, including timber engineering, construction, bioenergy and alternative proteins to support a climate-neutral, circular bioeconomy. Above all, this research highlights the need for a mindset shift to explore alternative, sustainable and resilient futures for the food and land sectors. Constructive dialogue across diverse stakeholders and stronger government guidance on the precise definition of "climate neutrality" and "net zero" with regard to non-CO2 emissions will be essential.

EPA RESEARCH PROGRAMME 2021–2030

Towards a Climate-neutral Land Sector by 2050

(2018-CCRP-MS.57)

Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals (SeQUEsTER)

EPA Research Report

Prepared for the Environmental Protection Agency

by

University of Limerick

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This report is based on research carried out/data from 2019 to 2022. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Ireland's agriculture, forestry and other land use (AFOLU) sector accounts for *c*.43% of national inventoried greenhouse gas (GHG) emissions. The Climate Action and Low Carbon Development (Amendment) Act 2021 commits Ireland to reaching a legally binding target of net-zero emissions by 2050, yet emissions from the AFOLU sector continue to increase. The SeQUEsTER (Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals) project generated over 3000 randomised AFOLU configurations for Ireland in 2050, and calculated GHG emissions and removals using a new model validated against Ireland's National Inventory Report. Scenarios were filtered according to various definitions of "climate neutrality", enabling delineation of a climate-neutral AFOLU sector. Despite uncertainty around some GHG fluxes and definitions, sensitivity analyses support robust conclusions. Achieving climate neutrality will require a combination of the following (or variations thereof):

- reducing milk and beef output by 30% (or a more dramatic cut in either milk or beef); further reductions will be required if the below measures are not implemented;
- implementing widespread emissions abatement across farms to reduce the GHG intensity of production by 30%;
- restoring virtually all degraded peatlands;
- raising the water table across thousands of hectares (kha) of organic soils under grassland (actionable area subject to revision in the light of emerging evidence on the extent of effective drainage in organic soils);
- planting at least 500 kha of new forest (avoiding organic soils).

The above is predicated on assumptions that climate policy evolves to reflect the distinctive warming effect of methane as a short-lived climate pollutant and that national methane emissions are reduced to a level compatible with climate stabilisation. In that case, carbon dioxide removal (CDR) will be required to offset residual emissions "only" of long-lived carbon dioxide and nitrous oxide. Alternatively, using current GHG accounting to determine "net zero", over 850 kha of new forest would be needed to also offset methane emissions. Thus, achieving climate neutrality implies afforestation rates of 20–35 kha per annum between 2025 and 2050 (2.5–4.5 times higher than current policy), even assuming agricultural emissions are reduced by 50%. Planting on mineral soils to ensure effective CDR implies competition with other agricultural uses.

Just 14–33% of beef and sheep farms are economically viable, and livestock rearing per se is often loss making, with farms supported by direct payments. Teagasc guidance suggests that forestry can generate higher gross revenue per hectare than cattle or sheep farming. Meanwhile, over 80% of Ireland's milk and beef production is exported, facilitated by effective green marketing and "social licence" for the agri-food sector – notably contingent on the sector operating within ecological limits (currently exceeded). Thus, there is an economic imperative to explore diversification options, safeguarding more efficient food production while ensuring that the next generation inherits viable farms. Barriers to change appear to be mainly social and cultural (outside the scope of this study). Widespread misconceptions regarding the need to dramatically reduce methane emissions and the difference between *maintaining carbon stores* and *creating new carbon sinks* create confusion about what effective climate action looks like. There is an urgent need for an inclusive but robust, fact-based conversation among key stakeholders on realistic pathways towards a genuinely sustainable AFOLU sector. Climate-neutral land use configurations delineated in SeQUEsTER provide a reference.

The magnitude of the forest carbon sink required underlines the urgent need to start ramping up afforestation rates from a low base. Delay will translate into less CDR, and therefore less scope for emission-generating activities (including livestock production) in future. National carbon budgets based on *cumulative* fluxes place further emphasis on prompt action. *Maintaining* climate neutrality post 2050 may require cascading wood value chains to store carbon in wood

products and to supply bioenergy (coupled with carbon capture and storage in future, i.e. permanent CDR). Timber engineering for construction, organic waste biorefineries and grass–clover swards are promising mitigation options. As global demand grows for carbon credits, biomaterials and bioenergy, the government has a crucial role in fostering the development of strategically important bio-based industries in Ireland capable of delivering a climate-neutral and circular economy. Meanwhile, peatland restoration and native woodland planting could deliver biodiversity and water quality co-benefits. A bold, multi-sectoral and long-term plan could ensure a just transition. Strong leadership and strategic vision are required.

1 Introduction

The 2021 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report has left no doubt about the scale of the global climate challenge facing humanity. Every region of the globe is projected to experience concurrent and multiple changes in conditions that will affect societies and ecosystems. Limiting future warming to a specific level will require, at least, reaching "net-zero" carbon dioxide (CO_2) emissions along with "strong, rapid and sustained" reductions in methane (CH_4) and other greenhouse gas (GHG) emissions (IPCC, 2021). The United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement (Erickson and Brase, 2015) emphasises that we must reach peak GHG emissions as quickly as possible, with parties striving to achieve a balance between anthropogenic emissions and removals.

The agriculture, forestry and other land use (AFOLU) sector incorporates both agricultural activities (such as animal husbandry and crop production) and land use, land use change and forestry (LULUCF) activities. Therefore, it contains important GHG sources and sinks, contributing *c.*13–21% of global GHG emissions between 2010 and 2019 (Nabuurs *et al.*, 2022). However, LULUCF is regarded as a major potential CO_2 sink that will be central to any future balance between emissions and removals (IPCC, 2019; Smith *et al.*, 2021). Lóránt and Allen (2019) emphasise the central role that the AFOLU sector will play in reaching climate neutrality through (i) the mitigation of current emission sources, (ii) the reduced emissions intensity of agricultural production linked with increased efficiency, (iii) the production of bio-based products to replace more carbon-intensive products and (iv) carbon sequestration.

The Climate Action and Low Carbon Development (Amendment) Act 2021 commits Ireland to reaching a legally binding target of net-zero emissions no later than 2050. This is a particular challenge for Ireland's AFOLU sector, which sits at the international nexus of livestock production and climate mitigation, and utilises almost 5 million of Ireland's 7.1 million hectares (ha) of available land (Table 1.1). In 2020, agriculture emitted 21 million tonnes (Mt) CO_2 equivalent (CO_2e),

Table 1.1. Summary of GHG emissions or removals and areas related to the main source categories in Ireland's national inventory

	Land use/source	GHG emissions (+) and removals (−) (kt CO_2e)	Area (kha)
LULUCF	Forest land	–2984	779
	HWPs	–819	NA
	Cropland (incl. temporary grass)	–111	743
	Grassland – mineral soils	–2294	3874
	Grassland – organic soils	8445	339
	Wetland	2529	1225
	Settlements and other land	172	151
	LULUCF sub-total (net)	**4938**	
Agriculture	Enteric methane	12,605	
	Manure management	2200	
	Soil nitrous oxide	5760	
	Indirect nitrous oxide	231	
	CO_2 (lime and urea applications)	509	
	Agriculture sub-total	**21,305**	
TOTAL		**26,243**	**7111**

HWP, harvested wood product; NA, not applicable.

or 36% of national GHG emissions (P. Duffy *et al.*, 2022), owing to the large ruminant sector producing beef and milk largely (> 80%) for international export. Somewhat unusually within Europe, Ireland's LULUCF sector is a net source of GHG emissions. This reflects *c.*330,000 ha of drained organic soils emitting approximately 8 Mt CO_2e annually (Table 1.1), compared with a declining forestry sink of approximately 3.7 Mt CO_2 annually, including harvested wood products (HWPs; P. Duffy *et al.*, 2022) from a low share (11%) of land under forest (Table 1.1). In 2020, the entire AFOLU sector made up 43% of the Irish national emissions profile (P. Duffy *et al.*, 2022). CH_4 accounts for *c.*60% of agricultural GHG emissions, and LULUCF emissions of CH_4 could increase if organic soils are rewetted to reduce CO_2 emissions.

The agri-food sector is an important component of Ireland's economy, directly providing over 163,600 jobs and contributing 6% of gross national income and 9% of export value (DAFM, 2020). Irish agricultural output in 2020 equalled €8.8 billion and agri-food exports were valued at €14.2 billion (DAFM, 2020). A highly competitive grass-based spring-calving dairy sector continues to expand in response to market success, despite driving increasing divergence from climate and air and water-quality policy targets. The Climate Action Plan 2023 (Government of Ireland, 2022) sets out a sectoral roadmap designed to deliver a 51% reduction in GHG emissions by 2030 and reach net zero no later than 2050. Simultaneously, Food Vision 2030 (DAFM, 2020) sets out a target for Ireland to have a climate-neutral agri-food sector by 2050, while targeting a further increase in agri-food export values to €21 billion by 2030.

There is an urgent need for independent, holistic modelling to explore whether and how seemingly contradictory environmental and agri-food policies could be reconciled within a modified AFOLU sector. This research report provides an account of such modelling completed in the SeQUEsTER (Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals) project.

2 The GOBLIN Land–Emissions Model

2.1 Introduction

This chapter summarises a detailed model description available in *Geoscientific Model Development* (C. Duffy *et al.*, 2022a). Given the increasing divergence of Ireland's AFOLU sector from climate targets, pathways to climate neutrality cannot be objectively identified through extrapolation of recent trajectories, invoking the need for a backcasting approach to first establish what a climate-neutral AFOLU sector *could* look like. Backcasting is a complementary approach to scenario development that starts with the definition of a desired future state, which then determines various pathways that will achieve that future state (Gordon, 2015; Brunner *et al.*, 2016). The SeQUEsTER team developed a new biophysical model capable of generating random scenarios for Ireland's AFOLU sector. GOBLIN (General Overview for a Backcasting approach of Livestock INtensification) integrates key parameters that influence agricultural production, GHG fluxes, ammonia (NH_3) emissions and nutrient losses to water using a methodology aligned with Ireland's UNFCCC reporting. The model is designed to be run repeatedly with randomly varied, biophysically compatible, combinations of parameter inputs in order to identify specific combinations of agricultural production and land use that achieve climate neutrality by the target year. This means that identified climate-neutral scenarios are not limited or biased by *a priori* constraints with respect to "feasibility" or "plausibility".

2.2 Model Overview

2.2.1 Scope

GOBLIN accounts for the main AFOLU sources and sinks (Figure 2.1) reported in national inventory

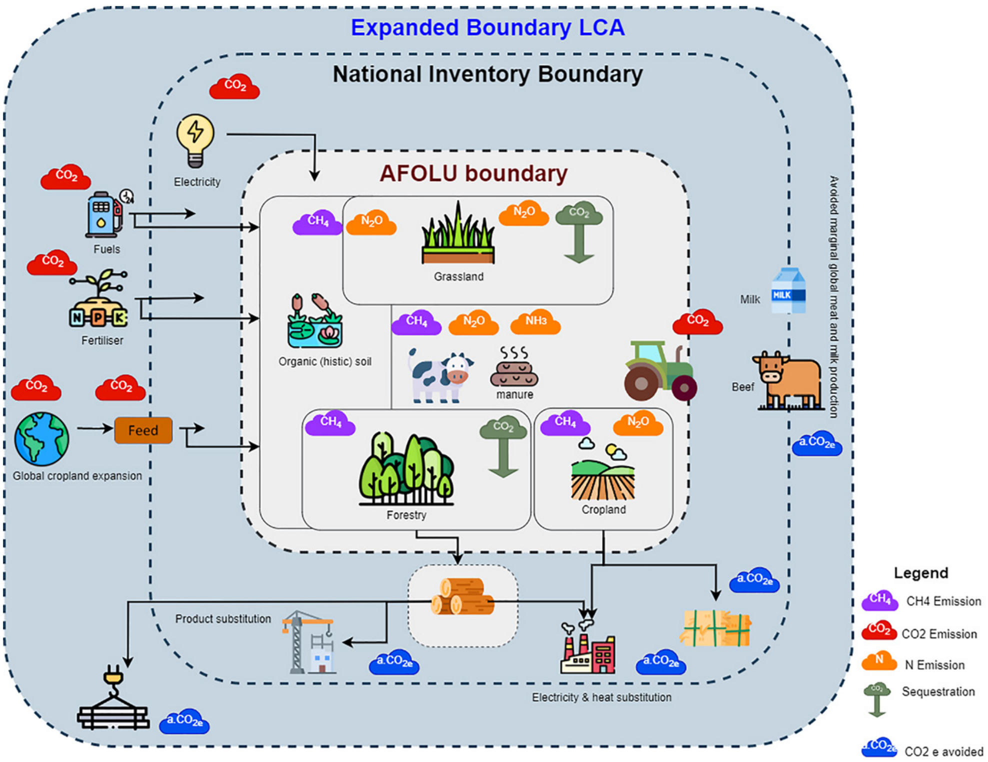

Figure 2.1. Key emission sources and sinks critical to the determination of "climate neutrality" in Ireland's AFOLU sector accounted for in GOBLIN (white), alongside linked upstream and downstream sources and sinks to be included in subsequent life-cycle assessment modelling to determine wider climate mitigation efficacy. LCA, life-cycle assessment.

reporting, including CO_2 fluxes to and from (organic) soils and forestry; CH_4 emissions from enteric fermentation, manure management, wetlands and other sources; and direct and indirect losses of nitrogen (N) from animal housing, manure management and fertiliser application in the form of nitrous oxide (N_2O), NH_3 and dissolved forms (e.g. nitrate, NO_3) (P. Duffy *et al*., 2022). A primary aim of the model is to ensure consistency of scenarios in terms of land use (e.g. within available areas for grazing and carbon sequestration), associated agricultural production potential within land constraints (related to key production efficiency parameters) and associated GHG fluxes. The scenarios can be filtered to identify which ones comply with climate neutrality based on different definitions and metrics, e.g. (i) net-zero GHG balance based on GWP_{100} (warming effect of emitted GHGs integrated over a 100-year period; IPCC, 2014); (ii) no additional warming based on GWP* (warming effect of emitted GHGs through time considering the distinct dynamics of CH_4 as a short-lived climate pollutant (SLCP); Allen *et al*., 2018; Lynch *et al*., 2020); and (iii) compliance with specific global CH_4 targets downscaled from integrated assessment models, combined with a GWP_{100} balance across CO_2 and N_2O fluxes. Climate neutrality can be determined at one point in time (e.g. 2050) and/or as a time-integrated outcome over the second half of the century, as per the Paris Agreement (Erickson and Brase, 2015).

A key feature of GOBLIN is its relation of complex interactions across livestock production, grassland management and emissions offsetting within the AFOLU sector to a few simple input parameters used to define a plethora of possible scenarios. Primary input data to initialise the model are (i) national herd sizes (derived from milking cow and suckler cow numbers); (ii) average animal-level productivity (e.g. milk yield per cow) to determine feed energy intake; (iii) fertiliser application rates; (iv) grass utilisation rates to determine stocking densities and production outputs; and (v) proportions of any spared grassland (relative to the baseline year) going to alternative land uses. In version 1.0 (v1.0), alternative land uses are limited to fallow, commercial or conservation forestry and rewetting of drained organic soils (bioenergy cropping and anaerobic digestion can be readily integrated for coupling with downstream energy models). Activity data and emission coefficients are largely based on those used in Ireland's National Inventory Report (NIR) (P. Duffy *et al*., 2022), which are, in turn, based on the IPCC (2006, 2019) good practice guidelines for national GHG reporting at tier 1 level for soil emissions, tier 2 level for animal emissions and tier 3 level for forestry carbon dynamics.

2.2.2 Model structure

GOBLIN incorporates seven modules (Table 2.1 and Figure 2.2) partially derived from previous models from McEniry *et al*. (2013), Jones *et al*. (2014), Styles *et al*. (2018) and C. Duffy *et al*. (2022a) (Figure 2.2).

