2

Transforming Landscapes

Key messages

Transformative change across multiple systems interconnected in the landscape offers a myriad benefits and opportunities in the fight against climate change and biodiversity loss, with wider gains for society and the economy. Of all transformations, inappropriate land management can have 'severe and unintended consequences', particularly for biodiversity loss, with implications for climate action and society. While conflicting land-use objectives cannot be avoided, decisions that maximise synergies while managing trade-offs can significantly reduce conflicts while enhancing benefits and opportunities. A long-term integrated strategy for land-use management is necessary if this is to be achieved.

Climate change and biodiversity loss share many underlying drivers related to unsustainable resource use, including the use of land. Tackling these crises together enhances synergies while managing the trade-offs that exist between them. Social benefits include sustainable job creation and the protection and enhancement of human wellbeing. Such benefits aid the social transformation required to enable action on climate change and biodiversity loss.

If planned and managed in an appropriate manner, carbon stores on land can be maintained and enhanced. Afforestation is a cost-effective and scalable option for carbon removal. There is an emerging industry and bioeconomy around forestry in Ireland. Forests have the potential to become centres for cultural heritage, craftmanship, traditional knowledge and innovation, alongside diversifying livelihood options in rural communities.

Nature conservation (immediate benefits) and restoration (longer-term benefits) are cost-effective, enhance carbon removals and reduce vulnerability and strengthen synergies between mitigation and adaptation actions. Benefits include improved food security, nutrition, health, wellbeing, support for livelihoods and sustainability and ensuring nature's contributions to people.

2.1. Introduction

Landscapes are the source of all nature's contributions to people, providing clean air and fresh water, food and materials, controlling disease and pests and moderating extreme events (Millennium Ecosystem Assessment, 2005; Pascual et al., 2017). They are also a source of amenity, cultural and natural heritage, spirituality, mental and physical health and education, alongside nature having its own intrinsic value (Millennium Ecosystem Assessment, 2005; Pascual et al., 2017; see Figure 2.1). For thousands of years, the rural and coastal landscapes of Ireland have been shaped by choices related to producing food, feed, fibre, fuel and fresh water, without which society and the economy would not exist (Glassie, 2014; Arneth et al., 2019). The choices made in the coming years have the potential to transform the landscape. It is possible for landscapes to play a central role in tackling climate change and biodiversity loss, while also acting on food insecurity, declining water quality and the energy crisis (Scott et al., 2016; IPCC, 2019; Pörtner et al., 2021). That said, conflicting land-use objectives are unavoidable. However, decisions that maximise synergies, while minimising and managing trade-offs, can reduce such conflicts (see Box 2.2).

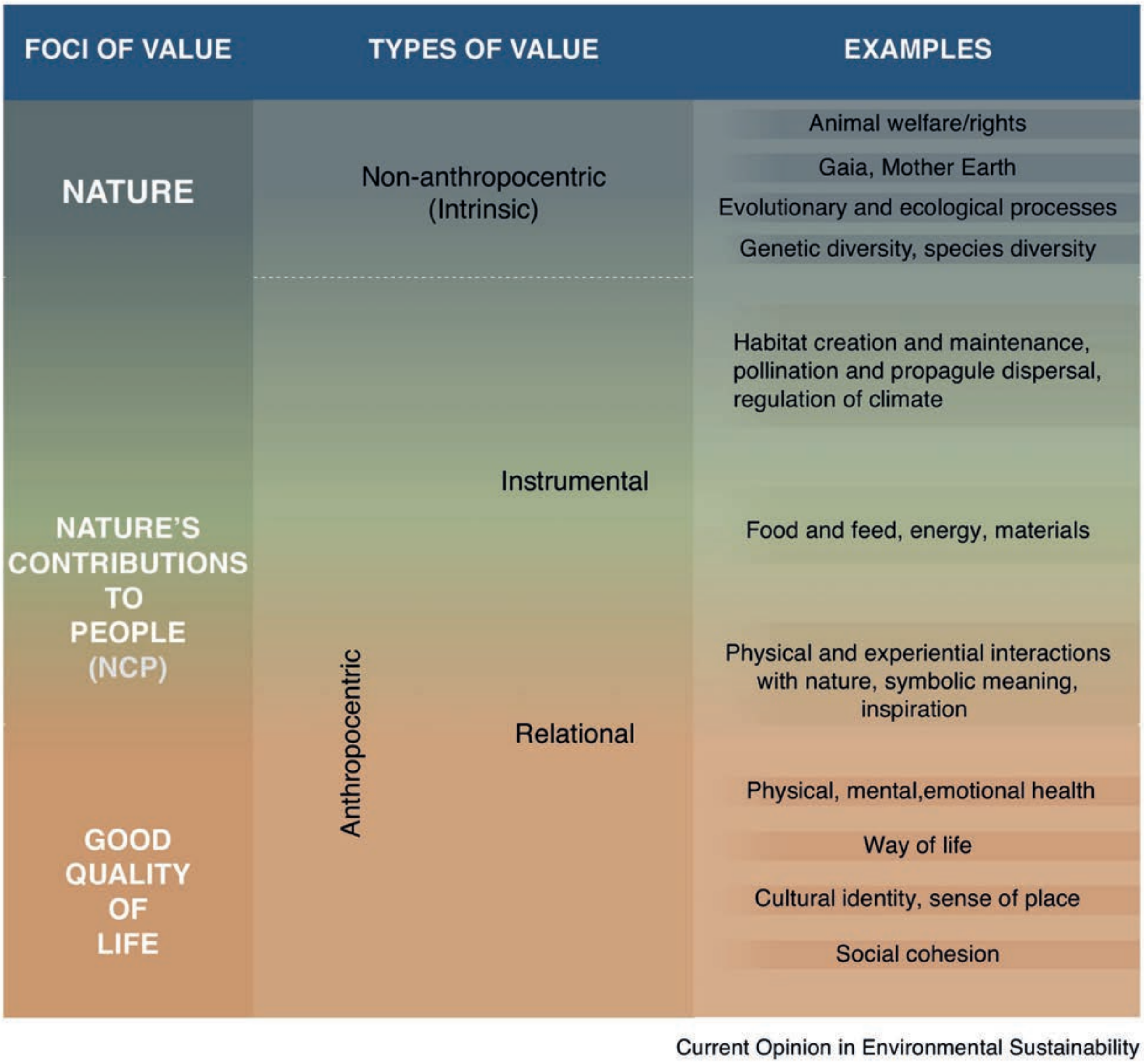

Figure 2.1 Nature's intrinsic value and nature's contributions to people. Source: Pascual et al. (2017). Reproduction licensed under the Creative Commons Attribution CC BY-NC-ND 4.0 licence (https://creativecommons.org/licenses/by-nc-nd/4.0/).

A transformative reshaping of Irish landscapes is required if the vision of a climate-neutral, biodiversity-rich, sustainable and resilient Ireland, as set out in the national climate objective (Government of Ireland, 2021a) and obligations under EU law and the Paris Agreement, are to be achieved. This is no small task and incremental changes are not sufficient (Haughey et al., 2023). There is evidence to suggest that elements of transformative change are emerging, particularly in policy and planning related to landscapes in Ireland. However, it should be noted that the time that remains to enact significant change and avail of opportunities that landscapes have the potential to provide is running out, and the time for action is now (IPCC, 2019, 2023b).

2.1.1. Dual crises: climate change and biodiversity loss

Like climate change, addressing the global biodiversity crisis also requires urgency. Humans are part of nature, and a stable climate and healthy environment, with functioning ecosystems, are essential for human wellbeing and the foundation upon which society and the economy are built (IPBES, 2019b; Dasgupta, 2021; IPCC, 2022a). There is a lack of awareness of the vulnerability of society and human wellbeing to biodiversity loss and damage to ecosystems. Changes to climate and biodiversity because of human activities are a grave threat to the life support systems necessary for human survival (Díaz et al., 2019; Pörtner et al., 2021; Uitto, 2022; see Volume 1). Both crises diminish society's capacity to act, for example climate change both causes and exacerbates biodiversity loss, which affects society's ability to protect nature and biodiversity (Bulkeley et al., 2020; Pörtner et al., 2021; see Volumes 1 and 3), while biodiversity loss affects society's ability to act on climate change, by reducing the capacity of forests and soils sequester and store carbon (Pörtner et al., 2021; Haughey et al., 2023). Biodiversity loss will also affect society's ability to adapt, as nature's contribution to people includes moderating the frequency and intensity of climate impacts (McVittie et al., 2018).

These crises are inextricably linked through shared human drivers, direct and indirect (see Chapter 1, Figure 1.3), mutual reinforcement and the predominantly negative impact they have on human wellbeing. However, tackling them together is an opportunity to optimise the strong synergies that exist, not only between action on climate change and biodiversity loss, but also in considering how solutions will affect society (Pörtner et al., 2021). For example, restoring ecosystems on land and at sea provide opportunities for climate mitigation and conservation. They are also cost-effective and can provide social benefits, such as job creation, and other economic benefits (Pörtner et al., 2021). This aids the transformative societal change that is required to limit global temperature increases, reverse biodiversity loss and achieve good quality of life (Pörtner et al., 2021). On the other hand, if climate change and biodiversity are not tackled together then this can lead to severe unintended consequences with the potential to exacerbate both, with detrimental impacts for society and the economy. A transformative approach can safeguard human wellbeing, today and in the future, while enhancing resilience and strengthening rural communities.