The scenario generation module (1) varies the key input parameters utilised in the sub-modules. The cattle and sheep livestock herd module (2) computes the size of the national cattle herd and ewe flock from milking and suckler cow numbers and upland and lowland ewe numbers (input parameters) based on coefficients derived from the average national composition (Donnellan *et al*., 2018). The grassland module (3) computes the energy (feed) requirements of each animal cohort within the national herd, fertiliser application and, subsequently, the area of grassland needed (depending on concentrate feed inputs, fertiliser application rates and grass utilisation rate) and the grassland area freed for extensification or for other purposes ("spared grassland"). Emissions related to livestock production are computed in the livestock module (4) and rely on inputs from the cattle herd (2) and grassland (3) modules based on a tier 2 IPCC approach (IPCC, 2019; P. Duffy *et al*., 2022). Once the grass and concentrate feed demand has been calculated using the herd and grassland modules, the land use module (5) computes the remaining emissions from land uses related to forests, croplands, wetlands and other land. The remaining LULUCF categories related to forests are captured in the forest module (6) and are utilised by the land use module (5). The scenario generation module provides the proportion of spared grassland to be converted to each alternative land use (forestry, rewetting, etc.) (Figure 2.3).

An HWP module takes harvestable biomass outputs from the forest module-related tree cohorts (species, yield class and age profile) and management practices and applies the relevant HWP carbon storage decay functions to calculate downstream carbon storage

Table 2.1. Summary of module functions within GOBLIN

Module	Function	Details
Scenario	Generation of randomised scenario parameters	Sample input variables from predefined maximum ranges (technical potential) with a Latin hypercube algorithm to build each of the scenarios
Herd	Generation of dairy, cattle, and upland and lowland sheep national herd/flock numbers	Utilises herd/flock coefficient data derived from Donnellan *et al.* (2018) to create the national herd number, which is based on milking and suckler cow numbers and ewe numbers (from the scenario module)
Grassland	Calculation of the grassland area required for livestock production and calculation of nutrient applications to grassland area	Utilises IPCC (2006) guideline tier 2 functionality to calculate grassland area required based on the (i) nutritional requirements of the national herd (equation 2.1); (ii) organic N returns to soil; and (iii) average fertiliser application rates, linked with a fertiliser response curve for grass productivity Deduces the spared grassland available for extensification or for other purposes (Equation 2.1)
Livestock	Calculation of agricultural emissions and nutritional requirements related to livestock production	Algorithms for emissions of CH_4, N_2O, NH_3 and CO_2 to air based on IPCC (2006, 2019) methodologies Includes tier 2 functionality for the estimation of the nutritional requirements of livestock
Land use	Calculation of emissions and removals related to land use and land use change (excluding forests)	Algorithms for emissions of CH_4, N_2O, NH_3 and CO_2 to air based on IPCC (2006, 2019) methodologies Land use calculations relate to croplands, wetlands and grasslands
Forestry	Calculation of emissions and removals related to existing forests and afforestation	Calculation of forest sequestration based on IPCC (2006, 2019) methodologies and C. Duffy *et al.* (2022a). Past sequestration is estimated as well as projected future sequestration. Other emissions associated with management of soils under forestry are also calculated here
GOBLIN	Coordination and integration of the programme modules and production of final results	Management module utilising tools and functions from previous modules to produce the final results

and CO_2 emissions. The sequential resolution of these modules allows for an accurate representation of biophysically resolved land use combinations in terms of land areas, production (meat, milk, crops and forestry) and GHG fluxes.

2.3 Model Validation

Validation of emission and removal calculations for livestock production and land use (change) were carried out utilising activity data supplied by the Central Statistics Office (CSO). These activity data were also input into the NIR (with some minor differences relating to derived variables for simulation purposes) so that GOBLIN was calibrated to closely match the NIR time series of emissions and removals using historic input data. GOBLIN outputs from 1990 to 2015 were compared with NIR outputs over the same time period using Common Reporting Format files dating back to 1990. Figure 2.4 illustrates the validation of GOBLIN's replication of NIR flux accounting across major emissions and removals sources.

Beginning with land use and land use change (Figure 2.4), the solid lines represent CO_2, CH_4 and N_2O emissions modelled in GOBLIN, while the dashed lines represent equivalent emissions reported in the NIR. Absolute emission levels and trends calculated by GOBLIN very closely match those of the NIR, with the most notable deviation arising for forest sequestration (representing the complex tier 3 modelling of fluxes, which is sensitive to compound estimates of stand

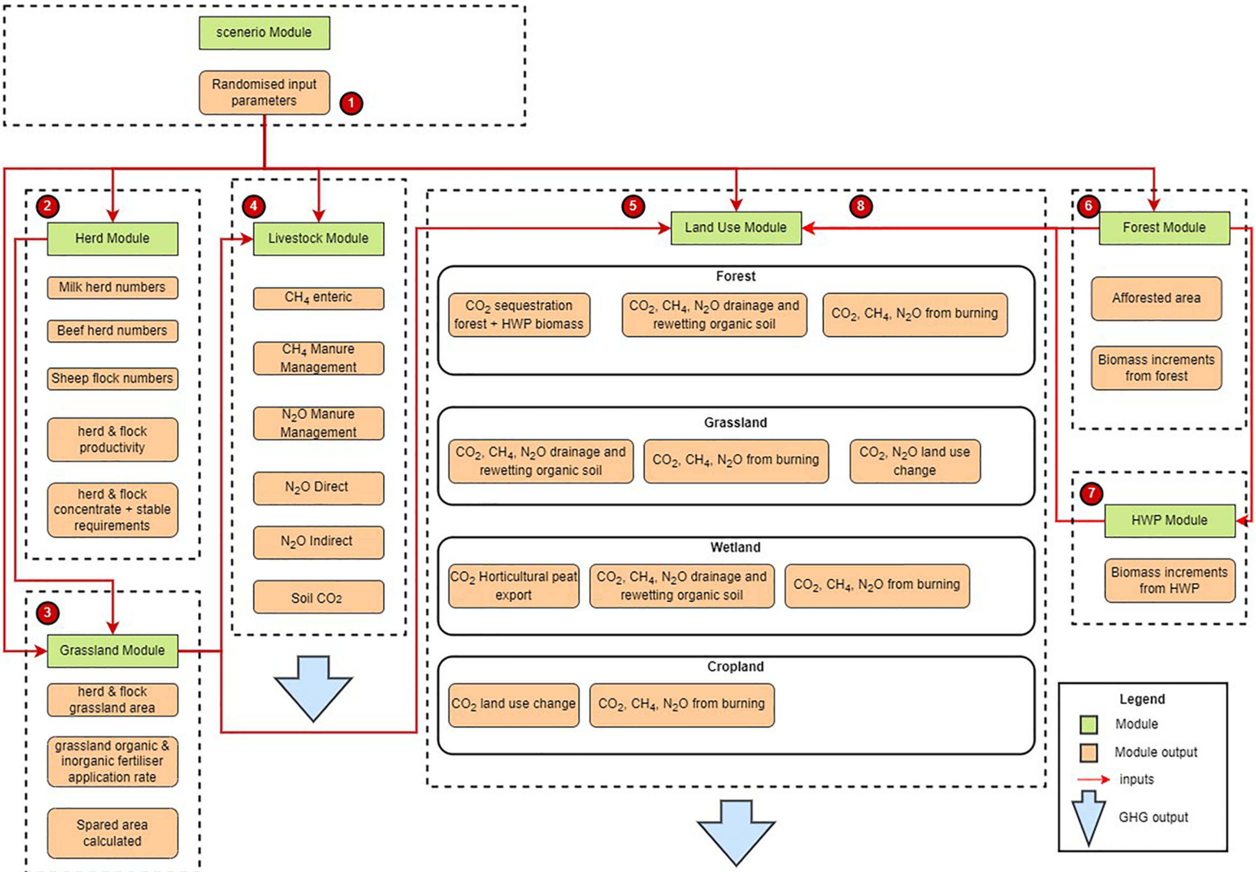

Figure 2.2. GOBLIN data flow diagram. Arrows represent data flow. Modules are represented by green boxes and processes are represented by brown boxes.

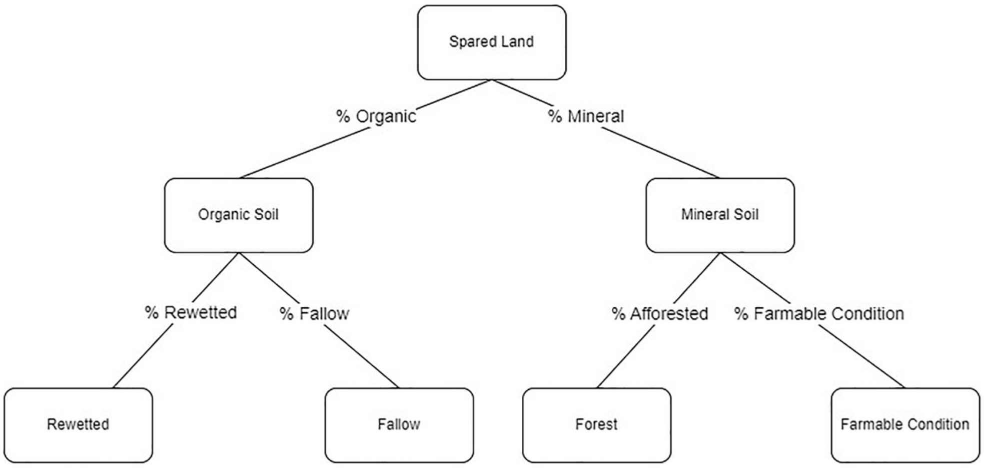

Figure 2.3. Allocation of spared land across different primary uses.

age profiles across hundreds of land parcels). Figure 2.4 shows validation of agricultural emission sources. Enteric and manure management CH_4 from GOBLIN and the NIR are almost identical, while CO_2 and N_2O emissions levels and trends are very similar. This validation specifically indicates that emission factors, land area calculations, forest volume increments and harvest removals, and animal feed intake calculations derived from raw input data are in line with NIR methodology, thus providing confidence in scenario extrapolations based on variations in these input data.

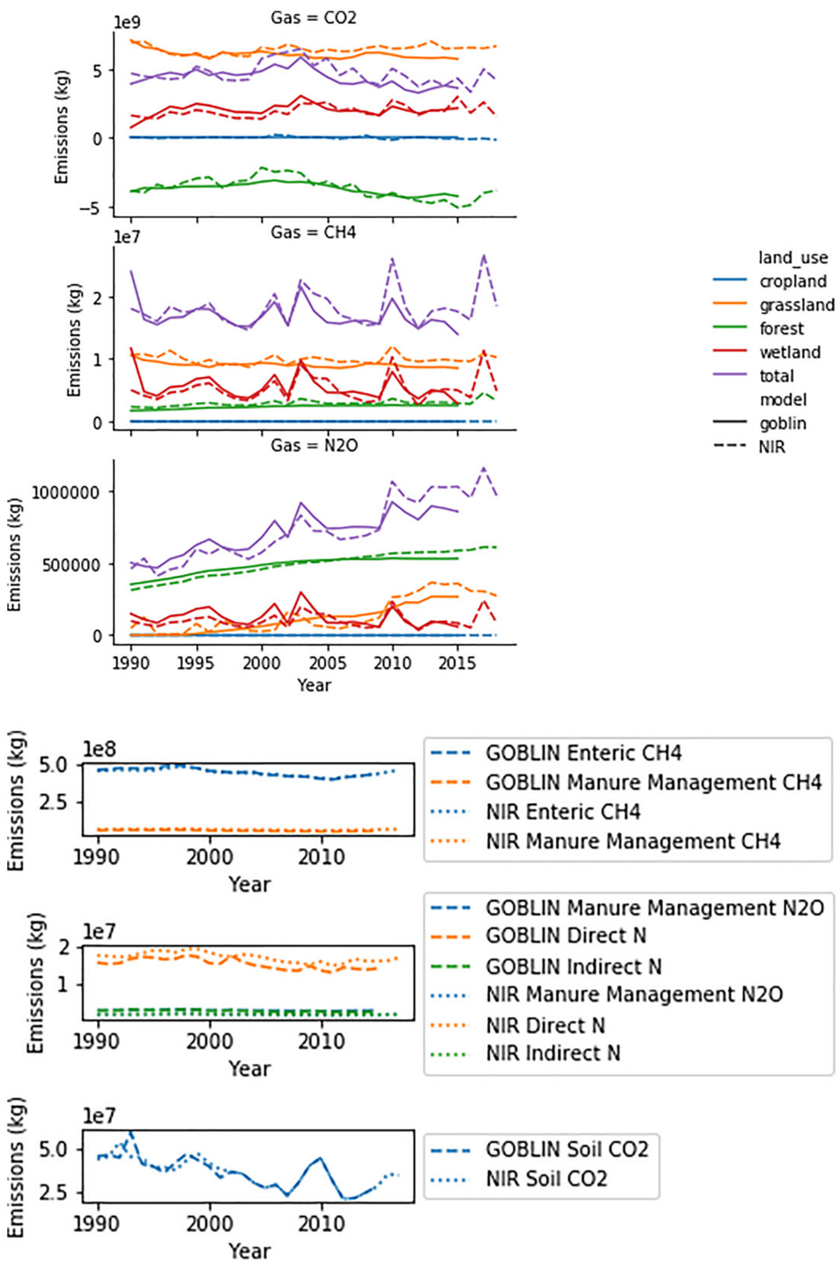

Figure 2.4. Comparison of land use (top) and agricultural (bottom) GHG fluxes computed by GOBLIN with those reported in the NIR, derived from the same activity data from 1990 to 2015.

2.4 Model Limitations and Development Priorities

GOBLIN examines the rewetting of drained organic soils and forestry as the primary mechanisms of emissions mitigation and offset within Ireland's LULUCF sector, thus reflecting the "main levers" that can be pulled to achieve climate neutrality. GOBLIN can be adapted and coupled with downstream energy emissions models to explicitly represent bioenergy diversification (Figure 2.1), or with cascading value chain models for wood use potentially culminating in bioenergy carbon capture and storage (BECCS) that could transform forestry CO_2 sequestration into potentially permanent offsets (Forster *et al.*, 2021). Cropland areas are kept constant, reflecting the minor role of crop production in Ireland's current agri-food system and GHG emission profile. Nonetheless, with minor developments GOBLIN could model consequences of changes in cropping areas to reflect a potential increase in demand for plant-based proteins (Tilman and Clark, 2014). Finally, while GOBLIN has been extensively validated against the NIR for current management practices, components such as fertiliser response curves for grass productivity could be altered by new grass varieties or mixed grass–clover swards or updated to be more spatially explicit in relation to soil and land categorisations (O'Donovan *et al*., 2021). There is potential to adapt this (and other) components of GOBLIN to represent specific mitigation options.

The main value of GOBLIN is the ability to decouple the generation of plausible, coherent scenarios from preconceptions of what pathways to climate neutrality could look like through randomisation and filtering (backcasting). Although such modelling on its own cannot provide all the answers, it does cut through to the "big picture" and establishes biophysically plausible targets for stakeholders to engage with.

2.5 Code Availability

The exact version of the model used to produce the results used in this report is archived on Zenodo (C. Duffy *et al*., 2021) and is freely available for download.

3 Randomised Land Configurations for Net-zero Emissions (GWP_{100})

3.1 Introduction

The detailed results from this chapter are published in *Nature Sustainability* (C. Duffy *et al.*, 2022b). Headline results are presented here. The objective of this chapter is to elaborate and interpret independently generated scenarios depicting AFOLU scenarios that achieve net-zero GHG emissions at 2050. The activity inputs to GOBLIN were randomly varied utilising a Latin hypercube model (McKay *et al.*, 2000) between predefined floor and ceiling values (Table 3.1) to generate 850 scenarios. Randomised scenarios were then classified as (i) failed to meet neutrality (N-Z-Fail), with a net flux > 2.5 teragram (Tg) CO_2e; (ii) achieved AFOLU neutrality (N-Z-AFOLU), with a net flux ≤ 2.5 Tg CO_2e, ≥ −2.5 Tg CO_2e; and (iii) contributed to national neutrality (N-Z-National), with a net flux ≤ −2.5 Tg CO_2e. The national neutrality scenarios were those that exceed AFOLU neutrality by a margin sufficient to offset 5–10% of non-AFOLU national emissions in 2020 (P. Duffy *et al.*, 2022), i.e. capable of balancing out a plausible level of residual emissions from energy-related activities in a decarbonised future economy.

3.2 Results

A total of 666, 146 and 38 scenarios were classified as N-Z-Fail, N-Z-AFOLU and N-Z-National, respectively. Kruskal–Wallis testing showed significant differences across groups for dairy, beef and lowland sheep populations; areas of total spared land (grassland area that no longer supports livestock) and forested land (land converted to forest); and proportions of forest classed as conifer and land rewetting. Dunn's post-hoc analysis indicated highly significant differences in dairy animal numbers across all three categories (Figure 3.1). The average reduction in the dairy and beef herds, for N-Z-AFOLU and N-Z-National respectively, was 42% (confidence interval (CI) 40–44%) and 52% (CI 50–54%) for dairy, and 38% (CI 36–41%) and 44% (CI 40–47%) for beef. Furthermore, there were significant differences regarding total spared area, additional forest area and wetland area between N-Z-Fail and the successful N-Z groups at the 1% level. Finally, the proportion of rewetted drained wetland was significantly different between N-Z-Fail and N-Z-National (1% level) and between N-Z-AFOLU and N-Z-National (5% level).

Among the most notable observations between the three scenario groups are the differences in animal population numbers (Figure 3.1), with both net-zero groups requiring a significant reduction in the size of dairy and beef herds. The resulting reductions leave a significant area of "spared land" (Figure 3.1). This allows for additional afforestation in the AFOLU and national neutral scenarios. Wetland area (organic grassland area rewetted) is constrained by the total area of organic soil under grass, and, therefore, the total area classified as wetland is similar between the groups.

The scenario input data were averaged by group to generate average characteristics (Figure 3.1) for each of the scenario groups (N-Z-Fail, N-Z-AFOLU and N-Z-National). The averaged characteristics were then used to generate three scenarios representing N-Z-Fail, N-Z-AFOLU and N-Z-National. Across the three categories, and relative to the baseline year, CH_4 emissions from enteric fermentation and manure management were, on average, reduced by 37% and 38%, respectively. N_2O emissions relating to manure management and other direct and indirect sources were reduced by 37%, 43% and 41%, respectively. Lastly, CO_2 emissions related to fertiliser application were reduced by 48%.

Afforestation inputs were "front-loaded" up to 2050 across scenarios, with no additional land being afforested after this point, resulting in a "carbon cliff" between 2080 and 2090, and again in *c.*2115, across each of the three scenario groups when large areas of forest planted up to 2050 are harvested (Figure 3.2). However, large increments in HWP carbon storage arising from harvests during this period avoid forestry becoming a (temporary) net source of emissions at any point. As a consequence of the declining forestry sink through time, out of the 850 scenarios generated,

Table 3.1. Definitions of key model inputs and scenario value boundary ranges

Parameter category	Definition	Baseline (2015) values		Scenario value range	
				Minimum	Maximum
Livestock population	Milking cow/suckler cow numbers	Milking cow	1,268,000	507,200	1,268,000
		Suckler cow	1,065,000	426,000	1,065,000
	Sheep numbers	Lowland ewe	1,960,000	784,000	1,960,000
		Upland ewe	490,000	196,000	490,000
Productivity	Milk output $head^{-1}$	Milk output	13.8 kg day^{-1} $year^{-1}$	13.8 kg day^{-1} $year^{-1}$	15.9 kg day^{-1} $year^{-1}$
	Beef output $head^{-1}$	Heifer weight (1 year)	275 kg $head^{-1}$	275 kg $head^{-1}$	322 kg $head^{-1}$
		Heifer weight (2 year)	430 kg $head^{-1}$	430 kg $head^{-1}$	504 kg $head^{-1}$
Grassland area	Area of grassland required to support national herd	4.07 Mha		Deduced	
Cropland area	Area under crop	361.6 kha		Static	
Drained wetland area	Area of organic soil drained grazing utilisation	287 kha		20%	100%
Wetland area	Area of wetland utilised for grazing	1226 kha		0%	20%
Grassland utilisation	The proportion of grass production consumed by livestock via grazing and feeding on conserved grasses (silage and hay)	57%		57%	73%
Afforested area	The proportion of grassland area on mineral soils spared from livestock utilised for forest	NA		20–80% of spared mineral soil area	
Proportion broadleaf	Proportion of forest area that is under broadleaf (vs conifer)	20% (existing forest)		30–70% (new forest)	
Proportion conifer	Proportion of forest area that is under conifer (vs broadleaf)	80% (existing forest)		30–70% (new forest)	
Proportion conifer harvested	Proportion of conifer area that is harvested	90% (existing forest)		50–90% (new forest)	
Proportion of conifer thinned	The proportion of harvested conifer area that is thinned	50% (existing forest)		50% (new forest)	

NA, not applicable.

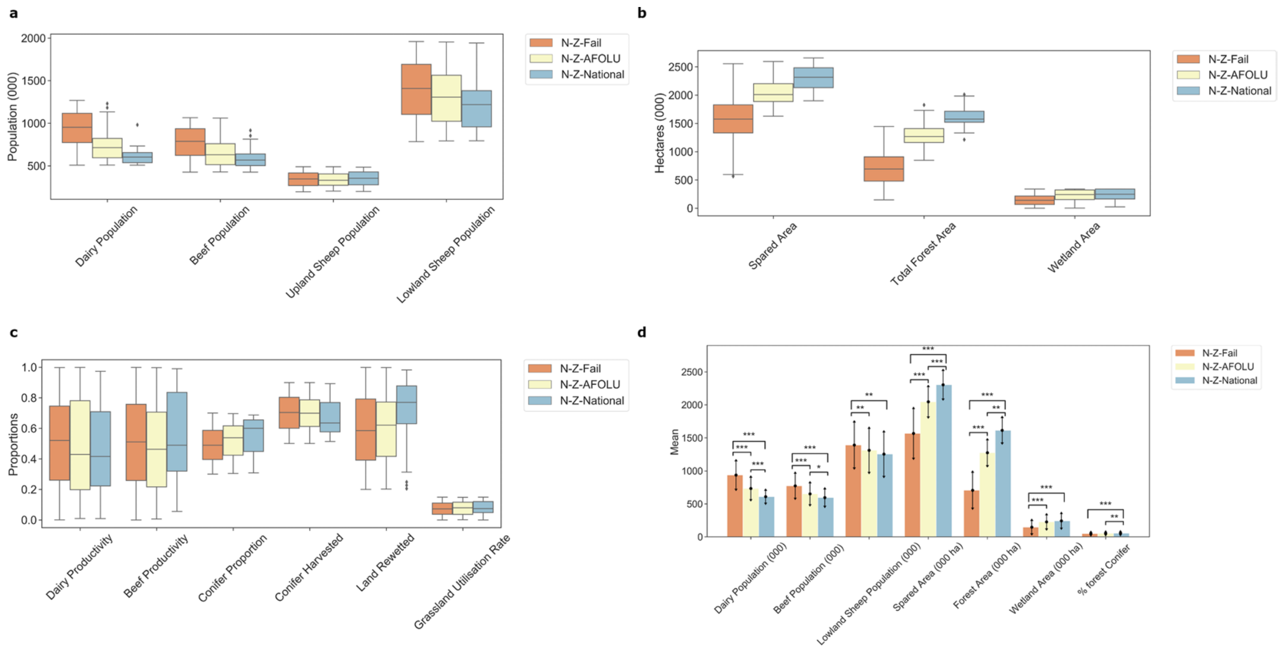

Figure 3.1. (a) Variation and spread of animal population input parameters. (b) Total spared, forest and wetland area outputs. (c) Proportional input parameters related to livestock productivity, forestry, rewetting and grassland utilisation. (d) Significant differences between specific groups from a Dunn's post-hoc analysis. ***Statistically significant at the 1% level; **statistically significant at the 5% level; *statistically significant at the 10% level. The standard deviation is represented by vertical black lines.

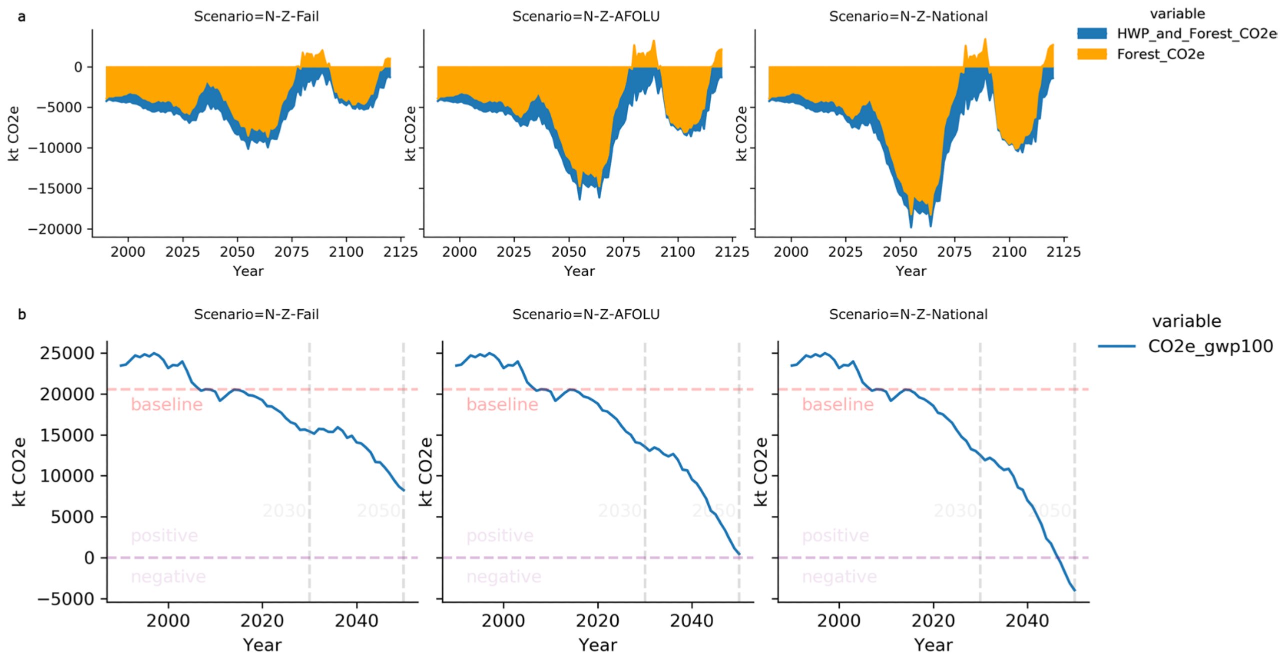

Figure 3.2. CO_2 removals from biomass growth and net carbon storage increment in HWPs, displayed from 1990 through to 2120 (a), and net CO_2e emissions and removals to 2050 (b). Removals for the 2015 baseline year are indicated.

a total of 40 scenarios sustained climate neutrality. The majority of these scenarios were in the N-Z-National category (80%). However, only one N-Z-National scenario continued to contribute to national-level neutrality beyond 2100. The remaining 20% of scenarios sustaining carbon neutrality were from the N-Z-AFOLU category.

The achievement of climate neutrality incurs a significant trade-off in relation to national agricultural output (C. Duffy *et al*., 2022b). The highest milk-producing scenario(s) within the N-Z-AFOLU group achieved over 87% of 2015 production, but simultaneously just 21% of 2015 beef production. The maximum beef production in the N-Z-AFOLU group was just 49% of 2015 production, with milk production equivalent to 58% of the 2015 level in the same scenario(s). Investigation of the maximum milk and beef production in the N-Z-National group shows a maximum value of 66% of 2015 production for milk coupled with 20% of 2015 national beef production. Maximum beef production on the other hand is 41% of 2015 production, coupled with milk production at 43% for the same scenario(s).

The N-Z-AFOLU and N-Z-National scenarios are associated with much larger areas of land use change, driven by higher rates of afforestation and relatively smaller shares of spared grassland maintained in a "farmable condition". Here, we define a farmable condition as the removal of animals from the land, with land maintained under current grassland use (i.e. no land use change arising). The mean proportion of spared area kept in a farmable condition was, on average, *c*.27% and *c*.19% lower for N-Z-AFOLU and N-Z-National scenarios, respectively, than for the N-Z-Failed scenarios. Average areas of rewetted grassland are comparatively smaller, constrained by drained organic soils representing less than 10% of grassland area in the baseline. However, the rewetting of previously drained organic soils under grassland results in average emissions reductions of 0.5, 5.2 and 5.5 Tg CO_2e for the N-Z-Failed, N-Z-AFOLU and N-Z-National scenarios, respectively.

3.3 Discussion

3.3.1 Main findings

The key differences between scenarios that achieve net-zero GHG emissions and those that do not are animal numbers and how the remaining (non-farmed) land area is utilised. Larger reductions in animal numbers lead to more spared land for other activities. However, it is active utilisation of this spared land for CO_2 removal (CDR) that is critical to achieve net zero. Afforestation stands out as the most important driver in achieving the net-zero balance, being the primary scalable and near-term option for CDR (C. Duffy *et al*., 2022a). Afforestation removals for the N-Z-AFOLU and N-Z-National scenarios are, on average, 73% and 114% greater, respectively, than those for the N-Z-Failed scenario. Removing animals without an ambitious CDR strategy will result in a much higher penalty on national herd numbers and, ultimately, on animal protein production.

Given the cyclical nature of forestry, it is important to account for the HWP flows resulting from forest outputs when calculating emissions balances. These flows offset the "carbon cliff" that would otherwise result in net emissions. Recent research by Forster *et al.* (2021) highlights that, via a supply of wood into an expanding future bioeconomy, commercial afforestation is a highly effective option for long-term climate mitigation – through HWP carbon storage, the displacement of GHG-intensive products and, potentially, permanent biogenic CO_2 storage following energy generation in future bioenergy carbon capture and storage systems. The specific tree species (or functional types) that constitute future afforestation efforts are contentious and debated. Forster *et al.* (2021) demonstrate that the fast-growing species utilised in commercial forestry support much greater climate mitigation than slow-growing semi-natural species over a 100-year time horizon. However, that does not mean that biodiversity has to be sacrificed. The average proportions of conifers planted in N-Z-AFOLU and N-Z-National scenarios are 52% and 55%, respectively, thus implying considerable scope for the establishment of more biodiverse native woodlands within net-zero constraints.

Though a significant number of scenarios did achieve net-zero GHG emissions by 2050, few scenarios were able to maintain this balance through to the end of this century. In the race to net-zero GHG emissions by 2050, it is important to factor in the sustainability of the emissions balance, in particular the longevity of carbon sinks. This will require not just high levels of ambition across stakeholder groups, but also coherent inter-sectoral policymaking informed by horizon scanning (Prudhomme *et al.*, 2021).

3.3.2 Further model and scenario development

Though GOBLIN represents a significant step forwards in terms of holistic modelling of future land use scenarios compatible with national climate neutrality targets (C. Duffy *et al.*, 2022b), future research and development is expected to realise significant emissions abatement for livestock production (Eory *et al.*, 2021). For example, the utilisation of 3-nitrooxypropanol could substantially reduce CH_4 emissions from enteric fermentation (Van Wesemael *et al.*, 2019), while the use of protected urea fertilisers and enhanced biological nitrogen fixation via clover in grasslands could significantly reduce N_2O emissions (DAFM, 2018; Lanigan *et al.*, 2019). Furthermore, the incorporation of beneficial land management practices such as inversion tillage of grassland soils (Madigan *et al.*, 2022), although not a “game changer”, will give a more nuanced indication of the scale of land use change necessary in the Irish AFOLU sector. Scenarios that develop additional circularity within the AFOLU sector should also be explored. For example, the use of biochar in agriculture has been extensively studied in recent years (Kalus *et al.*, 2019), with potential uses as a soil amendment, manure additive and feed additive for livestock. The use of forest and agriculture residues as feedstock for biochar has the potential to reduce fertiliser application, soil leaching and GHG emissions while promoting healthier soils and livestock (Kalus *et al.*, 2019; Palansooriya *et al.*, 2019). Alternative forest management also has considerable potential to change medium-term terrestrial fluxes (Black *et al.*, 2022). As GOBLIN is developed to include additional country contexts, the abatement potential of practices more suited to areas with a greater focus on crop, as opposed to livestock, production will be necessary. Practices such as zero or minimum tillage and agro-forestry have potentially wide applications (Uprety *et al.*, 2017). Further work is needed to define plausible upper bounds for abatement and productivity factors, and how AFOLU management for climate neutrality could create price signals affecting food supply and demand. Given the spate of 2050 targets that have been announced by countries and companies alike, the generation of randomised, biophysically resolved combinations of land sector activities is an important step towards improved clarity and context for currently vague climate neutrality plans. Such modelling should help to explore expected environmental and economic outcomes in relation to adequacy and fairness (Rogelj *et al.*, 2021).