2.1.2. The need for transformative change

Agricultural practices and land use, land-use change and forestry (LULUCF) activities not only contribute to climate change, but also have significant impacts on the environment at large. Agriculture and forestry, when managed unsustainably, can be detrimental to water quality because of nutrient and sediment runoff and pesticide contamination (EPA, 2020). A wide range of species and habitats are also affected by land-use change, including agriculture, extraction of resources (peat and minerals) and forestry (NPWS, 2019).

Forestry accounts for 808,848 hectares (ha), 11.6% of land cover in Ireland (DAFM, 2023a), compared with an EU average of 35% (Eurostat, 2021). Most peatlands (85%) have been damaged and only 20% remain of conservational value (Wilson et al., 2013; Renou-Wilson et al., 2019). The status of biodiversity in Ireland on land, at sea and in protected areas is poor (NPWS, 2019; Environmental Performance Index, 2022; Gorman et al., 2023). Just 13% of Irish land area is designated for biodiversity protection, compared with a 26% average across the EU (Eurostat, 2022).

Rebalancing environmental, social and economic priorities will be necessary to (1) tackle the indirect drivers of climate change and biodiversity loss, (2) maintain and enhance carbon sinks within Irish landscapes, (3) conserve and restore ecosystems and (4) enhance the benefits and opportunities for society and the economy. The speed, scale and depth of the change required means that rural communities will need to adapt. There are some groups, particularly those working in extractive industries and in emissions-intensive agricultural activities, where fundamental changes to livelihoods will be necessary. This is a systemic issue. High-level policy levers will be required to change the operational preferences of companies towards sustainable business models to ensure that they can continue to support local communities and local livelihoods. This highlights the need for a just and equitable transition for all, especially those at the forefront of change.

2.1.3. Pathways to a climate-neutral and biodiversity-rich landscape

Under the Paris Agreement and the European Climate Law, Ireland has a commitment to rapid and deep reductions in greenhouse gas emissions[8]. As it will not be possible to eliminate all greenhouse gas emissions, Ireland will also need carbon removals to achieve balance between emissions from sources and removals by sinks. If rapid, deep and sustained reductions in emissions are not achieved in the near-term, addressing any overshoot of the Paris Agreement's 1.5°C and 2°C temperature goals will require greater net-negative emissions (see Volume 2, Chapter 7). In the near term, it is the land sink, through land management, forest management (10 years) and afforestation (10–20 years), that will provide these emissions reductions (Smith et al., 2023). This chapter focuses on enhancing 'conventional'[9] CO_2 removal (CDR) through natural processes, which are responsible for 2 billion (or gigatonnes (Gt)) of CO_2 global removals per year, as opposed to 'novel'[10] processes, which are responsible for 0.002Gt of CO_2 global removals per year (Smith et al., 2023). All existing research related to CDR in Ireland has been comprehensively assessed in Volume 2, Chapters 1, 4, 7 and 9.

The Climate Action and Low Carbon Development (Amendment) Act 2021 sets out a 51% target for emissions reductions across all sectors, by 2030, with a baseline of 2018 (see Volume 2, Chapter 1). The 2030 target is split into two 5-year carbon budgets proposed by the Climate Change Advisory Council, while sectoral ceilings have been set by the Government. Agriculture's sectoral ceiling is set at 25%, which translates to cutting agricultural emissions from 23MtCO_2-eq per year, in 2018, to 17.25MtCO_2-eq per year, in 2030. Each 5-year carbon budget for agriculture has a cumulative allowance of 106MtCO_2-eq, between 2021 and 2025, and of 96MtCO_2-eq, between 2026 and 2030. The sectoral ceiling for LULUCF has not been decided[11,12], but a 37–58 % reduction in emissions is presented in the 2021 Climate Action Plan (DECC, 2022a). For the second carbon budget, there is also a 5.25MtCO_2-eq of unallocated savings, in recognition that it is not yet possible to identify all the solutions that will assist Ireland in achieving its full ambition (DECC, 2022a).

There is debate around whether or not the budgets proposed satisfy the (1) temperature, (2) equity and (3) "common but differentiated responsibilities and respective capacities" goals of the Paris Agreement (Jackson, 2022; McMullin and Price, 2022), and suggests that Ireland as a developed country needs to do more to satisfy its obligations. This is relevant as it could be argued that Ireland's carbon budgets and sectoral ceilings, decision on the LULUCF outstanding, is the minimum level of mitigation required, which helps to put the scenarios presented in the next section into context.

While there is debate about how strict carbon budgets should be, cumulative budgets to 2025 and 2030 are already highly constrained. The less action that is taken in the near term, the more constrained carbon budgets will be. Achieving the emissions reduction target in any 1 year is not sufficient. It is the cumulative total for each 5-year budget that is significant. Any budget overrun in the first carbon budget, 2021 to 2025, is to be carried forward and reduces the second carbon budget, 2026 to 2030 (An Taisce, 2023a, 2023b). To date, around 45MtCO_2-eq of the first budget has been spent, with emissions in the sector projected to increase (EPA, 2022a). Alongside even greater reductions in emissions that will be required in all sectors if the carbon budgets are to be achieved, land management, including the protection, restoration and enhancement of the land sink, is a significant and essential component of delivering on highly constrained carbon budgets in the short and long terms. The challenge is even greater, considering that emissions from agriculture and LULUCF increased in 2021 (EPA, 2023b; see also Volume 2, Chapters 2 and 6). There is not enough evidence to quantify the extent of negative emissions that may be required to 2050 in Ireland (see Volume 2, Chapter 7).

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8 Carbon dioxide (CO_2) and nitrous oxide (N_2O) and other long-lived climate forcers will require deep and rapid reductions and any remaining emissions balanced by carbon removals. Methane (CH_4) will also require deep and rapid reductions, but will not have to be reduced to zero because it is a short-lived climate forcer (see Volume 1).

9 Methods that capture and store carbon in the land reservoir and reported on a national level to the United Nations Framework Convention on Climate Change under LULUCF activities, including afforestation/reforestation, soil carbon in croplands and grasslands, peatland and wetland restoration, agroforestry, improved forest management and durable harvested wood products. (Smith et al., 2023).

10 All other methods that store carbon in the lithosphere and ocean or products that are deployed at smaller scales (Smith et al., 2023).

11 At the time of publishing this report.

12 Unlike the national sectoral emission ceiling approach in Ireland, the EU treats the LULUCF sector differently, because of its underlying complexity in relation to its greenhouse gas profile, from other sectors and does not include it as part of the EU Effort Sharing legislation. Instead, the EU has developed a specific regulation for LULUCF to set out targets. A new EU-wide target of 310MtCO_2-eq by 2030 will be implemented through ambitious, fair and binding net removal national targets for the LULUCF sector (European Union, 2023).

In relation to biodiversity, Ireland has commitments under the Convention on Biological Diversity. Biodiversity had a 'Paris Agreement moment' with the adoption of the Kunming–Montreal Global Biodiversity Framework at the Conference of the Parties 15 (COP15) in December 2022. Almost 200 countries agreed to set goals and targets to 'halt and reverse' biodiversity loss by 2030, and an ambition to conserve 30% of the world's land and 30% of the ocean by 2030. The agreement includes a target to identify and phase out or reform incentives and subsidies that are harmful to biodiversity. In June 2023, the European Council reached agreement on its proposed Nature Restoration Law. This law proposes conservation measures covering 20% of land and 20% of seas by 2030, and all ecosystems in need of restoration by 2050. This complements the EU 2030 Biodiversity Strategy, to legally protect a minimum of 30% of the EU's land areas and 30% of sea areas, and integrate ecological corridors (European Commission, 2023).

Box 2.1 Ireland's 'fair share' of methane reduction

While rapid, deep and sustained reductions in CO_2 emissions, that is emissions from burning fossil fuels, are necessary to limit and in the long term halt climate change, the UN has called cutting CH_4 emissions "the strongest lever we have to slow climate change over the next 25 years and also points to many co-benefits for air quality, food security and jobs (United Nations Environment Programme, 2021). Scenarios produced by the IPCC indicate that global CH_4 emissions must fall by around 50–60% by 2040 for a pathway consistent with limiting global temperature rise to 1.5°C (Rogelj, 2021). Reductions in CH_4 emissions are necessary if Ireland's statutory carbon budgets and commitments under the Paris Agreement are to be achieved. Ireland and the EU have also signed up to the Global Methane Pledge, which aims to collectively reduce CH_4 emissions by 30% between 2020 and 2030.

A 'fair share' approach to calculating the necessary reduction in Ireland's biogenic CH_4 quota suggests a reduction of between 30% and 80% by 2050, relative to 2010 levels (Prudhomme et al., 2021). Annual reductions of 2.2% per year between 2020 and 2050 would be sufficient to achieve a 50% reduction in CH_4, and these small but sustained rates could make it easier to meet Ireland's carbon budgets (McMullin and Price, 2020). The question of what is a national 'fair share' of CH_4 reduction is not developed in the academic literature and Ireland, as a country with high CH_4 emissions, relative to population, and strong decarbonisation ambition, is facing this question sooner than others. It should be noted, especially in relation to scenarios developed in Haughey et al. (2023), that excluding CH_4 emissions from net zero greenhouse gas calculations assumes that ambitious reductions in CH_4, which align with global temperature stabilisation, will occur (Huppmann et al., 2018; Styles and Duffy, 2021). If appropriate reductions in CH_4 do not occur, then much larger carbon removals, that is afforestation rates by 2050, would be necessary to balance these CH_4 emissions (Styles and Duffy, 2021). From a global perspective, if CH_4 emissions are not reduced as much as required to avoid additional warming and limit temperature increase to 1.5°C, CO_2 emissions would have to reach net zero before 2030, 20 years earlier than planned (Reisinger and Leahy, 2019).