3.4 Conclusion

This chapter has shown that large reductions in animal numbers combined with ambitious afforestation are necessary to achieve net-zero GHG emissions by 2050. There are several important messages for policymakers. Active management of land spared from livestock production for CDR (primarily via new forestry) is crucial, and achieving net-zero GHG emissions will require careful reallocation of spared land (i.e. an integrated national land use plan (Department of the Taoiseach, 2021)). Without careful planning to maintain emission sinks beyond 2050, the achievement of net-zero GHG emissions may be fleeting. To sustain an emissions balance beyond 2050, future pathways will require greater ambition in terms of land use change, as well as careful planning in terms of HWP utilisation (i.e. parallel development of appropriate bio-based industries and bioenergy infrastructure linked with carbon capture capability).

3.5 Code Availability

The exact version of the model used to produce the results used in this paper is archived on Zenodo (C. Duffy *et al.*, 2021) and freely available for download.

4 National Methane Targets Compatible with 1.5°C

4.1 Introduction

This chapter summarises key outputs from a paper and extensive supplementary information published in *Journal of Environmental Management* (Prudhomme *et al.*, 2021). The paper by Prudhomme *et al.* (2021) addresses how biogenic CH_4 could be treated distinctly in climate targets, acknowledging that mitigation of fugitive CH_4 emissions from fossil fuel extraction and use should be prioritised for immediate action.

Most national climate plans are based on aggregation of the principal GHGs – CH_4, N_2O and CO_2 – using the 100-year average global warming potentials (GWP_{100}) recommended for national inventory reporting (UNFCCC, 2014). Recent modelling has demonstrated that short-lived GHGs such as CH_4 (*c*.20-year atmospheric half-life) behave more like flow pollutants, while long-lived GHGs such CO_2 and N_2O act more as stock pollutants, in terms of their climate-forcing effects (Allen *et al.*, 2018). This results in overestimations of long-term climate forcing being attributed to current CH_4 emissions under the GWP_{100} metric, and the GWP* aggregation metric has been proposed to better represent cumulative climate forcing of different emissions through time (Allen *et al.*, 2018; Cain, 2019). Global climate modelling indicates that biogenic CH_4 reductions of 24–47%, relative to 2010, are sufficient to achieve climate stabilisation at a global mean surface temperature of 1.5°C above pre-industrial times (Rogelj *et al.*, 2018).

According to the GWP* method (Allen *et al.*, 2018; Cain *et al.*, 2019), the *future* climate-forcing effect of emissions depends on the recent *change* in CH_4 emissions (usually over a 20-year period). This representation is more consistent with climate modelling used to determine pathways towards climate stabilisation at the global scale (IPCC, 2018), and could be used to more accurately determine the contribution of national CH_4 emissions, at given fluxes of CO_2 and N_2O, to climate neutrality. However, when applied at a national scale, it involves the "grand-parenting"[1] of national CH_4 emissions, which has pronounced implications for how the global CH_4 budget is apportioned, and that may be challenged in terms of international fairness (Rogelj and Schleussner, 2019). New Zealand's climate neutrality policy is not directly based on GWP*, but aims to reduce biogenic CH_4 emissions by 24–47% between 2017 and 2050 (Ministry for the Environment, 2019). There is no internationally agreed method to establish separate targets for CH_4 in national climate plans. The aim of this chapter is to elucidate trade-offs and complementarities among different approaches to establish national biogenic CH_4 targets in terms of specific possible measures of international equity, national food security and national climate targets. To do this, implications of different national biogenic CH_4 targets, compatible with global climate stabilisation for national CH_4-emitting food production (milk, eggs, meat, rice) and national agriculture and land use GWP balances, are explored across four contrasting countries (Brazil, France, India and Ireland).

Finally, climate plans do not exist in isolation of other policy objectives and societal priorities. There is a challenge to reduce global CH_4 emissions while increasing the production of nutritious food by 82–149% by 2050, compared with 2010, in order to deliver food security (Huppmann *et al.*, 2019). Biogenic CH_4 emissions are largely associated with the production of nutritious (high-quality protein) food (Key and Tallard, 2012). Some might argue that tackling global malnutrition could be threatened by the introduction of quotas on ruminant production (Adesogan *et al.*, 2020), while rice, the only CH_4-emitting crop, represents a primary source of energy for 3.5 billion people who depend on it for more than 20% of their daily calories (Maclean *et al.*, 2013). The amount of livestock and rice production compatible with climate neutrality will depend not just on CH_4 but also on other GHG emissions associated with such production (especially N_2O) and also land requirements that influence areas available for emissions offsetting via afforestation or

1 "Grand-parenting" refers to the inferred allocation of emission "allowances" at the level of a baseline year.

other CDR options (IPCC, 2019). Therefore, there is an urgent need to understand the implications of different approaches to establishing separate biogenic CH_4 targets for, inter alia, food security and AFOLU climate neutrality objectives at a national scale.

The primary objective of this chapter is to provide new insights into linkages between different value judgements, national biogenic CH_4 targets compatible with global climate stabilisation, food security and national climate neutrality objectives.

4.2 Methodology (Short Summary)

Readers are directed to Prudhomme *et al.* (2021) for full methodological details. In essence, national biogenic CH_4 targets for Brazil, France, India and Ireland compatible with the 1.5°C scenario are derived by scaling down global targets (Huppmann *et al*., 2019) using different allocation rules. The four selected country examples provide a diverse spread of AFOLU and socio-economic contexts. The impacts on agricultural production, other AFOLU emissions and land-based carbon sequestration potential are then quantified to elucidate the wider climate and food security implications of how global biogenic CH_4 emissions targets are allocated. The methodology comprises six steps, and a core series of nine equations that are detailed subsequently (Figure 4.1).

1. The allocation of national CH_4 quotas according to different rules.
2. The influence of different CH_4 quotas on production.
3. The influence of different levels of production on land use.
4. The influence of different national CH_4 quotas on AFOLU CO_2 emissions.

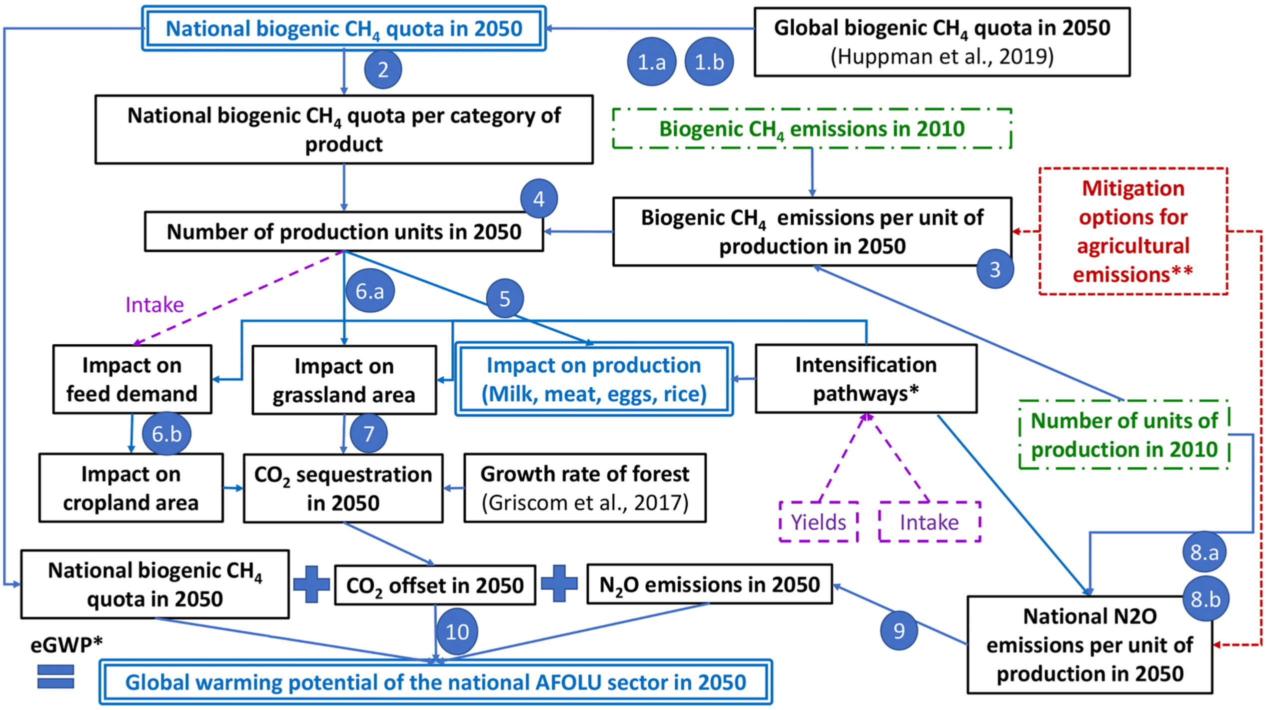

Figure 4.1. Overview of the methodology used in this study. Data used to compute purple (dashed box) elements are taken from the Global Livestock Environment Assessment Model – interactive (GLEAM-i) database (FAO, 2022). Data used to compute green elements (long–short dashed box) are taken from FAOSTAT (FAOSTAT, 2015). Data used to compute red elements are taken from national abatement cost curves presented in Eory *et al.* (2017) (short dashed box). Numbers in the schematic represent the equations presented in the following method. Blue boxes (double line boxes) represent the major outputs from this study. eGWP* data taken from Rogelj and Scleussnner (2019). *Production and emission intensities are detailed in table 1 of Prudhomme *et al.* (2021). **Mitigation potentials are detailed in table S9 of Prudhomme *et al.* (2021).

5. The influence of different national CH_4 quotas on AFOLU N_2O emissions.
6. The influence of all the above on the aggregate GWP balance for national AFOLU sectors, calculated using GWP_{100} and an adapted equity GWP* (eGWP*) approach (Rogelj and Schleussner, 2019). This adaptation of GWP* replaces contemporaneous national emissions of CH_4 as the reference for calculating future warming effects with a modified reference level of CH_4 emissions based on some definition of a national "fair share" of global emissions.

4.3 Key Results

4.3.1 *National biogenic CH_4 quotas and production*

To comply with global emission scenarios compatible with climate stabilisation, national biogenic CH_4 emissions would need to be reduced by 11–81% for Brazil, 28–80% for France, 26–59% for India and 30–79% for Ireland, depending on the allocation rule (Table 4.1). The choice of allocation rule has a greater influence on the national CH_4 quota than the choice of global scenario compatible with 1.5°C of warming, with the quota for Ireland varying by a factor of more than 6 depending on the allocation method (Table 4.1). Based on the inverse gross domestic product (GDP) effort, the smallest *relative* reduction on 2010 emissions (11%) is seen for Brazil, reflecting high baseline emissions per US$GDP, while the largest required reduction in both absolute and relative terms (80%) is seen for France. In fact, because GDP allocation represents national shares of global emission reduction (rather than remaining budgets), France's CH_4 quota has a zero lower bound for many scenarios with GDP allocation (Figure 4.1). Population-based allocations require reductions in 2010 biogenic CH_4 emissions of 81% and 79% for Brazil and Ireland, respectively, reflecting high emissions from production for export of beef and milk from those countries. However, protein-based allocation results in a smaller required reduction (31%) for France than for Brazil or Ireland, because a high share of protein production in France comes from pigs and poultry, which are less CH_4 intensive than cattle. Finally, of the four studied countries, only India could not expand current production to fill all its 2050 CH_4 quota, owing to a high assumed level of CH_4 mitigation potential for rice and constraints on the area of land into which future rice production could expand. This resulted in non-used quotas of 0.9 to 4.4 Mt CH_4 in 2050 (Table 4.1).

4.3.2 *Climate efficacy and food security associations*

Dividing all national scenarios into quartiles reflective of their climate mitigation potential provides additional insight into associations between climate mitigation

Table 4.1. National biogenic CH_4 targets for 2050 across Brazil, France, India and Ireland based on four different allocation approaches to share the global biogenic CH_4 budget compatible with climate stabilisation (right), with percentage reductions from national 2010 emissions shown in brackets. Also shown are reference 2010 CH_4 emissions

Country	Reference emissions in 2010 (Mt CH_4)	2050 targets (Mt CH_4)				Non-used biogenic CH_4 quota 2050 (Mt CH_4)			
		GDP	Grand-parenting	Population	Protein	GDP	Grand-parenting	Population	Protein
Brazil	13.5	11.9 (–11%)	9.1 (–33%)	2.6 (–81%)	3.6 (–73%)	NA	NA	NA	NA
France	1.8	0.4 (–80%)	1.2 (–33%)	0.9 (–28%)	1.2 (–31%)	NA	NA	NA	NA
India	19.4	13.9 (–28%)	10.3 (–47%)	12.3 (–26%)	8.0 (–59%)	4.4	2.7	3.9	0.9
Ireland	0.6	0.4 (–30%)	0.4 (–35%)	0.06 (–79%)	0.2 (–58%)	NA	NA	NA	NA

GDP, gross domestic product; NA, not applicable.

efficacy and food security, within and across countries, in the context of eGWP* accounting for climate forcing (Table 4.2). CO_2 offset is strongly inversely associated with GWP quartile rankings – more negative GWP balances are associated with higher CO_2 offsets. Meanwhile, the biogenic CH_4 quota is positively associated with rankings. These associations, in particular involving CH_4, break down somewhat for India, reflecting the dynamics of mainly land-constrained (rather than CH_4-constrained) food production in India. Notably, India's third quartile is associated with a larger median CH_4 quota, but higher CO_2 offsets, than the second quartile, and a high share of "base" production efficiency – the lower production efficiency increases CH_4 emission per hectare utilised and means that land requirements for production could be constrained by CH_4 in some scenarios, as for the other countries. Across all countries, median CO_2 offsets vary more markedly than median CH_4 quotas, implying a dominant role of offsetting in determining GWP balances, but also showing that offsetting is typically inversely linked with CH_4 quotas via land requirements for "allowable" food production.

Production of CH_4-intensive foods increases strongly with quartile ranking. National protein production is just over three (India) to six (Ireland) times higher in the fourth quartile than the first quartile. For most countries, median protein production exceeds national population requirements in the upper quartiles, with the notable exception of India, where the fourth quartile food production is just short of meeting the needs of the current population of 1.35 billion people. AFOLU climate neutrality for India lies somewhere between the first and second quartiles (between negative and positive median eGWP* values in Table 4.2). Only the first quartile is compatible with climate neutrality at the national level for India, supporting $<30\%$ of national protein requirements. Protein security for France lies between the third and fourth quartiles, neither of which complies with climate neutrality at the national level. Ireland and Brazil can achieve national protein security alongside climate neutrality.

4.4 Discussion

4.4.1 Fairness of national methane reduction targets

In the light of recent criticism of representation of CH_4 warming through time by the GWP_{100} aggregation metric (Allen *et al*., 2018; Cain *et al*., 2019), as used to report national GHG emissions and to define national net-zero GHG targets (UK CCC, 2019), this study explored the implications of different approaches to determine separate national targets for biogenic CH_4 – with a particular focus on national food production and climate neutrality objectives for 2050 and beyond. Emitting GHGs to the atmosphere is not a basic need per se. Discussions of fairness in GHG mitigation burden-sharing therefore invoke the question of "allowances" to nations and to individuals (Caney, 2009; Arnold, 2011). In this study, this principle of distributive justice is elucidated by considering biogenic CH_4 emission quotas alongside food production and CO_2 offset potential within the AFOLU sector. For example, large reductions in Ireland's CH_4 emissions may be ethically desirable in terms of international CH_4 quotas but could lead to a 90% reduction in livestock production that, via export, feeds millions of people living in other countries, and could lead to the unemployment of many Irish farmers. Conversely, a hypothetical Indian government desire to achieve territorial climate neutrality would lead to a decline in rice production that could undermine national food security while "over-shooting" national biogenic CH_4 targets based on the principles of equity. There is an urgent need for international and cross-sectoral negotiation on burden sharing for CH_4 reduction that considers ethics alongside, inter alia, food production and CO_2 offset obligations (which ultimately will need to compensate for ongoing emissions in other sectors) (McMullin *et al.*, 2020).

4.4.2 Climate policy implications

Either using GWP* or establishing a national biogenic CH_4 reduction target directly in line with the global 24–47% reduction required for climate stabilisation to set climate neutrality targets in industrialised countries (Ministry for the Environment, 2019) involves emission "grand-parenting" at a national level. This could deny developing countries an opportunity to expand livestock production and is thus likely to be challenged internationally on grounds of equity (Rogelj and Schleussner, 2019). Therefore, it is difficult to envisage how the separate treatment of biogenic CH_4 in national climate policies can be removed from issues around the equitable sharing of global biogenic CH_4 budgets (and mitigation burdens). It would be naive to expect international agreement on a harmonised approach to determine national CH_4 "quotas" as fixed climate

Table 4.2. Median results for key metrics relevant to GHG mitigation and food security within quartiles of AFOLU global warming potential balance according to the eGWP* method, across all scenarios – based on all 1.5°C scenarios from Huppmann *et al*. (2019) multiplied by all allocation rules and all food production pathways (base case, marginal abatement cost curve mitigation and sustainable intensification). Food security metrics represent total calories and protein within rice and animal products produced within CH_4 quotas for each scenario, divided by per capita recommended daily intakes

		GHG			Food		Pathway			Allocation rule			
Country	Quartile	AFOLU balance (with eGWP*) in Mt CO_2e	CO_2 offset (Mt CO_2)	CH_4 emissions (Mt CH_4)	Persons fed in energy (million head)	Persons fed in protein (million head)	% scenario with base	% scenario with 2050 marginal abatement cost curve	% scenario with 2050 sustainable intensification	% scenario with GDP	% scenario with grand-parenting	% scenario with population	% scenario with protein
Brazil	First	–2917	3077	2.2	22.6	56.1	33.3	27.1	39.6	0	14.7	62.5	22.8
	Second	–2472	2776	3.6	34.3	85.5	31.4	36.3	32.4	0	14.7	34.6	50.7
	Third	–1679	1466	8.9	82.6	204.5	32.7	33.7	33.7	11.8	58.8	2.9	26.5
	Fourth	233	443	12	126.1	298.4	35.7	35.7	28.6	88.2	11.8	0	0
France	First	–631	184	0	0	0	34.3	34.3	31.4	95.6	4.4	0	0
	Second	–76	76	0.9	10.4	39.6	38.5	30.8	30.8	1.5	66.9	25	6.6
	Third	17	74	0.9	11.8	48.2	35.3	33.3	31.4	2.9	14.7	52.2	30.1
	Fourth	111	5	1.3	18.6	73.5	25	35	40	0	14	22.8	63.2
India	First	–316	549	9	361.9	383.6	80	9.3	10.7	0	56.6	7.4	36
	Second	761	–270	10.4	938	923.1	28.3	34.9	36.8	2.2	40.4	29.4	27.9
	Third	1444	5	17.7	709.7	778.8	41.2	27.8	30.9	47.8	2.9	24.3	25
	Fourth	2352	–1658	9.7	1254	1279	4.6	50	45.4	50	0	39	11
Ireland	First	–40	44	0.1	0.4	1.5	33	33	34	5.9	35.3	58.8	0
	Second	–31	31	0.2	1.2	4.4	35	32	33	19.9	30.1	41.2	8.8
	Third	–14	16	0.3	2	7.1	34.7	33.7	31.7	43.4	15.4	0	41.2
	Fourth	6	9	0.3	2.6	9.3	30.8	34.6	34.6	30.9	19.1	0	50

targets in the near future, not least because of the wide range of global budgets from which to allocate these quotas depending on climate stabilisation pathways and modelling choices (Huppmann *et al*., 2019). We do not recommend a specific approach to setting biogenic CH_4 targets, but recommend open discussions on how this could be done in a robust and internationally fair manner – we provide an open-source modelling tool (https://github.com/prudhomme-nuig/methane) in the hope of stimulating the necessary debate.

4.5 Conclusion

Short-lived GHGs such as CH_4 behave more like flow pollutants than stock pollutants in terms of their climate-warming effects. Recent modelling indicates that climate stabilisation requires biogenic CH_4 reductions of 24–47% globally, and GWP* has been proposed as an alternative GHG aggregation metric that better represents the climate-forcing effects of CH_4 through time than the GWP_{100} metric currently used for national GHG reporting. However, the application of GWP* to determine national GHG budgets compatible with climate stabilisation implies grand-parenting of CH_4 emissions, which may be perceived as unfair to countries with low baseline emissions. Separate treatment of biogenic CH_4 in climate policies will therefore necessitate consideration of how global biogenic CH_4 budgets, compatible with climate stabilisation, can be translated into national climate policy targets.

This chapter explored the effects of alternative approaches to set national biogenic CH_4 targets on food production and an ability to achieve net zero GHG emissions (GWP_{100} metric) or climate stabilisation (eGWP* metric) within national AFOLU sectors, using four contrasting countries as examples: Brazil, France, India and Ireland. National biogenic CH_4 budgets were derived by downscaling global budgets defined for 1.5°C scenarios based on allocation rules representing the principle of equity (emissions proportionate to population), ability to reduce emissions (mitigation proportionate to GDP) and protein security (emissions proportionate to protein production in 2010), alongside a grand-parenting approach for reference. Choice of allocation method was shown to have a profound effect on the level of "allowable" ruminant production in milk- and beef-exporting countries, such as Brazil and Ireland. Nonetheless, owing to relatively low population densities, AFOLU sectors in these countries have a high level of potential to achieve climate neutrality if spared land is used for forestry. Meanwhile, countries such as India have constrained land areas to fill their CH_4 quota with CH_4-emitting food production (milk, meat, eggs, rice), and may not be able to achieve climate neutrality targets while maintaining food (protein and calorie) security. Our results illustrate the need for more detailed coordination of international GHG mitigation efforts in order to achieve climate stabilisation, with a particular focus on how global biogenic CH_4 budgets can be equitably allocated. Such coordination will require consideration of food security and land banks available for offsetting activities.

5 Defining National “Climate Neutrality”

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5.1 Introduction

Separate accounting for CH_4 to reflect its particular role as an SLCP implies a non-zero target for this gas, which may be reflected in separate CH_4 targets (Chapter 4 and Prudhomme *et al*., 2021) or alternative metrics (e.g. GWP*) that integrate the effects of SLCP with long-lived CO_2 and N_2O gases (Cain *et al*., 2019). In addition, recent research has shown that the time-horizon considered for climate neutrality has a major influence on the extent of land use change required (Chapter 3 and C. Duffy *et al*., 2022b). Despite these important uncertainties, there has been little research published on how different possible definitions of climate neutrality could influence agricultural and land use policies at the national scale. This chapter provides new evidence on the consequences of applying various contemporary definitions of “climate neutrality” for prospective climate-neutral configurations of Ireland’s AFOLU sector. The implications for sustainable levels of milk and beef production (with and without further ambitious GHG abatement measures), and land use transformation, are explored.

5.2 Methodology

5.2.1 Scenarios

A total of 3000 randomised scenarios were generated using a Latin hypercube model (McKay *et al*., 2000) by randomly varying the key input parameters, utilised in the GOBLIN model, between set minimum and maximum values for each individual scenario (Table 5.1). Total animal numbers were set between one and values reported for 2021 (CSO, 2022), with grassland utilisation rates calibrated at between 67% and 80% productivity, based on calculated grass uptake and total grassland area utilised by the updated national herd and flock numbers. Further details on GOBLIN input parameters can also be found in C. Duffy *et al*. (2022a). It is important to note that the target year for AFOLU configurations is 2050; no further changes to agricultural production or land use are considered after 2050. Emissions beyond 2050 thus represent this new “equilibrium” land use, incorporating forestry (re)growth and harvest cycles.

5.2.2 Climate neutrality definitions

Ten different definitions for net-zero GHG emissions linked with climate neutrality were explored (Figure 5.1). These definitions included achieving net-zero CO_2 (only) emissions by 2050 (IPCC, 2022); net-zero GHG emissions (CO_2, CH_4 and N_2O) based on GWP_{100} (IPCC, 2014) – either for the year 2050 only or cumulatively between 2050 and 2100; separate specific “fair” CH_4 targets proposed by Prudhomme *et al*., (2021) in addition to GWP_{100} net-zero emissions from N_2O and CO_2 by 2050; no net warming effect by 2050 or 2100 based on GWP* (Smith *et al*., 2021); or no net warming by 2050 based on GWP* with a modified “fair” reference level of CH_4 emissions (eGWP*) (Rogelj and Schleussner, 2019). Each of the 3000 scenarios was classified as succeeding (S-Neut) or failing (F-Neut) to meet climate neutrality according to each of the definitions.

5.2.3 Abatement

It is possible for climate neutrality targets to be met not just through specific configurations of agricultural production and land use but also through the reduction of agricultural emissions at source following the implementation of abatement measures. Important abatement measures include reducing N fertiliser application (including via grass–clover pastures), applying abated-urea fertilisers, improving animal genetics, low-emission storage and spreading techniques for manures, acidification of manures, and using CH_4 and nitrification inhibitors (O’Brien *et al*., 2014; Lanigan *et al*., 2019). The GOBLIN model randomly accounts for animal productivity

Table 5.1. Input scenario value ranges for selected key parameters required for the GOBLIN model

Parameter	Definition	Scenario value range	
		Minimum	Maximum
Livestock population	Milking cow numbers	1	1,604,500
	Suckler cow numbers	1	940,300
	Lowland ewe numbers	1	2,252,320
	Upland ewe numbers	1	563,080
Productivity	Milk output head^{-1}	13.8 kg	15.9 kg
	Heifer weight head^{-1} (1 year)	276 kg	322 kg
	Heifer weight head^{-1} (2 years)	431 kg	504 kg
Grassland area	Area of grassland to support national herd and flock	Deduced	
Cropland area	Area under crop	361.6 kha	
New wetland area	Area of available drained organic soil to be rewetted	20%	100%
Grassland utilisation	The proportion of grass production consumed by livestock via grazing and feeding on conserved grasses (silage and hay)	67%	80%
New afforested area	The proportion of spared grassland area on mineral soils that will be utilised for forest	20%	80%
Proportion broadleaf	Proportion of forest area that is under broadleaf (vs conifer)	30%	70%
Proportion conifer	Proportion of forest area that is under conifer (vs broadleaf)	30%	70%
Proportion conifer harvested	Proportion of conifer area that is harvested	50%	90%
Proportion conifer thinned	The proportion of harvested conifer area that is thinned	50%	

improvements of up to 15–20%. In addition to this, a 30% *post hoc* reduction in agriculture emissions was uniformly applied across enteric and manure CH_4 and manure, direct and indirect N_2O emissions, reflecting the upper end of abatement possible with identified technologies (Lanigan *et al*., 2019; Rees *et al*., 2020). Abated scenarios allow for a conservative approach with respect to the final conclusions, and thus are our default assumption. Each of the 3000 abated scenarios was classified as succeeding (S-Neut-A) or failing (F-Neut-A) to meet climate neutrality with abatement, according to each of the definitions.

5.3 Results

The definitions that saw most scenarios succeed in achieving climate neutrality were (Table 5.2) carbon neutrality, with 99% of scenarios attaining neutrality; GWP*, with 82% and 85% of non-abated and abated scenarios, respectively, accomplishing neutrality; CH_4 target grand-parenting, where 58% and 85% of non-abated and abated scenarios, respectively, reached neutrality; and eGWP* protein, where 61% and 84% of non-abated and abated scenarios, respectively, succeeded in neutrality. Conversely, the lowest counts of climate neutrality were for CH_4 target population (1% and 3% of non-abated and abated scenarios, respectively, achieved neutrality), GWP_{100} long-term balanced 2050–2100 (18% and 27% of non-abated and abated scenarios, respectively, succeeded in neutrality), and eGWP* population (26% and 39% of non-abated and abated scenarios, respectively, accomplished neutrality).