The EU's long-term goal is net zero greenhouse gases, based on a global warming potential (GWP_{100}[13]), by 2050. The approach to CH_4 in the draft long-term strategy (DECC, 2023) is not aligned with EU net zero and it is not clear if it is aligned with requirement for net zero under Irish Climate Act. The uncertainty around 'significant reduction' in the draft Long-term Strategy is problematic.

The Climate Action Plan 2023 has set out several measures to reduce agricultural CH_4 emissions, including lowering the slaughter age for beef and breeding animals for low-CH_4 traits (Government of Ireland, 2022; for a comprehensive assessment see Volume 2). The plan also includes measures that support farmers to diversify farm activities, including alternative land uses. Such alternatives include (1) producing biomethane from grass, (2) increasing tillage area, (3) reducing the intensity of production on organic soils in order to increase the water table and (4) increasing the area under organic farming, and afforestation.

[13] GWP_{100} allows the comparison of the warming effects of greenhouse gases such as CH_4 and N_2O to that of CO_2 on a per-molecule basis over a 100-year time span (see Volume 1, Chapter 2).

2.1.4. Scenarios for agriculture and land systems

Global pathways that aim to limit global temperature rise to 1.5°C by the end of the century are explored in the IPCC Special Report on 1.5°C (Rogelj et al., 2018). When these pathways include climate mitigation actions that require land, it is projected that (1) the amount of land used for food and feed production will be reduced and some biomass will be grown on marginal land, (2) second-generation bioenergy crops will expand, while deforestation decreases and afforestation and reforestation increase, which means less space for agricultural expansion, (3) if reforestation is used for carbon removal, then forest cover stays constant or contracts slightly, (4) pasture and cropland, for food and feed, are projected to decrease and (5) reductions in land available for agriculture are compensated by intensification on the land that is available to agriculture and in livestock production systems (Popp et al., 2017; Rogelj et al., 2018).

Scenarios for achieving net zero greenhouse gas emissions in agriculture and land use have been developed by Haughey et al. (2023; see Box 2.2) and other recent studies (Duffy et al., 2020; Styles and Duffy, 2021; Duffy, C. et al., 2022a, 2022b). These studies suggest that while achieving a pathway to net zero greenhouse gas emissions in Ireland is challenging, in particular as the LULUCF sector is a source of emissions, a pathway to net zero is possible, at least within the biophysical limits of the land system. These scenarios demonstrate what potential transformative pathways could look like in Ireland and the level and type of change that would be required to achieve not only climate neutrality, but to make space for nature as well.

These scenarios are only some of the possible options available to mitigate emissions and adapt agriculture, forestry and other land use to climate change. An assessment of potential response options is presented in Haughey (2021) and a comprehensive assessment of model scenarios associated with agriculture and land use are covered in Volume 2. While a reduction in herd numbers, rewetting of soil, afforestation and making space for nature, as suggested in Haughey et al. (2023), are all ‘technically’ possible and have the potential to transform agriculture and land-use systems in Ireland, much research is required to draw out both the synergies and the trade-offs, not just between climate and biodiversity, for example, but across all of society and the economy.

Box 2.2 Land-use review and land cover database

The strategic management of competing claims on land is being developed in Ireland, with the aim that "optimal land use options inform all relevant government decisions" (DECC, 2021). A national land-use review is being prepared to support the development of a land-use strategy (DECC, 2021; see Volumes 2 and 3). Phase 1 of the review provides evidence related to the environmental, ecological, social and economic characteristics of land use, providing a holistic view of land use in Ireland. The outcomes of this phase of the review were made public[14] in March 2023. Phase 1 will provide the evidence base to inform Phase 2. During the second phase, there will be a consultation with all stakeholders to consider the policies and measures that will need to be developed and implemented to achieve the Government's wider climate, environmental, social and economic objectives.

The *Land Use Review: Fluxes, Scenarios and Capacity* (Haughey et al., 2023)[15] develops a set of scenarios, some of which achieve long-term, to 2050, net zero reductions in greenhouse gas emissions associated with agriculture, forestry and other land use (for origins and explanations see Volumes 2 and 3). It provides information on key components and the role they could play in developing a pathway to a carbon-neutral and biodiversity-rich landscape in Ireland by 2050 and forms the basis of the assessment in this chapter.

A high-resolution land cover database has been developed by the Environmental Protection Agency (EPA) and Ordnance Survey Ireland, and was delivered in 2023[16] (DECC, 2021; Haughey et al., 2023). The land-use review and land cover map will be key to developing a long-term land-use strategy, of which climate and biodiversity are key components, within a land management framework with the potential to understand how each parcel of land in Ireland can be utilised to maximise opportunities (see Volume 3). The EPA are also developing a land-use map to aid in delivering the national inventory report.

2.1.5. Synergies and trade-offs in agriculture and land-use mitigation options

There are many potential synergies between agriculture and land use and acting on climate (IPCC, 2022a). There are also synergies between mitigation actions in this sector and biodiversity loss, increased resilience and sustainable development (Denton et al., 2022). However, strategies are required to manage potential trade-offs that can result from misguided or inappropriate land management (Smith et al., 2014; Nabuurs et al., 2022). When climate change and biodiversity loss are tackled together, it is possible to systematically identify synergies and trade-offs between the actions taken.

The synergies and trade-offs presented in Figure 2.2 demonstrate that synergies outnumber potential trade-offs. When considered in a more detail, even when strong synergies exist, there are caveats related to how to optimise these synergies. For example, restoration of exploited peatland is deemed as 'widely beneficial'; however, restoration activities are likely to be site specific. There are also considerable uncertainties associated with some types of land-use change, for example in relation to raising the water table in grassland settings and how that affects productivity and land management. When it comes to trade-offs, identification can lead to minimisation and management. For example, increases of livestock density on grasslands are likely to have detrimental effects on water quality, but there are simple actions, such as removing access to waterways, that can reduce those effects.

[14] The outcomes from Phase 1 of the Land Use Review can be found at the Department of Agriculture, Food and the Marine and the Department of the Environment, Climate and Communications: https://www.gov.ie/en/publication/f272c-land-use-review-phase-1/#

[15] Research commissioned by the EPA to inform the National Land Use Review: https://www.epa.ie/publications/research/evidence-synthesis-reports/evidence-synthesis-report-3.php and https://www.epa.ie/publications/research/evidence-synthesis-reports/evidence-synthesis-report-4.php

[16] Ordnance Survey Ireland and EPA Land Cover Map: https://osi.ie/products/professional-mapping/national-land-cover-map/

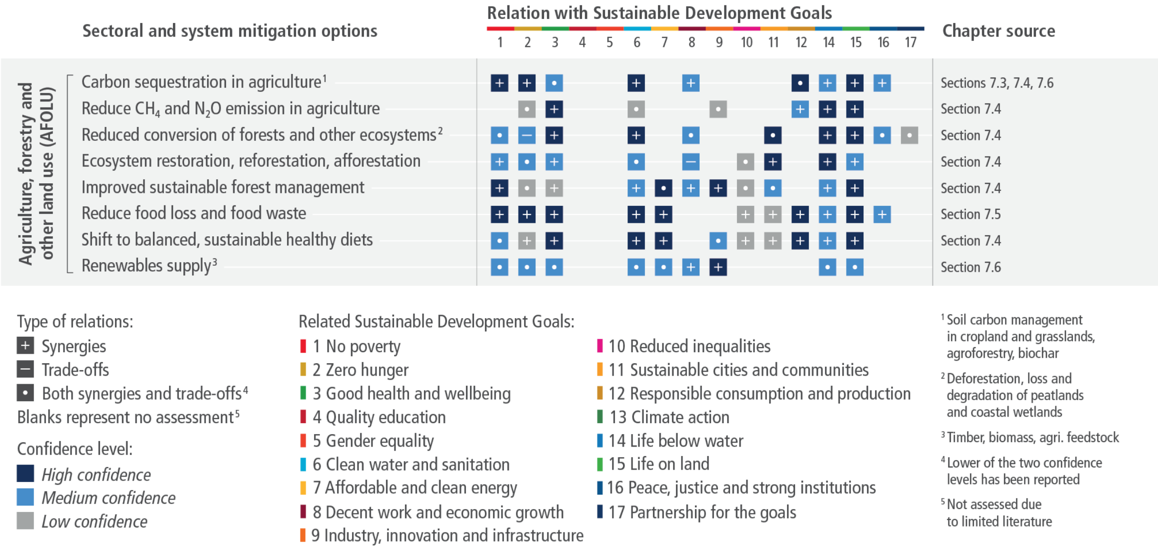

Figure 2.2 Synergies and trade-offs, as identified in the most recent IPCC Sixth Assessment Report by Working Group III. Source: Adapted with permission from IPCC (2022b; their figure 17.1).

Significant synergise exist between adaptation and mitigation, particularly in relation to agriculture and sustainable land management, and can provide immediate benefits, including enhanced food security, nutrition, health and wellbeing, support for livelihoods and biodiversity, and sustainability, and ensuring natures' contributions to people (IPCC, 2019, 2023a). Natural regeneration can be an important benefit for adaptation, optimising synergies with mitigation. For example, making space for rivers can reduce vulnerability to flooding, increase biodiversity, restore natural systems and increase community wellbeing, by providing a green amenity while maintaining and enhancing carbon reductions and removals and strengthening the resilience of carbon stores (Warner et al., 2012).