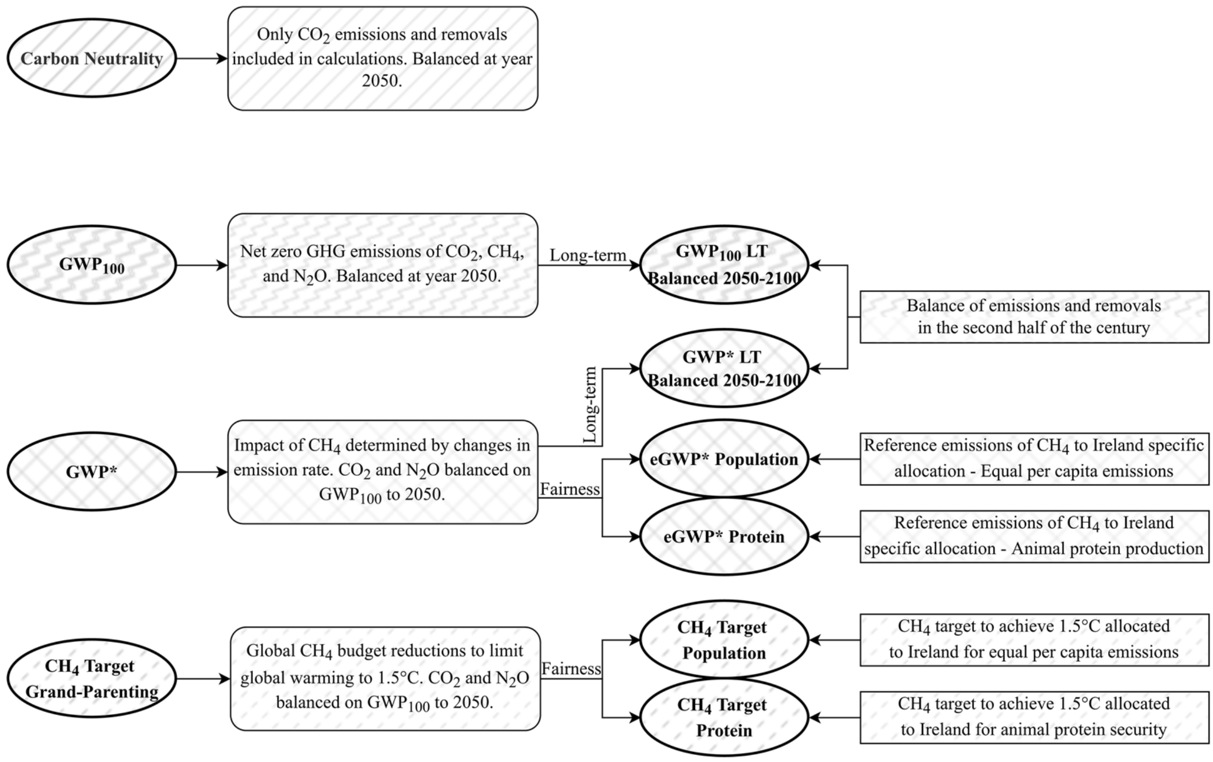


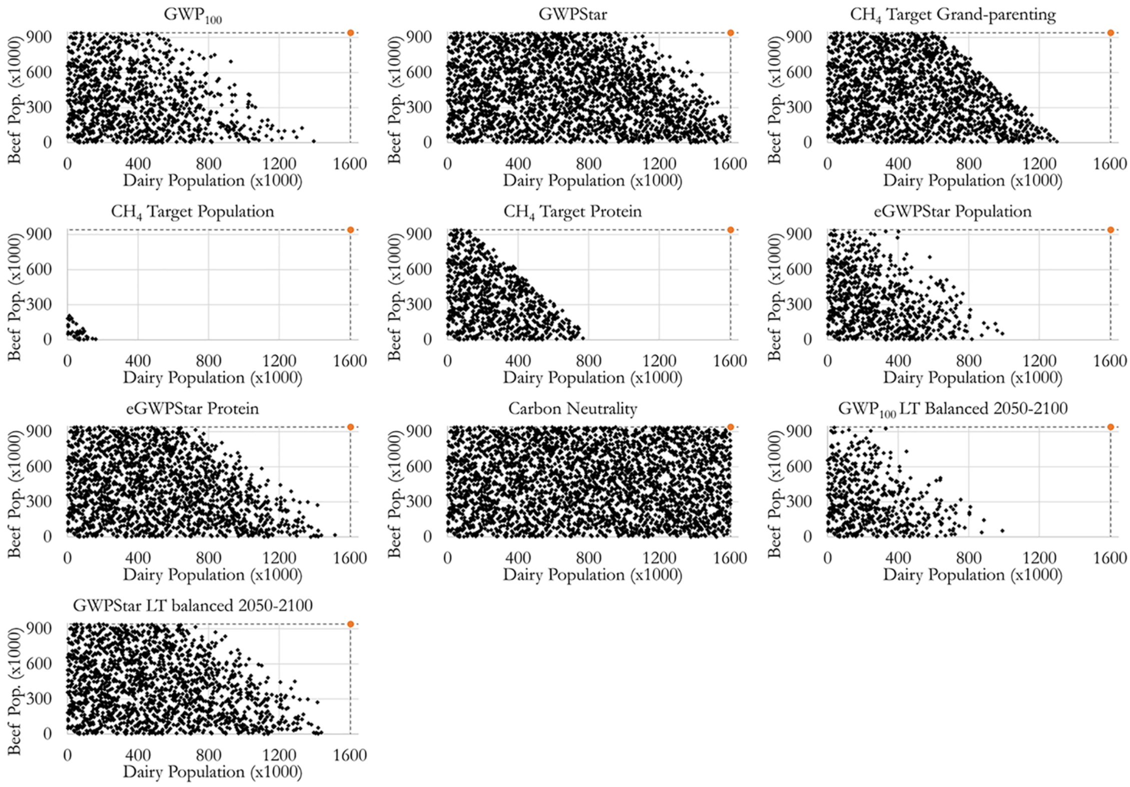
Figure 5.1. Definitions of climate neutrality explored. Ovals represent definitions. Definitions on the right are derivations from the four definitions on the left. LT, long term; grand-parenting, each country achieves the same percentage of CH_4 emission reduction as the global CH_4 emission reduction target.

Table 5.2. Total number (out of 3000) of scenarios that achieved climate neutrality according to each of the definitions explored. S-Neut and S-Neut-A: scenarios that succeeded in achieving neutrality without and with ambitious agricultural abatement, respectively

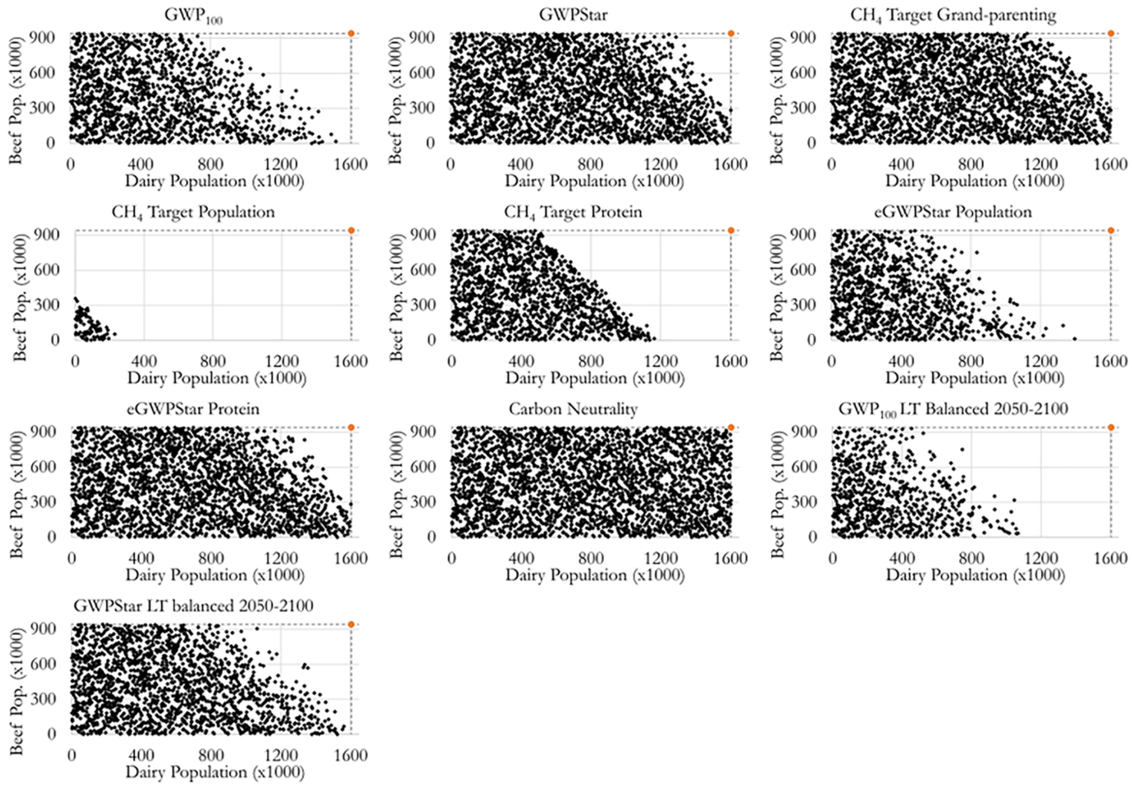
	Total count	
Metrics	S-Neut	S-Neut-A
GWP_{100}	1102	1513
GWP*	2464	2547
CH_4 target grand-parenting	1744	2560
CH_4 target population	35	92
CH_4 target protein	856	1505
eGWP* population	770	1172
eGWP* protein	1816	2511
Carbon neutrality	2969	2969
GWP_{100} LT balanced 2050–2100	551	805
GWP* LT balanced 2050–2100	1684	1891

LT, long term.

Overall, the successful scenarios had considerably larger areas of new forestry and wetlands, but lower quantities of milk and beef output. The median new forest areas for S-Neut were between 1100 and 2300 kha across the 10 definitions, whereas the median range for new forest area of F-Neut was between 300 and 1100 kha. The minimum new forestry area required to achieve S-Neut and S-Neut-A was lowest for the carbon neutrality definition and highest for the CH_4 target population and GWP_{100} long-term balanced 2050–2100 definitions. Milk and/or beef outputs declined relative to 2021 levels across all climate-neutral scenarios, even with ambitious abatement. It was difficult for the definitions to preserve 2021 dairy cow populations, with the scenarios that modelled high numbers of dairy cows needing to have large reductions in suckler cow numbers to achieve climate neutrality (Figure 5.2). Even with abatement measures, it was not possible for any of the S-Neut-A scenarios to achieve 2021 population levels for both adult suckler beef and



(a)



(b)

Figure 5.2. The relationship between adult dairy cow and suckler beef population for the 3000 non-abated (a) and abated (b) scenarios, which succeeded in their neutrality definitions (S-Neut-A) within each definition of climate neutrality. The dashed lines and orange point represent the animal numbers for the year 2021. (×1000), *x*- and *y*-axis values are multiplied by 1000; LT, long term; pop., population.

dairy cow numbers for any definition except carbon neutrality across the 3000 scenarios (Figure 5.2).

Dairy cow populations were significantly reduced to achieve neutrality within CH_4 target population and protein, eGWP* population and GWP_{100} LT balanced 2050–2100 definitions. Without optimistic abatement measures, only carbon neutrality and GWP* definitions allowed for the 2021 dairy cow population to be maintained, though with large reductions in the numbers of suckler cows. Milk output among S-Neut scenarios followed the dairy cow population patterns in Figure 5.2. Higher levels of milk output were generally associated with smaller areas of new forest among S-Neut scenarios, reflecting smaller areas of land spared from cattle at higher milk outputs. However, the spread of new forest area narrows in an upwards trend towards the highest milk yields for most definitions (especially GWP_{100}), reflecting minimum new forest areas needed to offset higher emissions from milk production (data not shown here). Milk production is more profitable for farmers than beef or sheep production. Taking the scenario that best reflects the 95th percentile of maximum milk output for S-Neut-A for each definition of neutrality, 2050 (and beyond) "sustainable" land use looks very different to 2021 land use (Figure 5.3).

Meanwhile, prioritising milk output in these scenarios requires large (7–92%) reductions in suckler beef output and, to a lesser degree, sheep populations (3–97% reductions) (Table 5.3). Although the levels of change were greatly influenced by the application of the different neutrality definitions, all the definitions

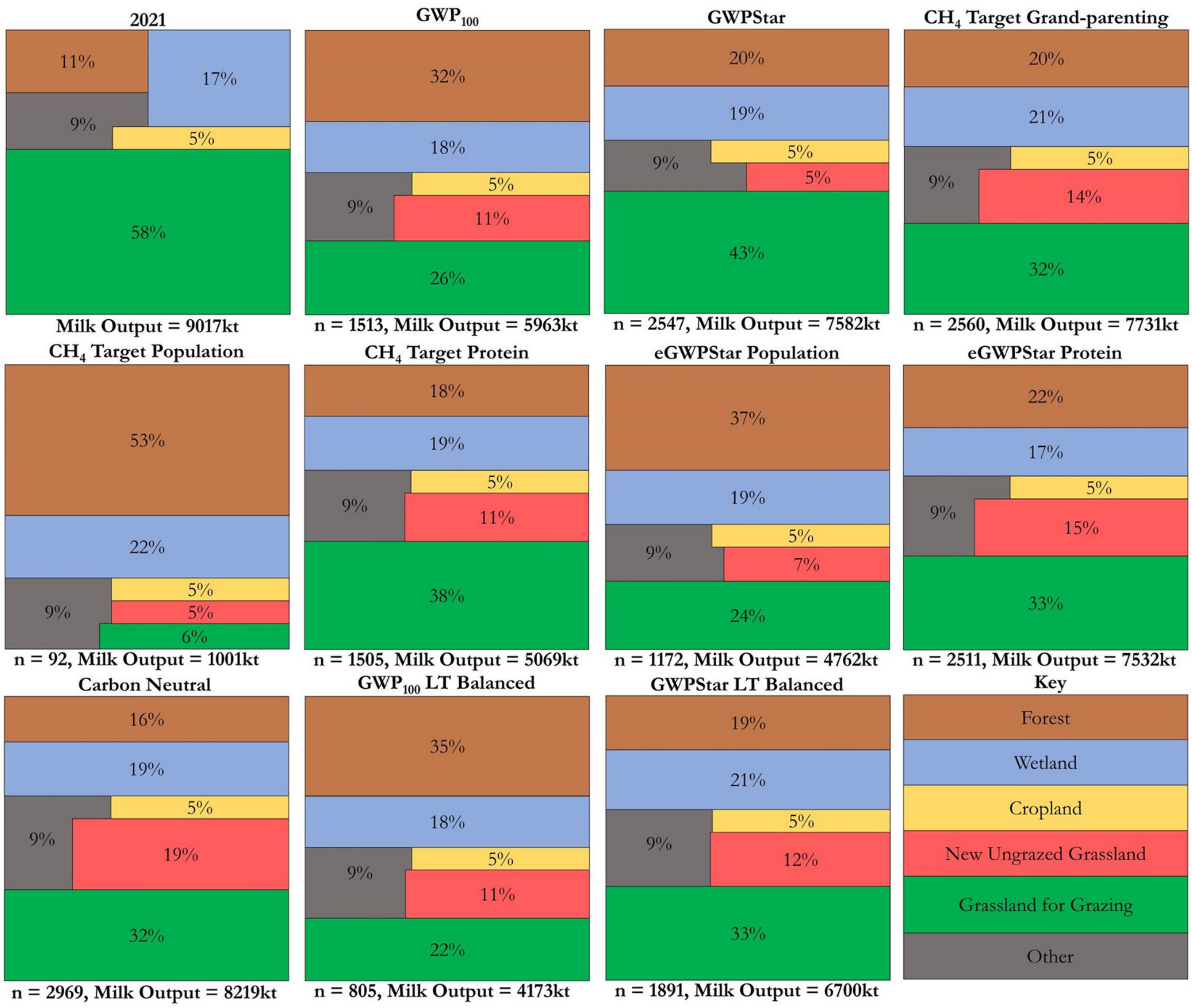


Figure 5.3. Land use configurations for the 95th percentile scenario of (maximum) milk output from the abated scenarios that succeeded in achieving neutrality (S-Neut-A) from the 3000 randomised scenarios, according to each definition of climate neutrality. Boxes represent total land use in Ireland. *n*, number of scenarios that achieved neutrality for that definition. GWPStar indicates GWP*.

Table 5.3. Changes required to reach the 95th percentile scenario of (maximum) milk output for each definition of neutrality, expressed as percentage changes from 2021 values for key land uses, sheep populations and production of milk and suckler beef liveweight (excludes dairy beef)

		Percentage change from 2021						
Metric	Scenario	Milk output	Beef output	Total forest area	Total wetland area	Lowland sheep population	Upland sheep population	Total grassland for grazing
GWP_{100}	S-NZ	–45	–75	222	28	–82	–13	–62
	S-NZ-A	–34	–94	189	1	–41	–52	–55
GWP*	S-NZ	–18	–85	164	15	–80	–35	–42
	S-NZ-A	–16	–22	80	7	–25	–4	–26
CH_4 target grand-parenting	S-NZ	–37	–34	103	16	–46	–7	–48
	S-NZ-A	–14	–72	84	19	–85	–36	–46
CH_4 target population	S-NZ	–92	–19	261	28	–79	–64	–74
	S-NZ-A	–89	–95	387	28	–77	–42	–90
CH_4 target protein	S-NZ	–63	–7	195	28	–97	–72	–60
	S-NZ-A	–44	–8	66	8	–17	–57	–34
eGWP* population	S-NZ	–59	–46	157	28	–21	–37	–54
	S-NZ-A	–47	–92	239	8	–44	–3	–59
eGWP* protein	S-NZ	–33	–95	118	9	–42	–87	–57
	S-NZ-A	–16	–76	97	0	–35	–54	–44
Carbon neutral	S-NZ	–9	–79	47	9	–87	–68	–44
	S-NZ-A	–9	–79	47	9	–87	–68	–44
GWP_{100} LT balanced 2050–2100	S-NZ	–61	–32	138	0	–9	–37	–51
	S-NZ-A	–54	–98	223	2	–20	–56	–62
GWP* LT balanced 2050–2100	S-NZ	–34	–69	182	10	–46	–37	–53
	S-NZ-A	–26	–59	76	23	–10	–86	–42

included considerable forest expansion (minimum 47% increase), reduced grassland for grazing, reduced sheep populations, and reduced milk and beef outputs when compared with 2021 (Table 5.3).