Nature-based approaches are strategies that address societal challenges, address biodiversity loss and increase human wellbeing (Cohen-Shacham et al., 2016; Pörtner et al., 2021; see also Volume 3). As part of these approaches, mitigation and adaptation actions meet biodiversity actions to strengthen synergies and reduce trade-offs (Seddon et al., 2020). Nature-based approaches have the potential to tackle climate change and biodiversity loss while contributing to sustainable development, making them powerful and attractive actions (Seddon et al., 2020). However, there is the potential for trade-offs if approaches, such as afforestation, focus on only carbon storage (i.e. single species in an unsuitable area). This would not be considered a nature-based approach, as there are no wider benefits for biodiversity, human wellbeing or adaptation and there can be 'severe unintended consequences' in terms of biodiversity loss (Pörtner et al., 2021), which can in turn impact the viability of the mitigation actions.

Haughey et al., (2023) present a comprehensive assessment of the synergies and trade-offs related to the scenarios developed as part of that work (see Haughey et al. (2023) table 6.1). The assessment focuses on the synergies and trade-offs between land-use change, including (1) large scale afforestation, (2) peatland restoration and organic soil rewetting, (3) increases in agricultural efficiency, (4) changing livestock density, (5) additional space for nature, (6) using grasslands for bioenergy and (7) converting grassland to croplands, and climate action, biodiversity and water quality.

Alongside potential negative effects of mismanaging synergies and trade-offs related to land-use change and climate and environmental considerations, there are potential negative consequences of an unmanaged change. To avoid both, a long-term, integrated, whole of government, whole of society land-use management and planning strategy is required (Haughey et al., 2023). This will allow land use to be optimised and will maximise synergies. These large-scale changes in land use would also need to deliver on societal and economic changes as part of a wider sustainable development pathway.

Translating high-level national and sectoral policies and objectives to spatial scales relevant for land, climate and biodiversity, such as at the catchment, habitat and field level, can help ensure positive outcomes of a managed transformation (Valujeva et al., 2016; Haughey et al., 2023). Translating to scales relevant to those who will implement the changes, regional and local, particularly in the case of including communities in decision making, can bring transparency and engagement between local communities and landowners and lead to a more comprehensive and integrated approach to finding solutions that work locally (Hurlbert et al., 2019; Murray, 2020; see Box 2.3).

2.2. The multiple roles of landscape

Human activities dominate Irish land use. Most land is dedicated to the production of livestock, mainly cattle and sheep (Teagasc, 2023). Forest area is predominantly used for producing timber. Under the current model, food, feed and fibre production is carbon intensive, reduces the ability of landscapes to sequester and store carbon, is in conflict with nature and limits adaptation. Transformation and diversification of landscapes to address climate change and biodiversity loss requires consideration of the multiple roles land currently plays, the optimisation of synergies and management of trade-offs between different activities. Integrated land-use policies and planning is needed to reconcile conflicting land-use objectives (Rogelj et al., 2018).

2.2.1. Food and feed

Irish land use is dominated by unsustainable and 'productive' uses, that is the production of food and animal feed, timber, fibre and energy as an alternative to fossil fuels[17]. Fifty-nine per cent of grassland in Ireland is used to feed cattle and sheep and an additional 10% is used to produce crops, mainly to produce livestock feed (Teagasc, 2023). Since joining the EU and the Common Agricultural Policy in 1972, food production in Ireland has focused on specialisation, intensification and concentration (Kenny et al., 2018; Walford, 2003). This, along with more than €50 billion from the Common Agricultural Policy, has resulted in Ireland becoming the sixth largest net exporter of fresh beef (Trade Map, 2022), the fourth largest dairy processor in Europe, holding 12% of global market for performance nutrition (O'Shaughnessy and Sage, 2016) and supplier of 12% of the world's infant formula (Fenelon and Tobin, 2019).

In 2021, dairy farms emitted 9.5 tonnes (t) CO_2-eq per hectare, while cattle and sheep farms emitted 4.7 and 4.1tCO_2-eq, respectively, and for tillage the value was 2.5tCO_2-eq per hectare (Buckley and Donnellan, 2021). These values do not include greenhouse gas emissions from land use or the 'carbon opportunity cost', that is the carbon that can be stored in the land, if it is taken out of productive use and natural vegetation allowed to grow, with the potential for carbon sequestration through ecosystem restoration (Hayek et al., 2020). Emissions and the carbon opportunity cost are largest in food production systems, with high land use, particularly beef and lamb (Schmidinger and Stehfest, 2012).

Haughey et al. (2023) and C. Duffy et al. (2022a) suggest that a transformation in land use is necessary if net zero emissions, in alignment with the Paris Agreement, and biodiversity goals are to be achieved. This research indicates that the land under agricultural production will need to be reduced to (1) make space for nature, which supports food production, (2) allow for the restoration of wetlands so that carbon stores can be protected and (3) increase forest area to enhance carbon sequestration. Typically, more profitable farm enterprises are associated with more greenhouse gas-intensive systems, which has created a trade-off between environmental and economic outcomes. Societal and environmental sustainability have been neglected in favour of economic progress (Fahy, 2020). The beneficiaries of the current model of production are large farms and agri-business, while small farms and people living in rural areas are losing out (Shucksmith et al., 2005; Hennessy and Moran, 2014; Matthews, 2016). Transformative change is also required to support people who farm and live in rural communities (see Chapter 4).

Change in food production systems and consumption patterns, including diets, are urgently required (Smith and Gregory, 2013; Clark et al., 2020; see Chapter 5). One way to achieve this type of change is with alternative proteins. Meat made from plants, cultivated from animal cells or derived from insects could be used to feed people and livestock in the future (Bezner Kerr et al., 2022). This emerging technology may lead to a reduction in the amount of land that is dedicated to grasslands and crop-based feed for livestock (Rosenzweig et al., 2020). Depending on the balance between the meat being substituted, the reduction in land use and the amount of energy being used to produce alternative proteins, it is possible that greenhouse gas emissions could be reduced (Rubio et al., 2020; Santo et al., 2020). In 2020, Teagasc, University College Cork, National University of Ireland, Galway, University of Limerick and Queens University Belfast, alongside 10 industry partners, received funding to the tune of €3 million from the Department of Agriculture, Food and the Marine to carry out a multi-disciplinary collaboration to investigate unlocking alternative protein opportunities to elevate nutrition in Ireland (Teagasc, 2020). This research has the potential to aid in transforming agriculture and land use and provide high-skilled and sustainable jobs in developing and delivering high-quality nutrition via alternative sources of protein in Ireland (Teagasc, 2020).

[17] The amount of land dedicated to non-fossil fuel energy sources in Ireland is currently small.

The Department of Agriculture, Food and the Marine's Food Vision 2030 uses system-wide transformation as a frame and food systems to organise the strategy (DAFM, 2022a). This includes consideration of the wellbeing of producers, but it does not extend to wider food system issues, for example hunger and food insecurity in Ireland or shifting consumption patterns towards healthier diets. Serious concerns have been raised in relation to claims of environmental sustainability[18] within the strategy (Emmet-Booth et al., 2019; Friends of the Irish Environment, 2022; O'Brien, 2022). While agricultural productivity takes priority in agricultural strategy, the Burren Programme (see Box 2.3) is an award-winning example of conservation (nature and heritage) and restoration of ecosystems on farmland in association with farmers and local communities in Ireland, rewarding farmers for improving biodiversity and demonstrating that there are huge opportunities for transformative change in developing projects like this.

Box 2.3 Burren (Farming for Conservation) Programme

Expert contribution from Brendan Dunford.

The Burren (Farming for Conservation) Programme (2010–2022) demonstrates the potential of local communities to act as stewards of their environment and heritage. Funded by the Department of Agriculture, Food and the Marine under the EU Common Agricultural Policy, and by the National Parks and Wildlife Service, it adopted what might best be summarised as a 'pocket, head and heart' approach to the conservation of natural and cultural resources by farmers.

The 'pocket' – or finance element – focused on a novel hybrid payment system for farmers: fields were scored from 0 to 10 based on their environmental health using a simple scorecard. Annual payments were linked to score, offering farmers a direct incentive to improve management while affording them freedom to innovate in doing so. Additional funding for conservation support actions – repair of walls, removal of invasive scrub, protection of water sources – was also available: nominated by farmers, these works helped address environmental challenges on the farm and thus improve annual scores and payments.

The 'head' refers to research, advice and support on how to 'farm for nature' and this was provided through a local office that not only advised on best practice – often based on innovations co-created with the farmers themselves – but also dealt with the significant bureaucratic workload involved in undertaking conservation work in protected landscapes such as the Burren. Feedback from farmers suggested that this local office – similar to a Teagasc office, offering advice on beef or dairy farming – was a key factor in their willingness to engage constructively with the programme.

The 'heart' refers to an often-overlooked issue: farmer engagement. Like all of us, a farmer will do a better job when he/she feels it is worthwhile and meaningful. Decades of innovative educational programmes in local schools, farmer-led walks, community 'tea-talks', farming festivals such as the Winterage Weekend – all organised by a local charity, the Burrenbeo Trust – helped farm families feel valued and respected and gave them ownership of an issue from which they typically feel excluded. In addition, under the Burren Programme, every effort was made to minimise paperwork for farmers, to simplify the language used, to take a practical approach and to allow them freedom to farm, all simple but significant ways of creating a more user-friendly experience for farmers.

The result-based scoring system employed by the Burren Programme suggests evidence of the positive impact of this approach, with consistent improvements in environmental health scores for 12 years across 23,000ha of prime Burren habitat. In addition, the programme cost of just over €1 million per annum suggests that these results have been achieved with relatively modest investment, representing value for money. The programme's landscape–scale and 13-year time frame means that it has much to offer in terms of learnings for other regions and for policymakers who seek a sustainable, scalable grassroots solution to the environmental challenges that lie ahead for Ireland[19].

18 Both in Ireland and in relation to imports used in the Irish food system.

19 www.burrenprogramme.com, https://burrenbeo.com, www.burrenwinterage.com

Box 2.4 Carbon leakage

The potential for a reduction in Ireland's dairy and beef production to be offset by an increase in production of these products in regions with a higher carbon intensity, a form of carbon leakage, is under discussion. The expansion of Irish food production and a consequent rise in greenhouse gas emissions has been rationalised on the basis for carbon leakage (Lanigan et al., 2018). However, there has been very limited research on the likelihood of carbon leakage in the Irish context, or on policy measures that can reduce the likelihood of carbon leakage. A review of evidence on climate mitigation in agriculture and land use for the Climate Change Advisory Council concluded that:

> ***leakage is likely to occur but there is insufficient evidence to provide a definitive answer to whether a reduction in agricultural production in Ireland will lead to a net increase in global greenhouse gas emissions. The balance of probability suggests that mitigation measures implemented with the support of subsidies, together with an extended range of mitigation options, would not increase global emissions (Emmet-Booth et al., 2019).***

This indicates a clear gap for research related to carbon leakage and also a need for an assessment of comparative efficiency of agricultural production systems across countries in order to be able to compare like with like in terms of outputs. Furthermore, research at the European level suggests that addressing agricultural greenhouse gas emissions from the consumption side, by reducing carbon-intensive foods (particularly meat) in diets, is an important mitigation strategy to avoid carbon leakage (Fellmann et al., 2018). This is consistent with the findings in Chapter 5, which show that dietary shifts in high-income countries are necessary for mitigation pathways consistent with the Paris Agreement commitments. Multilateral agreements, climate diplomacy and trade-related measures, such as import standards and border adjustment mechanisms, have been proposed to reduce the impact of carbon leakage (Matthews, 2022).

2.2.2. Energy and fuels

The area dedicated to renewables, on land and at sea, and to bioenergy will increase in response to the greater need for renewable energy. Under the second EU Renewable Energy Directive, Ireland is committed to increasing its renewable energy share from 13.6%, in 2022, to 34.1%, possibly 45%, under RePowerEU, by 2030 (SEAI, 2022). Requirements related to sustainability and greenhouse gas emissions savings are also needed to be fulfilled in relation to biomass, biogas and biofuels. These requirements are intended to assure sustainable land use, protect biodiversity, conserve ecosystems, and address the rights of workers and local communities and efficient use of resources (Mai-Moulin et al., 2021). While there have been significant developments related to sustainability, particularly in the EU, concerns about the impact the bioenergy sector on biodiversity, soil, water and land use remain (Mai-Moulin et al., 2021). Integrated environmental and economic research and policy are still lagging the rapid development of energy crops (Dauber et al., 2010).

The bioenergy scenarios developed by Haughey et al. (2023; see Volume 2) suggest that 420,000ha from grassland can be made available to bioenergy crops (grasses or fast-growing trees) while achieving net zero greenhouse gas emissions (including CH_4) by 2050. While land can be dedicated to bioenergy crops as part of this scenario, when CH_4 is included, ambitious afforestation (35,000ha per year) and rewetting of organic soils alongside reductions in livestock emissions and numbers would also be required. When CH_4 is not included in the net-zero calculation, the only change is in the level of afforestation, which could be reduced (20,000ha per year).

From a nature conservation perspective, research by Santangeli et al. (2016) suggests that bioenergy is a major threat to biodiversity, while the threat from land-based solar and wind appears smaller. There are also concerns around biogas that is produced with a high share of grass sileage, which has negative environmental impacts (Beausang et al., 2021), and that leakage of CH_4 from biogas plants can offset greenhouse gas emissions savings (Bakkaloglu et al., 2022). In areas that have high potential for development of renewables and high levels of biodiversity, the potential for trade-offs is high. In Ireland, there are also biodiversity concerns related to the construction and decommissioning of renewable energy infrastructure and the land requirement for solar (Gorman et al., 2023). Increasingly, research focuses on solutions where solar can co-exist with farming if space is left underneath panels for grazing and food production (Schneider et al., 2023; Shivaram and Buckley Biggs, 2023).

Strategies for the effective management of bioenergy that draw out synergies and reduce the risk of trade-offs will be necessary if negative impacts are to be avoided (Fraanje et al., 2019). Food systems research suggests that agricultural production take a circularity approach, and this could be extended to bioenergy (de Boer and van Ittersum, 2018). Yet, there is no coherent framework to systematically approach synergies and trade-offs in this area. Research to date focuses on the competition between food, feed and fuel. In the main, biodiversity loss has not been incorporated as it is seen, by some researchers, to be more of a long-term issue, in contrast to food and energy, which are seen as short-term issues (Muscat et al., 2020). Careful and integrated land use and energy planning and implementation will be required to prevent further pressure on biodiversity from climate action, particularly in relation to developing renewable infrastructure and the associated changes in land use (Gorman et al., 2023; Shivaram and Buckley Biggs, 2023).

Box 2.5 Energy and planning

Ireland is committed to a 34.1% or 45% increase in renewable energy by 2030. A large part of that, 5 gigawatts, will be delivered through developing offshore wind. There have been several developments that will significantly enhance Ireland's capacity to develop offshore wind and enable the transformation of the energy system. These include development of the regulatory framework, the National Marine Planning Framework (NMPF), the Maritime Area Planning Act, including maritime area consent, and the establishment of the Maritime Regulatory Authority. Background work related to the infrastructure necessary to being offshore energy onshore is also being carried out for two main sites – the Shannon Estuary and the Port of Cork – both of which already have major energy infrastructure developed on site and extensive brownfield areas.

The enactment of the Maritime Area Planning Act (Government of Ireland, 2021c) and the publication of the NMPF[20] (Government of Ireland, 2021b), developed through extensive cross-sector and stakeholder engagement, lay a strong foundation for the strategic management of Ireland's extensive marine resources. The main aim of the NMPF is to balance the use and development of marine resources, for example offshore renewables and protection of the marine environment, and streamline the marine planning process. A Marine Protected Areas Bill has been proposed also so that sites can be identified, designated and managed as marine protected areas (see Volume 3, Chapter 2). These are important developments for both climate action and conservation of biodiversity and in creating opportunities for coastal communities.

Box 2.6 Bord na Móna: peatland regeneration and just transition

Expert contribution from Jamie Rohu.

Approximately 20.6% of Ireland comprises peatland (Connolly and Holden, 2009). These wetlands are at the centre of contemporary debates surrounding climate change, biodiversity loss and just transition. The latest estimate indicates that these ecosystems store over 2.2 billion tonnes of carbon (Renou-Wilson et al., 2022). Irish peatlands have been drained for hundreds of years to facilitate extraction of turf for domestic and industrial energy needs, with implications for uniquely adapted plants and animals, including sundews (*Drosera*) and curlew (*Numenius arquata*). Moreover, these activities lead to the release of harmful greenhouse gases into the atmosphere and adjacent watercourses.

There are two types of bog in Ireland. The blanket variety carpet entire landscapes. They are found in uplands and on the western seaboard, where rainfall is high. Raised bogs are mostly found in the midlands. They emerged from shallow lakes filled in by slowly decomposing aquatic vegetation. Feehan et al. (2008) estimate that as much as half had been cut away prior to the establishment of Bord na Móna in 1946, a state-owned peat company set up with a remit to provide rural employment and supply the nation with an indigenous source of energy. Like all fossil fuels, peat is a finite resource. Production bogs inevitably become exhausted, or 'cutaway'. Consideration of the subsequent use of these landscapes began shortly after Bord na Móna's founding (Mooney, 1958). Their conversion to agriculture and forestry proved uneconomic due to their low nutrient profiles and heterogeneity (Renou-Wilson and COFORD, 2008; Black et al., 2017).

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[20] The maritime equivalent of the National Planning Framework.

Peatland rehabilitation, renewable energy and resource recovery are now at the forefront of Bord na Móna's business activities. Following the announcement of the end of its peat extractive operations in January 2021, the company commenced the EU and Irish Government-funded Peatlands Climate Action Scheme. This €126 million endeavour will result in the 'enhanced' rewetting of some 33,000ha of post-production bogland to limit ongoing carbon emissions. Rehabilitated peatlands rapidly repopulate with flora and fauna. Common cranes (*Grus grus*), a species once extirpated in Ireland, have recently bred in post-industrial bogland in Co. Offaly. Bord na Móna is developing wind energy in some of its landholdings in response to government policy that aims to derive 80% of the country's energy requirements from renewable sources by 2030. However, concerns remain for individuals and businesses dependent on the peat sector.