5.4 Discussion

5.4.1 Core actions and food security consequences

Identifying possible climate-neutral AFOLU configurations is an important step in informing appropriate climate action. It can help stakeholders to visualise the scale of the challenge and to prioritise effective actions. Randomised scenario modelling supports foresight analysis that does not predetermine a "solution" configuration, but rather informs stakeholders about the real constraints involved and depicts boundaries around a climate-neutral "space" that the AFOLU sector can occupy. Those boundaries do appear to alter considerably depending on the definition applied, highlighting the need to build international consensus on clear definitions for national climate neutrality. Nonetheless, there are important commonalities that point to similar actions being required in the near term across all likely definitions. It is clear that expanding low forest cover and rewetting organic soils are essential actions to achieve climate neutrality in Ireland's AFOLU sector. Even under optimistic agricultural abatement, substantial reductions in the cattle herd will be required for all definitions excluding carbon (only) neutrality. These results highlight the inescapable need for difficult decisions to be made on whether to prioritise milk or beef output (or reduce both similarly) if Ireland is to achieve climate neutrality. They also confirm the results of simplified land–GHG balance modelling undertaken by the SeQUEsTER team for the Land Use Review (Haughey *et al*., 2023). That work indicated that a minimum 30% reduction in cattle numbers is necessary to achieve climate neutrality, alongside 30% emission abatement, very high levels (90%) of organic soil rewetting and afforestation of at least 20 kha per year from 2025 to 2050 (on the assumption that CH_4 emissions will be substantially reduced but will not need to be offset).

While there is a risk of international carbon leakage based on the possibility that milk and/or beef production could be displaced to regions with less efficient production systems (Searchinger *et al*., 2018), this outcome is neither inevitable nor a justification for not meeting national climate obligations. Milk and beef production in other countries is, or has the potential to be, at least as efficient as in Ireland. And the realisation of a more sustainable and equitable global food security requires increasing the volume and efficiency of food production in developing countries where more food is needed (compared with a sustainability imperative to reduce food waste and excessive consumption in industrialised countries). Furthermore, Irish milk and beef exports are supported by heavy marketing of product quality and sustainability (Shortall, 2019) – such marketing is subject to increasing scrutiny, and will ring hollow if Ireland continues to fall behind national climate targets. Academic literature and European policy discussions increasingly recognise the need to move beyond narrow definitions of efficiency in order to respect critical sustainability thresholds (Steffen *et al*., 2015). Realising sustainable and resilient food systems will require transformative change – including diet shifts, waste reduction and closing yield gaps in developing countries, as well as efficiency improvements (Springmann *et al.,* 2018; Searchinger *et al*., 2019).

5.4.2 Uncertainties

In addition to uncertainty over an internationally acceptable definition of climate neutrality for countries with high CH_4 emissions, GHG accounting in the land sector is more uncertain than in other sectors. In particular, soil carbon fluxes in both mineral and organic soils are highly variable, and are currently estimated based on a default tier 1 IPCC methodology in the NIR. Ongoing work is aiming to refine these flux estimates. Notably, a new emission factor for organic soils under forestry has been introduced into the NIR (Jovani-Sancho *et al*., 2021), increasing CO_2 emissions from LULUCF by approximately 2 Mt CO_2 annually. These emissions are not included in the scenarios analysed in this chapter, and will only add to the challenge of achieving climate neutrality (not least because they imply an imperative to exclude organic soils from ambitious tree planting targets). On the other hand, Tuohy *et al*. (2023) explored past evidence on organic soil drainage and concluded that the area of effectively drained organic soils under grassland is likely to be considerably smaller than the 335 kha stated in the national inventory and assumed in the GOBLIN model. Thus, there remains high uncertainty on both the extent and emission factors applicable to organic soil drainage in Ireland. Future climate neutrality modelling will need to reflect ongoing NIR developments to improve these estimates.

It should also be noted that Ireland's soils are huge carbon stores, and probably close to saturation, so that any measured increases in organic carbon sequestration in mineral soils are likely to be time limited, and of little consequence for the long-term climate neutrality balance. Similarly, whether organic soil emissions are higher or lower than implied by default emission factors, the actions required to mitigate them will be similar, and will need to be widely deployed in order to achieve climate neutrality. Nonetheless, there is a need to better understand how agriculture and existing forestry on organic soils can best be managed (or removed) to mitigate emissions.

Hedgerows and isolated trees are not included in the NIR but are expected to be included in the near future as spatial resolution on tree cover improves with a new land cover map. Nonetheless, many of these hedgerows and trees are maintained at fixed volumes (width and height) or are mature, and, therefore, will not deliver any substantial amount of CDR (Black *et al.*, 2023).

As GHG accounting improves through improved resolution of activity data and more accurate emission factors, the potential boundaries of a climate-neutral land sector will alter somewhat. However, there is no indication that the "big picture" will change substantially. Therefore, it is important that necessary efforts to reduce specific uncertainties do not delay the deployment of the core actions outlined above that are certainly needed to move towards climate neutrality.

5.5 Conclusion

Ten previously proposed definitions of climate neutrality were applied to filter 3000 randomised scenarios of future agricultural production and land use combinations in Ireland's AFOLU sector, with and without a 30% reduction in agricultural emissions to reflect possible future abatement. Different definitions and levels of abatement resulted in between 1% and 99% of the 3000 scenarios being categorised as "climate neutral". Despite considerable variation in implied climate-neutral AFOLU configurations, common patterns support a core set of actions that should be progressed in the near term irrespective of the definition(s) ultimately agreed on, namely high rates of afforestation, ambitious rewetting of organic soils, widespread uptake of agricultural abatement measures and cattle destocking. Difficult policy decisions are unavoidable, and there is an urgent need for clear yet tactful engagement with stakeholders on the need for transformative action, robust to the ultimate definition of climate neutrality. Meanwhile, there is a need for international consensus on appropriate national definitions of climate neutrality compatible with the Paris Agreement, to provide greater clarity on precise "target"-sustainable AFOLU configurations – especially for countries with a large share of CH_4 in their emission profiles.

6 Economic and Policy Considerations

6.1 Context

6.1.1 Past trends

The agricultural sector in Ireland is not static and has changed dramatically through time. Past trends can be used to infer the driving forces behind these changes, and, therefore, indicate how future change may be realised. Figure 6.1 highlights the trend in the total number of cattle, and the number of dairy and other cows, over the past 100 years. Total cattle numbers declined from 1922 to a low point in 1948. Cattle numbers then rose exponentially to a peak of 7.41 million in 1975, after Ireland joined the European Economic Community (EEC). The Calved Heifer Subsidy Scheme was an important policy driver during the late 1960s in advance of the (anticipated) higher supported price within the EEC from 1973. An uneven decline saw total cattle numbers fall to a low of 6.46 million in 1988, but dairy cow numbers remained high until 1984, when milk quotas were introduced. With milk volumes fixed and rising milk yields, the number of dairy cows began a rapid decline of *c*.30% to a low point of just over 1 million in 2005. Dairy farmers replaced dairy cows with beef cows, and rapid growth in beef cow numbers in the late 1980s and early 1990s led to a new peak in total cattle numbers of 7.64 million in 1998. The Common Agricultural Policy (CAP) Health Check in 2008, which gradually increased quota until its abolition in 2015, saw a gradual growth in the number of dairy cows to 2015 and a rapid rise afterwards, so that the number of dairy cows in 2020 was near the 1979 peak (28% above the pre-quota levels). On the other hand, the number of beef cows decreased at a slower rate of 13% over this period. These trends illustrate the important interaction between policy drivers and market forces in determining cattle numbers.

6.1.2 Business-as-usual projections

Figure 6.2 shows the number of male and female calves over time. Female calves represent potential breeding animals, and their numbers are continuing to increase, surpassing their peak in 1998. Therefore, without policy intervention, it appears that cattle numbers will continue to grow and exceed the 1998 peak in the coming years. Indeed, the EPA (2023) projects that increasing dairy output, in line with the Foodwise 2025 policy, will result in a flatlining of agricultural GHG emissions at a very high level out to 2030 without additional policy measures.

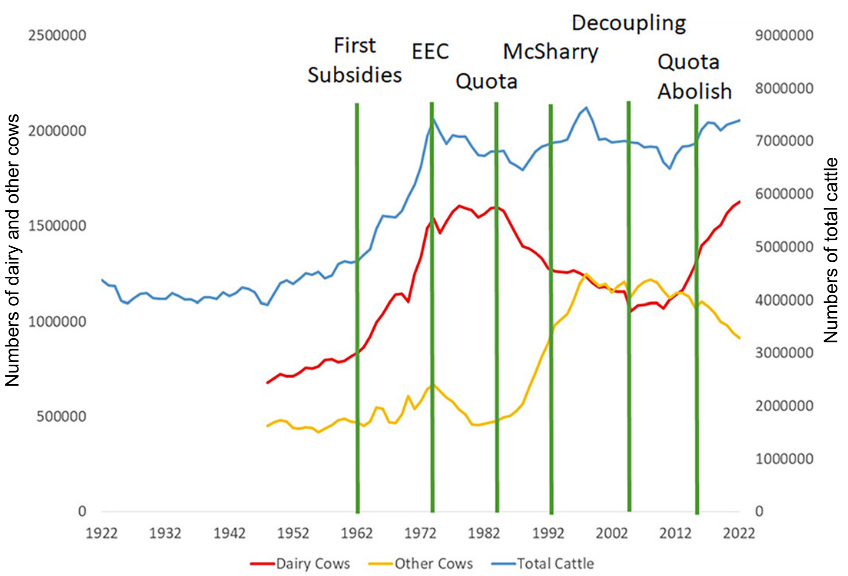


Figure 6.1. Cattle numbers over the period 1922–2021. EEC, European Economic Community.

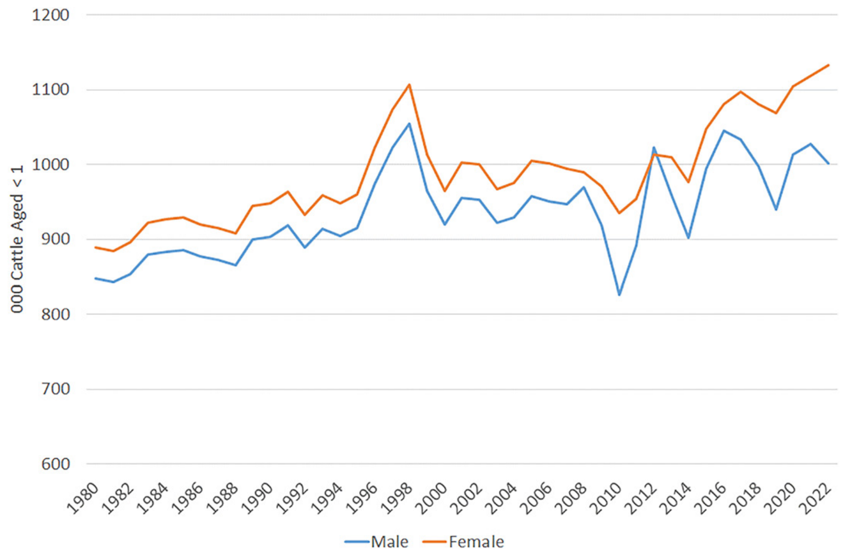


Figure 6.2. Male and female calf numbers over the period 1980–2022.

6.2 Economics

6.2.1 Farm profitability

The agri-food sector is one of Ireland's largest industries, accounting for approximately 7% of gross national income, 10% of export value (>€14 billion) and 7% of total employment. However, these statistics do not reflect a universally vibrant and profitable agricultural sector. Profitability on dairy farms is high owing to an efficient grass-feeding spring-calving model, meeting strong international demand for solid milk products. However, beef and sheep farms are less profitable, and, on average, make a loss on animal rearing, surviving mainly on subsidies under the CAP. The 2021 Teagasc National Farm Survey (NFS) indicates that only 42% of all surveyed farms are economically viable, i.e. farm income is sufficient to remunerate family labour at the minimum wage and provide a 5% return on capital investment and non-land assets (Dillon *et al*., 2022). Of the remaining farms surveyed, 31% were classed as being sustainable (largely due to the presence of off-farm employment income) and 27% as vulnerable. Although 85% of dairy farms and 73% of tillage farms were viable, only 14% of cattle-rearing farms and one-third of "cattle other" and sheep farms were deemed viable in 2021 (at least 30% of these farm types were deemed vulnerable). There are also regional differences, reflecting the distribution of farm types and land and climatic suitability. Only 25% of NFS-surveyed farms in the north and west regions were considered viable, compared with 49% in the east and midlands and 51% of farms in the south. However, these statistics do not include small farms with a standard output of less than €8000 annually. Past survey data for these small farms indicate that half are vulnerable, and less than 20% are viable. These results indicate that business as usual is economically and socially unsustainable for many farm businesses. In this context, there is an economic and social (as well as environmental) imperative to explore diversification options.

6.2.2 Forestry profitability

Based on the previous forestry programme, Teagasc (2022) presents indicative annual gross margins of over €500 per ha, which compares favourably with average gross margins of €334–479 for cattle and sheep farms surveyed in the NFS (Dillon, 2022). In early 2023, the Department of Agriculture Food and the Marine proposed a new investment of €1.3 billion in the new National Forestry Programme for 2023 to 2027, which will be implemented once state aid approval is secured from the European Commission. The comprehensive package of measures included in the programme will see an increase in forestry premiums of between 46% and 66%, increasing to over €1000 per ha per year depending on the tree species, management and location. This will further strengthen the economic case for many farmers to diversify into forestry. Furthermore, harvested trees could generate harvest incomes of tens of thousands of euros (depending on quality, size and market). Lower viability for smaller farms, and new, more generous, forestry grants established since the Teagasc indicative gross margins were calculated, would suggest that forestry could be an economically advantageous option for many farms.

6.3 Policy

6.3.1 Climate Action Plan targets: agriculture

The Climate Action Plan (Government of Ireland, 2022) includes the following targets and measures for the agriculture sector in order to achieve a 25% cut in emissions by 2030 (relative to 2018) under the agreed Sectoral Emissions Ceiling:

- reduce synthetic nitrogen use to <300,000 t by 2030;
- replace 90–100% of calcium ammonium nitrate with protected urea fertiliser;
- reduce average slaughter age from 27 to 24 months by 2030;
- produce up to 5.7 TWh of biomethane from 200 new anaerobic digestion plants by 2030;
- increase area under organic farming from 110 to 450 kha;
- increase tillage area from 350 to 400 kha;
- target 90% uptake of low-emission slurry spreading;
- focus on low CH_4 traits in animal breeding programmes;
- reduce crude protein fed to livestock (lower N_2O emissions from manure management);
- contribute agricultural feedstocks to anaerobic digestion.

These measures could cumulatively deliver up to 4 Mt CO_2e of the 5.8 Mt CO_2e of savings needed to comply with the carbon budget set for agriculture. However, in the absence of additional interventions to reduce output elsewhere in the sector, measures based on animal breeding tend to drive efficiency improvements and, therefore, higher agricultural output and overall emissions. Climate goals over the coming decades will not be achieved without active policy intervention to manage cattle numbers. More ambitious emissions decoupling from production is possible beyond 2030 through widespread adoption of grass–clover swards and CH_4 inhibitor feed additives.

A zero-synthetic-nitrogen blueprint dairy system, which is being pioneered at Teagasc's Solohead research farm (Scully *et al*., 2021), could significantly improve the wider sustainability of Ireland's dairy sector if it can be widely deployed. In the meantime, early progress with the diversification out of cattle production, necessary to achieve climate neutrality by 2050, has been included in the 2023 Climate Action Plan and will be critical.

6.3.2 Climate Action Plan targets: land use, land use change and forestry

Net emissions from LULUCF in 2018 were 4.8 Mt CO_2e. A sectoral emission ceiling has yet to be established for LULUCF, but even a modest reduction from 2018 would be highly challenging because the age profile and harvest pattern of commercial forestry, alongside emission factor revisions, mean that forestry will move from being a net sink of almost 4 Mt CO_2e in 2018 to a net source of almost 2.8 Mt CO_2e by 2030, based on recent projections (Figure 6.3). The implementation of new emission factors for organic soils under forestry (Jovani-Sancho *et al*., 2021) adds approximately 2 Mt CO_2e onto the LULUCF inventory. Meanwhile, the recent rate (since 2020) of new forest planting in Ireland stands at around 2 kha per year, compared with a minimum rate of 20 kha per year required to achieve climate neutrality (at least for the scenarios without massive reductions in both milk and beef output).