The socioeconomic implications for workers following industrial bog closures were recognised in the 1970s (O'Connor et al., 1977). Employment in Bord na Móna peaked at 7,171 in 1983, following its rapid expansion in response to the oil crises of the decade before (Clarke, 2010). By 1992, just 2,767 people were employed in the company (Clarke, 2010). In 2018, Bord na Móna's Littleton briquette factory ceased production. This marked the beginning of a series of redundancy programmes at the company. Trade unions have lobbied for a 'just transition' for those affected. This sees fossil fuel workers redeployed in alternative, sustainable roles with similar terms of employment (Leopold, 1995). To meet this challenge, over €200 million in Irish and EU funding is being invested into the redevelopment of the Irish midlands. However, Banerjee and Schuitema (2022) identified frustration among community members and peat workers concerning the rollout of this process. Healy and Barry (2017) described just transition as 'intensely political', as it involves considerable trade-offs. There are few jobs available in renewable energy once construction is completed. The Peatlands Climate Action Scheme provides employment in reprofiling bogs and blocking drains to workers previously made redundant, albeit on a short-term basis. It remains to be seen how communities and workers once dependent on the Irish peat industry will fare in the future.

2.2.3. Carbon storage and sequestration

Afforestation and restoration of peatlands and organic soils are opportunities for Ireland to protect, maintain and enhance carbon stores to tackle climate change. They are key to achieving net zero greenhouse gas emissions in scenarios presented by Haughey et al. (2023). Based on indicative scenarios that include CH_4, the levels necessary to create a net-negative carbon sink in Ireland are ambitious: 500,000–875,000ha of afforestation, 302,000ha of rewetting of grasslands on organic soils and 70,000ha or exploited peatland restored by 2050 would be required (Haughey et al., 2023).

An enormous level of change is required in the landscape. This means change for rural communities, farmers, foresters and all those who work the land if transformative change is to be achieve. If a transformative, nature-based approaches perspective is adopted, it could become much greater than opportunities to sequester carbon. It could also improve livelihoods, bring good jobs, help to sustain and revitalise rural areas, tackle environmental degradation and enhance the resilience of ecosystems, communities and the local economy. Such an approach is necessary to ensure that trade-offs are managed and the risks to the future integrity of carbon stores from the impacts of climate change are also managed. Land-use change cannot be tackled in isolation. Mitigation actions in other sectors are also necessary for Ireland to play its part in keeping the increase global temperature below 1.5°C. The carbon stored in forests or peatland becomes more vulnerable with increasing climate change. Careful planning to create, restore, protect and ensure a sustained net sink for natural carbon removal to 2050, 2100 and beyond is required, as these are the timescales relevant to carbon stores. Conservation, management and restoration of forests and peatlands have the most potential to provide economic opportunities and improve rural livelihoods (IPCC, 2023b). A long-term, integrated strategic plan for carbon stores is needed as part of a wider planning framework, in some ways similar to the level of planning that is more familiar in urban areas (Scott, 2022), to benefit from these opportunities.

2.2.3.1. Afforestation, reforestation, natural regeneration and management

Forests are a proven, cost-effective and scalable option for the removal of carbon from the atmosphere (Fuss et al., 2018; Duffy, C. et al., 2022a). According to indicative scenarios developed by Haughey et al. (2023), if net zero greenhouse gas emissions, when CH_4 is included, are to be achieved, current forest cover, 11.6%[21], will need to more than double, up to 24%, or around 1.7 million ha, between 2025 and 2050. These scenarios give an indication of the level of afforestation, and other significant changes to land use, necessary to balance emissions from agricultural practices and land use to achieve net zero emissions by 2050. The net zero 'landing zone' achieved because of the ambitious changes required is narrow, around 100,000tCO_2-eq per year. These scenarios and the simplified assumptions used to parameterise them can be a useful guide in developing a land-use strategy, but more research and data will be necessary to better understand the magnitude of the forest sink that will be required if Ireland is to bring its emissions into balance.

As of 2023, carbon budgets are already highly constrained, and Ireland is not yet on track to achieve near-term carbon budgets, excluding LULUCF, and it is possible that future carbon budgets will be even more constrained and that a significantly larger net-negative carbon sink is required to balance excess emissions. Another important factor when considering carbon removal through afforestation is that it takes decades for trees to grow and mature and deliver on higher levels of carbon storage. In order to achieve net zero or net-negative emissions by 2050, forests need to be planted in the near term so that carbon stores are mature as required. This is because there is a limited capacity of young forest to capture CO_2 in the short term. However, in the longer term, as sequestration rates increase, they will play a greater role in achieving carbon neutrality to 2050.

When the 'right trees' are planted in the 'right places' and for the 'right reasons', healthy, biodiverse and resilient forests can be created. This is a prerequisite for providing food, fibre, fresh water and medicines, alongside jobs and wider social and economic goods, for rural communities (European Commission, 2021). This idea is central to the European Commission's new forest strategy, which builds on best practice that suggests that growing, restoring and protecting forest is not just good for nature and society, but that sustainable forestry is economically viable when managed in an appropriate way (European Commission, 2021). Afforestation and reforestation can be an opportunity to employ nature-based approaches.

Climate-smart forestry management is an important element of meeting forests' potential to address climate challenges (Korosou, 2023). To increase the effectiveness of carbon removals and enhance forest resilience, a balance of wood production, biodiversity protection and ecosystem services is required, with more timely monitoring of greenhouse gas fluxes (Verkerk, 2020).

Doubling forest cover in Ireland will be a significant undertaking. Research on afforestation on mineral agricultural soils suggests that it is possible to make significant gains in the short term with very high levels of afforestation (Duffy et al., 2020). It is not clear when an overall land-use strategy may emerge to guide land-use change in Ireland. However, the Department of Agriculture, Food and the Marine has recently published Ireland's Forest Strategy (2023–2030) (DAFM, 2023b)[22]. It broadly reflects the approach taken in the new EU Forest Strategy for 2030. Both strategies are high level, with little information related to implementation. They link to the EU Nature Restoration Law, EU Biodiversity Strategy for 2030 and support enhanced sustainable forest management and ecosystem-based restoration that aim to restore, protect and enhance resilience of all forests in the EU.

In other European countries forests have for a long time been centres for cultural heritage, craftmanship, traditional knowledge and innovation (European Commission, 2021). In Ireland, rural identities and culture have stronger links to agriculture and trees are not often seen as part of traditional agriculture (DAFM, 2022b). There is a growing industry and bioeconomy emerging in the forestry sector in Ireland. Timber materials can replace emissions-intensive materials such as cement and steel. If supported and managed appropriately, there is no reason that forests in Ireland cannot store more carbon, while at the same time enhancing biodiversity in the future. Forests could become important hubs for highly skilled jobs, innovation and ecotourism, opening new opportunities for those living in rural areas (European Commission, 2021).

Natural forest regrowth has the potential to generate substantial global carbon removals and is a cost-effective large-scale strategy (Strassburg et al., 2019). By 2100, it has the potential to be more than 40 times as effective in carbon storage than

[21] Despite the low forest cover, afforestation rates in Ireland in the last century have increased national forest cover from around 1.4% in 1918 to the present level of 11.6% (Haughey et al., 2023).

[22] While this strategy is now published, it was not available for inclusion in this assessment during drafting..

monoculture plantations (Lewis et al., 2019). This would also have important benefits for biodiversity. There are encouraging signs from Europe and in Ireland, related to natural regeneration of forest and woodland. Spontaneous forest regrowth is the dominant force increasing forest cover in the EU (European Commission, 2021).

Closer to home, 26,760ha of native woodland has come from natural regeneration and accounts for one-third of the overall increase since 2006 (DAFM, 2023a). This approach offers multiple synergies, as naturally regenerated woodland, dominated by broadleaved native species, have greater levels of biodiversity and resilience.

Hedgerows also have the potential to be an important carbon store in Ireland, with hedgerows covering 267,509ha or 3.8% of land area (DAFM, 2023a). However, research suggests that, at a county level, hedgerows are a source of emissions because of their removal and intensive management (Black et al., 2023). Traditional hedgerow management and alignment of farm payments for increasing hedgerow width could increase the maximum carbon storage potential of existing hedgerows, while new hedgerows could compensate for the loss of hedgerows in other areas (Black et al., 2023). This research suggests that there are ways to align policy related to farm payments that benefits carbon stocks, nature and farming communities.

Research by Irwin et al. (2022) documents the benefits of agroforestry, or 'trees on farms'[23]. Agroforestry has the potential to increase carbon stocks, reduce pollution, provide habitats and enhance farm-based benefits. These benefits include timber provision and improvements in animal health and welfare. Despite these benefits and subsidies, there is very little appetite for agroforestry in Ireland. This work investigates barriers to agroforestry and suggests, in contrast to other studies on afforestation (e.g. Ryan and O'Donoghue, 2016), that the long-term commitment that comes with planting trees is not necessarily a barrier, as half of farmers questioned did not see planting trees as a major decision. Lack of knowledge about agroforestry and the schemes and grants available to farmers were cited as possible barriers. Studies related to afforestation have suggested that barriers to uptake include the relative financial return from agriculture and forestry (Breen et al., 2010), farmer demographics (Frawley and Leavy, 2001) and farmer goals (Duesberg et al., 2013). Research by Ryan and O'Donoghue (2016) suggest that soil type, agricultural market income and subsidies affect the economic attractiveness of afforestation. Eighty-four per cent of farmers questioned as part of this study said that they would never take up afforestation, despite the financial incentives on offer. Economic incentives encouraging farmers to plant trees are at odds with those encouraging some farmers to increase their dairy herd (Duffy et al., 2020). Potential policy options have been identified by Ryan and O'Donoghue (2016) and include providing environmental public goods; overcoming inertia; timing of scheme payment; risk management; linking afforestation and agricultural land-use decisions; linking carbon neutrality objectives; extensions; a requirement to re-forest; establishment costs of subsequent rotations and differential land availability.

Aligning policy in land use to support the achievement of carbon neutrality by 2050 is important, not just for landowners and farmers but also for local communities. One example, from Nepal, saw a community lead doubling of forest cover over 25 years. A change in legislation allowed forest rangers to give responsibility for areas of national forest to local communities who developed plans to manage the forest and began restricting over grazing and limiting the amount of firewood that could be removed (Fox et al., 2019; Fox et al., 2020; Van Den Hoek et al., 2021; Cassidy, 2023). This example suggests that (1) local communities can play a role in achieving the necessary level of forest cover, (2) it is possible to double forest cover before 2050 and (3) simple changes to policy can have powerful effects. This does not mean that this particular example is the answer for Ireland, it is just an example of what can be done when changes in legislation and community participation are combined.

Details on synergies and trade-offs related to mitigation, biodiversity and water associated with afforestation are presented as part of Haughey et al. (2023). Synergies and trade-offs need to be identified, optimised and managed as part of an integrated approach across all sectors to reduce emissions. The risk to forests (particularly those made up predominantly of single species of the same age), their carbon stores, biodiversity, resilience and long-term sustainability increases and becomes less predictable as the climate warms. Sustainable forest management, nature-based approaches, ecosystem-based management and ecosystem restoration can increase resilience and help adapt forests to climate change (European Commission, 2021). These approaches can also stimulate local adaptation actions (European Commission, 2021). However, adaptation can only do so much to store and protect carbon as risks from climate change increase. Irish leadership at an international level will be necessary if other countries are to be encouraged to increase, restore and protect forests to ensure a working global carbon sink, but also to reduce emissions in line with the ambition of the Paris Agreement.

[23] One barrier to agroforestry uptake maybe be the term itself, which may bring negative associations to mind, including the perception of forestry as a rival to agriculture, and prevent farmers from seeking additional information (Irwin et al., 2022).

> *"Synergies and trade-offs need to be identified, optimised and managed as part of an integrated approach across all sectors to reduce emissions."*

2.2.3.2. Conservation and restoration of wetlands

Peatlands are the dominant type of wetland in Ireland. They mitigate climate change, preserve biodiversity, reduce flood risk and enhance fresh water availability (IUCN, 2021). Ireland has 1.4 million ha of peat soils, 21% by land cover, and of this 330,000ha is drained grassland on organic soils (Wilson, 2021; EPA, 2022c). Natural and managed peatlands store 2216 million tonnes of carbon, and store twice the amount of carbon in all other soil types in Ireland (Renou-Wilson et al., 2022; see Volume 2). Natural and cutaway bogs hold just under half of this carbon (Renou-Wilson et al., 2022). However, most peatlands, 85%, are moderately or severely damaged by drainage, peat extraction, agricultural conversion and plantation forestry, and only 20% remain of conservational value (Wilson et al., 2013; Renou-Wilson et al., 2019). If peatlands become too badly degraded, they lose their ability to store carbon. Conservation of peatlands that have not been degraded can have immediate benefits, while restoration of degraded peatlands will see benefits in the longer term. As soon as rewetting takes place on peatlands suitable for rehabilitation, including those under agricultural use, there is the potential to for removals (Ojanen and Minkkinen, 2020). In the near term, it is the reduction of avoided emissions, those that would arise from degraded peat, that is significant for climate change mitigation. In relation to forested peat soils, it is important to consider that rewetting these soils is not considered a positive climate change mitigation action in the near term (Ojanen and Minkkinen, 2020). Rewetting of peatlands is important for biodiversity, as it allows the restoration of peatland ecosystems (Parish et al., 2008; Bonn et al., 2014).

Scenarios developed by Haughey et al. (2023) suggest that achieving net zero greenhouse gas emissions would require 100% rewetting of exploited peatland, that is 70,000ha, and 90% rewetting of organic soils under grassland, that is 302,000ha, between 2025 and 2050. In Ireland, in the case of rewetting organic soils under grassland, the goal is to store carbon instead of releasing it, not the restoration of peatland ecosystems, and allowing agriculture to continue. It is important to note that rewetting in this instance does not mean flooding land. It means returning water-saturated conditions to peatlands or organic soils under grassland by managing the water table to achieve carbon removals and minimal CH_4 emissions. For peatlands, that means raising the water table to optimal levels of 10–15 centimetres (cm) of the surface (Wichtmann et al., 2016), and in the case of organic soils under grassland rewetting could occur up to a depth of 25cm (Renou-Wilson et al., 2016).

Like afforestation, restoring peatlands can be a nature-based approach if actions to do so tackle climate change and bring wider benefits to society and human wellbeing. Again, here there is also the potential to make decisions that exacerbate carbon and biodiversity loss if the actions taken do not take full consideration of biodiversity loss and human wellbeing alongside climate change mitigation considerations. The restoration and protection of peatlands and rewetting of organic soils under grasslands can continue to provide employment, and livelihoods are aligned with climate, biodiversity and human wellbeing goals. Historically, jobs associated with peatlands have been extractive, new jobs have already been created and more will be required to start to repair the damage that has been done and work with nature to create significant, lasting and resilient carbon stores. Where peatlands are concerned, this work will also involve the restoration and protection of these ecosystems. As well as livelihoods associated with the planning and management of wetland restoration, there are also opportunities associated with tourism.

2.2.4. Nature and ecosystems

Globally, the biggest pressures on nature and biodiversity are land-use change, mainly caused by agricultural expansion, and overexploitation of natural resources (IPBES, 2019a; Jaureguiberry et al., 2022; see Volume 1). However, climate change is a significant and growing pressure and could soon be the main driver (see Volume 1). Like climate change, environmental degradation is fuelled by economic activities and systems of governance (Díaz et al., 2015; Chan et al., 2020) and demonstrates the unsustainable relationship between humans and the planet (Pörtner et al., 2021).

Nature’s contributions to people are worth billions of euros to the Irish economy every year (Bullock et al., 2016; Norton et al., 2018). However, despite decades of global coordinated action on conservation, as part of the United Nations Convention on Biological Diversity, biodiversity in Ireland is in poor condition (NPWS, 2019; EPA, 2020). Agriculture is the dominant driver of biodiversity loss, with the most notable declines in peatland, grassland, woodland and marine ecosystems (NPWS, 2019; EPA, 2020). Other land use, including peat extraction and forestry, and to a lesser extent urbanisation and recreation, also contribute to biodiversity loss (NPWS, 2019; EPA, 2020).

Despite the intricate links between people and nature, and the greater understanding of the benefits it provides and our role in safeguarding it, nature has been taken for granted in Ireland (European Commission Directorate General for Environment, 2019; EPA, 2020). More than half of native Irish plants are in decline, caused by the same agricultural and forestry practices that contribute to climate change (Botanical Society of Britain and Ireland, 2023).

Policy and economic signals incentivise carbon-intensive and environmentally damaging practices (Duffy et al., 2020; EPA, 2020, 2022c), for example plans to increase grass-based livestock production (DAFM, 2022a). A genuine and transformative rebalancing of agriculture and land use in Ireland offers an opportunity to halt and restore declines in nature and ensure that its contributions to people and climate mitigation continues (Whitmee et al., 2015; Díaz et al., 2019; Haughey et al., 2023). Addressing the root causes or indirect drivers (see Figure 1.1) of climate change and biodiversity loss, for example unsustainable production and consumption (see Chapter 5), will be necessary. If this is not prioritised, then the long-term viability of both nature and food systems are threatened (EEA, 2017; IPBES, 2019b; EPA, 2020; Verkuijl et al., 2022).

2.2.4.1. Conservation and restoration of nature

A mass extinction, that is a widespread and rapid decrease in biodiversity, is under way globally (IPBES, 2019a). It is no longer sufficient to conserve remaining habitats and species. Ecosystems, such as wetlands and natural forests, need to be rehabilitated to repair the damage resulting from human activities (IUCN, 2022). Translating Ireland's commitments under the Kunming–Montreal Global Biodiversity Framework and EU targets on the restoration and protection of nature into national plans is ongoing. Ireland's fourth National Biodiversity Action Plan has been in development since October 2021. The plan will set the national biodiversity agenda for the period 2023–2027. The Joint Committee on Environment and Climate Action has highlighted the need to restore biodiversity along with action on climate, and has recommended new statutory measures across Government and additional resources for research and data (Joint Committee on Environment and Climate Action, 2022).

If Ireland is to achieve LULUCF targets, in line with the Paris Agreement, it will be necessary to scale up nature restoration. Nature restoration reduces emissions from land, enhances the capacity of ecosystems (including forests and peatlands) to store carbon and enhances ecosystem resilience, which can prevent future carbon emissions (Kopsieker et al., 2021; Pörtner et al., 2021). From an adaptation perspective, nature restoration is important as it reduces the exposure of ecosystems and humans to climate impacts, builds resilience to impacts and in some cases reduces the frequency and intensity of the hazard (McVittie et al., 2018). Climate mitigation and adaptation can be delivered through nature-based approaches. Nature protection, retention and restoration will not be possible if rapid reductions in emissions is not undertaken at the same time (Arneth et al., 2020; Watson et al., 2020).