The measures proposed in the 2023 Climate Action Plan to reduce net emissions from LULUCF to 2030 include:

- increase the annual afforestation rate to 8 kha, from 2023 onwards;
- develop, assess and adopt as appropriate the new Forestry Programme and Coillte's strategic vision;
- promote forest management initiatives in both public and private forests to increase carbon sinks and stores;
- increase the inclusion of cover crops in tillage to 50,000 ha;
- increase the incorporation of straw to 55,000 ha of tillage (cereal) area;
- improve the management for carbon sequestration of 450,000 ha of grasslands on mineral soils;
- reduce the management intensity of grasslands on 80,000 ha of drained organic soils;

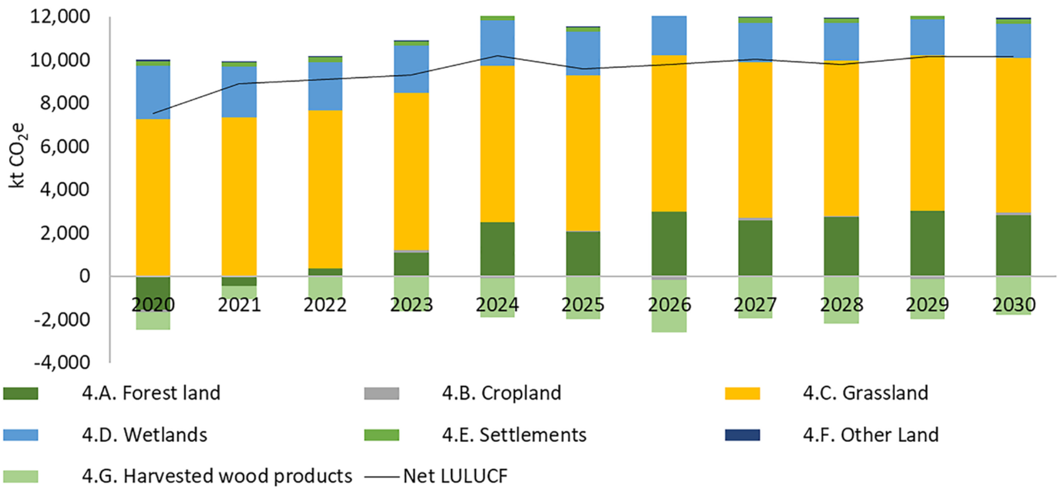


Figure 6.3. Projected emission profile for the LULUCF sector from 2020 through to 2030 under business-as-usual projections (modified from EPA projections[2] to include new organic soil under forestry emission factors).

- rehabilitate 35,900 ha of peatlands as part of the Bord na Móna's People and Peatlands programmes, and 41,700 ha of additional peatlands, to provide a total of 77,600 ha of rehabilitated peatlands.

Rewetting of organic soils under grassland through water table management is a key action, although much uncertainty remains over how this can be managed over large areas involving multiple farms. More in-depth understanding of how close to the surface the water table needs to rise, and how land could then be used, will help to inform detailed plans. In any case, presumably some form of state compensation will be necessary for farmers who may be required to reduce livestock production owing to flooding following water table management.

Afforestation represents another key strategy for meeting climate goals. Past goals for afforestation in Ireland have not been met, and the magnitude of planting needed to achieve climate neutrality implies that farmers will need to convert substantial areas of productive grassland on mineral soils to forestry. However, despite potentially generating higher gross margins than cattle and sheep rearing (section 6.2.1), farmers are generally averse to such a transition for a number of reasons – in particular, restrictions around reverting land to other uses once it has been planted into forestry, and a high administrative burden around licensing. At the farm level, the decision to convert involves multiple factors, including soil type, accessibility and succession planning. Long-term financial planning requires careful analysis of details affecting forestry income, including the location, species choice, yield class potential and whether trees will be grown as native woodland or for harvest. Licensing backlogs for both planting and felling trees imply a need to streamline this process. Farmers may also be discouraged from diversification by the memory of a previous "false dawn" for energy crops that left early adopters without a market for their biomass. This time around, there is clear evidence of large and increasing demand for carbon credits and bio-based materials across multiple industries internationally. However, there remains an important role for the government to provide the regulatory framework and early support for strategic growth sectors that could underpin the strong expansion of Ireland's bioeconomy – in addition to clearly signposting the higher rates of afforestation needed to achieve climate neutrality.

It will take some years to ramp up afforestation rates to the levels necessary for climate neutrality (minimum 20 kha per year). One limiting factor in the short term is sapling availability from nurseries, which will need to ramp up their seedling establishment. Another

2 Based on calculations run for the Carbon Budget Working Group using data modified from EPA WEM (with existing measures) projections as of 2020, which differ from the most recent projections.

limiting factor could be the need to avoid planting on organic soils, where the recently revised emission factors negate much of the carbon sink provided by biomass growth – implying that large areas of more productive milk and beef farming on mineral soils will need to be converted to forestry. Furthermore, the rate of carbon sequestration accelerates slowly in the early years after planting. There is an urgent need for clear policy signposting towards more ambitious target planting rates compatible with climate neutrality (which are 2.5 times higher than the official policy target in the Climate Action Plan). Even so, afforestation will not make a big contribution to 2030 carbon budget targets owing to the time lag between action and CDR. The Climate Action Plan 2021 proposed that future carbon credits from tree growth could be brought forward to the time of tree planting, in order to reconnect action with (future) GHG outcomes. So long as this approach is part of a strategy that ensures continued tree planting right through to attaining the necessary balance between emissions and removals in the land sector, and is clearly differentiated from retrospective inventory accounting, it could play a role in incentivising early action on the pathway towards climate neutrality. However, this approach would also bring with it value judgements about appropriate time horizons and future predictions of management practice, etc., as well as creating reporting complications in future budget periods from which credits have been brought forward. Thus, incentivising and reflecting LULUCF actions with delayed GHG responses, within national carbon budgets that are necessarily ambitious to drive timely action, will require careful consideration.

6.3.3 Sustainable land use

Beyond climate change, the land sector drives an exceedance of numerous “planetary boundaries”, namely biosphere integrity, land system change and biochemical flows (Steffen *et al*., 2015). In Ireland, this translates into air pollution and habitat degradation driven by NH_3 emissions exceeding the regulatory limits and declining water quality driven by nutrient leakage. As per EU 2018/1522, the National Air Pollution Control Programme outlines the pathway for Ireland to comply with the National Emission Ceilings Directive for air pollutants, including NH_3 primarily sourced from agriculture (livestock manures and non-abated urea-based fertilisers). Meanwhile, declining water quality is in part driven by agricultural intensification (high per hectare nutrient loading), especially in the dairy sector, and threatens compliance with the Water Framework Directive (2000/60/EC). Abatement measures and the destocking required to achieve climate neutrality could deliver co-benefits of reduced nutrient losses and NH_3 emissions, thereby contributing to national objectives for air and water quality. In terms of biodiversity, future land use change will need to include giving space back to nature, for example low-input grassland and native woodland. The latter is in line with increasing CDR for climate neutrality, while the former implies that considerably more land will need to be spared than that needed for CDR. Land sparing through intensification may pose risks to water quality, depending on the context. Reducing derogation limits for organic nitrogen loading under the Nitrates Directive (91/676/EEC) could be a useful mechanism to reduce this risk, and potentially also to curtail currently unsustainable expansions of dairy herds. Sustainable land use policies should also consider how land sector activities fit with sustainability transformations across the wider economy. There is a need to identify coherent, climate-neutral scenarios that integrate compatible activities across the AFOLU, transport, power generation, heating and industry sectors.

It is clear that the current shape of the land sector in Ireland reflects policy decisions as much as it does market forces. There are good reasons for policy support directed at the agriculture sector in terms of supporting food security, a robust export sector (thus balance of trade) and rural economic viability. Some progress has been made towards more sustainable land use via an increasing share of CAP payments directed towards agri-environmental schemes. Nonetheless, given the magnitude of change required to realise a climate-neutral land sector (let alone a climate-neutral economy), and the economic and reputational risks (including for agri-food exports) of failing to meet climate targets, policy support for ruminant production systems above and beyond existing market incentives appear, *prima facie*, perverse. Of course, this disregards important behavioural and political considerations that naturally create strong resistance to change. Another important barrier to change is the exposure of farmers to mixed messages. There appears to be widespread confusion around critical concepts, including the need to substantially reduce CH_4 emissions, and the difference between *maintaining large carbon stores* (in soils, hedgerows, etc.) versus creating *new carbon sinks* (by increasing long-term carbon storage – especially new forestry).

The conclusion we draw is that there is an urgent need for a tactful yet robust and fact-based conversation among key stakeholders on realistic pathways towards a genuinely sustainable land sector. The science, and implications for action, needs to be clearly and unambiguously communicated to farmers from trusted sources. Plausible, broad-brush, climate-neutral land use configurations delineated in the SeQUEsTER project provide an important evidence base to ground such discussions.

7 Conclusions and Recommendations

Ireland's AFOLU sector is responsible for *c*.43% of national GHG emissions. The Climate Action and Low Carbon Development (Amendment) Act 2021 commits Ireland to reach a legally binding target of net-zero emissions no later than 2050, yet emissions from AFOLU continue to rise. The SeQUEsTER project generated over 3000 randomised scenarios of potential agriculture and land use configurations for Ireland in the year 2050, and calculated GHG emissions and removals for each of those scenarios using a methodology validated against Ireland's NIR. The scenarios were filtered according to various definitions of climate neutrality, enabling the objective (without bias) identification of biophysical boundaries for a climate-neutral land sector in Ireland. Despite uncertainty around some GHG fluxes and definitions, extensive sensitivity analyses support robust conclusions. Achieving climate neutrality will require *all* of the following actions:

- reducing milk and beef output by 30% (or a more dramatic cut in *either* milk or beef output); further reductions would be required if the below options cannot be fully implemented;
- widespread adoption of effective abatement techniques across farms;
- planting at least 500,000 ha of new forest (on mineral soils);
- restoring and rewetting degraded peatland;
- raising the water table across *c*.300 kha of organic soils under grassland (area subject to revision in the light of emerging evidence on the extent of effective drainage in organic soils).

The above is a minimum requirement based on optimistic assumptions that (i) on-the-horizon abatement techniques can reduce the GHG intensity of agricultural production by 30%, (ii) climate policy evolves to reflect the distinctive warming effect of CH_4 as an SLCP and (iii) CH_4 emissions can be reduced to a level that does not require additional offset by CDR. If these assumptions are met, then CDR will be required to offset residual emissions "only" of long-lived CO_2 and N_2O. Avoiding the need to balance out future (much lower) CH_4 emissions by CDR reduces the rate of afforestation necessary to reach climate neutrality from 35 to 20 kha per annum between 2025 and 2050 (i.e. 2.5–4.5 times higher than the current policy target). Planting on mineral soils to ensure effective CDR implies competition with other agricultural uses.

Achieving climate neutrality requires balance across (i) GHG emissions and removals and (ii) land use area changes. Notably, agricultural emissions abatement, herd reduction and organic soil rewetting cannot achieve climate neutrality, individually or collectively, in the absence of ambitious afforestation – for the simple reason that new tree planting is the most effective and scalable carbon sink available in the land sector to 2050. However, there are many possible combinations of all of the above actions that comply with climate neutrality, and it is down to stakeholders to decide which of those combinations are more desirable (because they contribute to a wider range of societal objectives).

Current GHG accounting and policy targets are based on GWP_{100} of the three main GHGs – CH_4, N_2O and CO_2, expressed as CO_2e. Across the 3000 randomised scenarios modelled, around half achieved a GWP_{100} balance by 2050 on the assumption that abatement options can reduce the GHG intensity of production by 30% by 2050. However, among these climate-neutral scenarios, 95th percentile milk production still involved a 34% reduction in milk output (vs 2021), alongside a 94% reduction in suckler beef output and a near tripling of forest cover (from 11% to 32% of Ireland's land area).

Alternative prospective definitions of climate neutrality that recognise the distinctive (short-term) nature of warming caused by CH_4 emissions could alter the equation somewhat, although the same core actions outlined above would still be required. For example, meeting a separate CH_4 emission target and achieving a GWP_{100} balance for N_2O emissions and CO_2 fluxes would still require a 14% reduction in milk output (for the 95th percentile milk output scenario) alongside an 85% reduction in suckler beef output and an 89% increase in forest area (again assuming 30% abatement efficacy). That scenario is linked with an afforestation rate of 20 kha per annum between 2025 and 2050 – a rate 2.5 times higher than the official afforestation target. Overall, the results show that even with separate accounting for CH_4 that is generous for Ireland from the perspective of international fairness, and with very effective abatement of agricultural emissions, an afforestation rate of at least 20 kha per year is required to maintain either milk or beef production at close to 2021 levels.

Milk and beef production underpin national agri-food exports worth over €14 billion annually, but profitability is patchy within the primary agriculture sector. The NFS 2021 classifies less than one-third of beef and sheep farms as economically viable (income sufficient to remunerate family labour at the minimum wage and provide a 5% return on investment in non-land assets). Livestock rearing per se is often loss-making on these farms, which only remain in production owing to direct payments under the CAP. Meanwhile, dairy farms are highly profitable in the current market, but failure to meet national climate targets undermines green marketing and the "social licence" under which this sector operates. Thus, there is an economic imperative to explore diversification options, to ensure that viable farms can be passed to the next generation across the agricultural sector.

Maintaining climate neutrality through to the end of this century and beyond is likely to require development of cascading wood value chains that store carbon in wood-derived products and supply biomass for bioenergy (that could be coupled with carbon capture and storage to permanently lock biogenic carbon out of the atmosphere). Timber engineering to produce high-quality construction materials, and biorefineries involving anaerobic digestion and fed by organic wastes (including manures) and grass–clover swards, are among many promising options that merit consideration for intensive research and development to expedite commercial out-scaling. Teagasc guidance suggests forestry can generate higher gross margins than average cattle and sheep farms, but cultural preferences and a cumbersome licensing system are among numerous barriers to tree planting on farms. Farmers may also be put off by memories of a failed push towards bioenergy in the mid-2000s, which stumbled owing to a lack of demand for the biomass produced. As global demand for carbon credits and feedstock for bio-based materials and bioenergy grows, there is a crucial role for the government to foster development of strategically important bio-based industries in Ireland that fit within a climate-neutral and circular economy.

This study indicates that the minimum requirements and bounds for a climate-neutral land sector will need to look very different from how they do today. The magnitude of forest sink required by 2050 points to an urgent need to start ramping up afforestation rates from a low base as soon as possible. Delay will translate into a smaller carbon sink during the second half of this century, and, therefore, less scope for emission-generating activities (including livestock production). National carbon budgets based on *cumulative*, rather than annual, fluxes also place an emphasis on prompt action in the land sector. Widespread misconceptions persist among stakeholders regarding, inter alia, the need to dramatically cut CH_4 emissions and the difference between *maintaining carbon stores* and *creating new carbon sinks*. There is an urgent need for a tactful yet robust and fact-based conversation among key stakeholders on realistic pathways towards a genuinely sustainable land sector. The science, and implications for action, needs to be clearly and unambiguously communicated to farmers from trusted sources. The delineation of possible climate-neutral land use configurations in the SeQUEsTER project is a starting point.

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Abbreviations

AFOLU	Agriculture, forestry and other land use
CAP	Common Agricultural Policy
CDR	Carbon dioxide removal
CI	Confidence interval
CO_2e	Carbon dioxide equivalent
CSO	Central Statistics Office
eGWP*	Equity GWP*
GDP	Gross domestic product
GHG	Greenhouse gas
GOBLIN	General Overview for a Backcasting approach of Livestock INtensification
GWP	Global warming potential
GWP*	Warming effect of emitted greenhouse gases through time considering the distinct dynamics of methane as a short-lived climate pollutant
GWP_{100}	100-year average global warming potential
HWP	Harvested wood product
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land use change and forestry
Mt	Million tonnes
NFS	National Farm Survey
NIR	National Inventory Report
SeQUEsTER	Scenarios Quantifying Land-Use & Emissions Transitions Towards Equilibrium with Removals
SLCP	Short-lived climate pollutant
UNFCCC	United Nations Framework Convention on Climate Change

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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