If biodiversity loss is to be reversed and nature restored, it will be necessary to dedicate land to habitats. Thirteen per cent of land in Ireland is designated as protected (DAHG, 2014). Action on biodiversity and nature restoration is happening in Ireland at different scales and there is significant diversity among those actors, including landowners, from farmers to state and semi-state organisations. The implications of converting 10% of current grasslands to nature restoration and considering broadleaved dominant afforestation to enhance biodiversity and water quality outcomes have been considered by Haughey et al. (2023). The level of nature restoration on farmland may have already been achieved, but this is difficult to assess, as the current land cover database does not have the necessary resolution (Haughey et al., 2023; see Volume 3).

Benefits of protecting marine ecosystems include benefits for biodiversity, society and the economy. Fishing can benefit from the conservation, restoration and protection of marine habitats, particularly if the location of marine protected areas considers fish nurseries (Roberts et al., 2017). Marine protected areas offer a refuge to species under pressure from fishing and climate change and allow the ecosystems within these areas to recover (see Volume 3). This results in overspill of recovered species outside the protected areas, with benefits for fishers, including the prevention of long-term stock collapse and the resultant loss of income (OECD, 2017). Fishers are also able to supplement their incomes, as marine protected areas offer opportunities for nature-based tourism (OECD, 2017). Ecosystems, at sea and on land, will also need to be managed in the future to allow them to adapt to climate change.

Protected marine territory in Ireland at the start of 2023 was 8.3% and is indicated to rise to 10% by the end of the year (DAHG, 2014; DHLGH, 2022b). The implementation of the Marine Protected Areas Bill (Government of Ireland, 2022) will put Ireland on track to deliver on 30% protected marine areas by 2030. In 2023, Ireland also became a signatory of the UN High Seas Treaty, which protects aims to protect 30% of the world's oceans outside country boundaries.

While Ireland was part of the high-ambition coalition at the Convention on Biological Diversity COP15, it has not committed to designate 30% of land as protected by 2030. Furthermore, Ireland, while recognising the transformative power of the Nature Restoration Law, has told the EU Environment Council that it will have significant implications for planning and that there are concerns around how it can be funded (McDonnell, 2022). This indicates that while the ground is being prepared in some areas, including marine planning, the land-use review and land cover mapping, there is no clear, shared vision about the long-term management and protection of habitats and species on land and at sea.

2.2.5. Human health and wellbeing: amenity, clean air and fresh water

Landscapes play a crucial role in sustaining human health and wellbeing. Human activities are negatively impacting air and water quality, at the detriment of human health and nature. Many of the activities causing pressure on air and water quality are also the main sources of greenhouse gas emissions, to varying degrees: combusting fuels, mainly solid fuel for heat, agricultural and forestry activities, transport and energy and industrial process all contribute to poor air quality, as well as climate change. Mitigation measures for pollution and climate change often overlap and therefore reducing direct greenhouse gas emissions can have a double dividend for reducing pollution.

An estimated 610 premature deaths occur in Ireland each year because of poor air quality (EEA, 2022), mainly from particulate matter that arises from combustion. The agriculture sector accounts for nearly all ammonia emissions in Ireland. Unlike other pollutants under regulation, ammonia emissions are increasing (EPA, 2020), mainly caused by a growth in livestock numbers, including a 3% increase in dairy cow numbers in 2021 (EPA, 2023a). Ireland is not meeting EU targets on emissions of ammonia to air under the National Emissions Ceiling Directive (2016/2284/EU). Ammonia causes acidification and eutrophication of sensitive ecosystems (Guthrie et al., 2018) and atmospheric emissions contribute to particulate matter with a diameter of ≤ 2.5μm (PM2.5) formation, which has been linked "to higher death rates, respiratory problems, cardiovascular diseases, cognitive decline and low birth weights" (Wasley et al., 2019; Thangavel et al., 2022). Moreover, CH_4 emissions, which arise from livestock, are a precursor for tropospheric (ground-level) ozone, which damages human health and ecosystems (West et al., 2006).

Water quality in Ireland has been in decline over the past 20 years. Almost half of water bodies fail to meet the legal requirements of the Water Framework Directive (EPA, 2020). Nitrogen emissions from agricultural activities are having a significant negative impact on water quality along estuaries and coastal water bodies in the south-east and southern coasts, where algal blooms can damage ecosystems (EPA, 2022b).

Properly managed soils, particularly wetlands, which are critically important for biodiversity, filter and remove nutrients and store water, minimising pollution and flooding risks, by absorbing excess water and slowing its release downstream (EPA, 2020; IUCN, 2020).

There are synergies between protecting air and water quality and mitigating climate change. For example, measures taken to reduce chemical fertiliser use cuts greenhouse gas emissions of N_2O and reduces ammonia emissions from the air and excess nitrogen in water. Similarly, managing peatlands and organic soils for carbon sequestration by increasing the water table also acts as a nature-based approach to flood prevention, limiting the need for the construction of relief schemes, which can have significant negative impacts on water quality and habitats (EPA, 2020).

2.3. Transformative adaptation in Ireland's coastal areas

The Sixth Assessment of IPCC Working Group II calls for a renewed engagement with values in climate change adaptation (New et al., 2022). The report shows how limits to adaptation are being reached in many human systems, meaning that individuals and society are no longer able to secure their goals from intolerable risk. Against this background, transformational adaptation that requires radical non-linear changes to the fundamental attributes of a system (including economic and political) in response to climate risks is increasingly advocated as a way to address climate change impacts as well as other societal challenges (Clarke et al., 2018; IPCC, 2018). Yet, choices for transformation will ultimately depend on the goals that individuals and society decide to pursue, and thus on the values they wish to prioritise, reconfigure or leave behind when pursuing radical changes.

In Ireland, response to climate change is largely risk focused, with adaptation efforts centred on reducing exposure to hazards rather than examining the attributes of social and economic systems that make people vulnerable to the impacts of climate change. With respect to coastal management in Ireland, that has often meant one-off engineering interventions (Farrell et al., 2023). There are a large number of public organisations with remits in coastal protection and management, often with different policy objectives, which has prevented joined-up, long-term adaptation planning to date (Farrell et al., 2023). However, there are efforts under way for coordinated coastal management, which could open up space for more transformative approaches to adaptation.

On a local scale, transformative adaptation requires engagement with place-based values and interests. Work by Clarke et al. (2018) in Clontarf in Dublin has explored barriers to transformative adaptation to coastal flood risk. They find that the symbolic values that local residents in Clontarf associate with place means that there is a cognitive dissonance between the desire for safety and security (from floods) and the desire for familiar local places to remain as they are (and to not be changed significantly through adaptation interventions). Their example, along with wider international research, raises the

important point that the less people are attached to an area, the more likely they will be open to transformative change and, conversely, the more attached people are to their local places, the more resistance may be experienced to adaptation that requires significant change. Navigating the place change that may be required for transformative adaptation will require careful management, given the diversity of values that communities hold. Research on managed retreat in the Shannon catchment following floods in 1954 outlines the importance of situating adaptation in the social and political contexts of communities, and that place attachments and ties to local communities informs responses to more transformative adaptation response (Tubridy et al., 2021). This work shows that when adaptations (in this case managed retreat) are part of larger radical and transformative approaches to reducing vulnerability (in this case land reform), they can enjoy political support as well as material benefits. The authors also highlight the risk that narratives of place can be mobilised by powerful actors to justify inaction in response to climate risks.

Going forwards, in Ireland, there is a need for joined-up thinking on coastal management that can potentially address a range of societal challenges rather than climate change risks in isolation (e.g. biodiversity, land reform). There will be trade-offs: the desire for continuity will have to be considered alongside the potential impacts of future climate-driven disruptions and indeed the needs of future generations. In 2020, the Inter-Departmental Group on Managing Coastal Change was formed to scope an integrated approach for a coastal change management strategy. The Climate Change Advisory Council acknowledge the limitations of the National Adaptation Framework in informing coastal management and has highlighted the need for nature-based approaches and broader regulatory change for more diverse approaches in coastal management. The new Marine Strategy Framework Directive's programme of measures flags the importance of nature-based approaches. As a national coastal zone management strategy is developed in Ireland there is scope for more transformational approaches to climate change that address vulnerabilities and biodiversity challenges. This will require shifts in governance practices and collectively and transparently engaging with the potential negative impacts that transformational approaches may require, especially in the near term, for longer-term benefits.

2.4. Towards transformed landscapes

There have been transitions in global land-use and food systems in the past, and while this has brought affordable diets the outcomes for nutrition, environment and equity have not been as favourable (Ambikapathi et al., 2022). Systems transformation can take time, perhaps decades, and so it is important to identify the characteristics of transformational pathways while at the same time developing mechanisms to encourage change, coordinate action and engage all actors and the general public in participation (Buckwell et al., 2020; Newell et al., 2022). Such an approach presents Ireland with an incredible opportunity to rebalance land use and ocean use, to realign food production and consumption with environmental sustainability and wellbeing, allowing space for nature and changing the focus of land management in order to ensure nature's contributions to people (EEA, 2017; Kenny et al., 2018; Buckwell et al., 2020).

2.4.1. Evidence of the emergence of transformative change

There is growing awareness and recognition of important elements of transformative change in Ireland, including (1) the role of nature and its contributions to people (e.g. EPA, 2020; Joint Committee on Environment and Climate Action, 2022), (2) the impact of human activities on ecosystems and climate (e.g. Joint Committee on Environment and Climate Action, 2022), (3) the necessity to halt and reverse biodiversity loss and to restore degraded ecosystems (e.g. DHLGH, 2022a), (4) the requirement to limit the impact of climate change and working within the limits of natural systems (e.g. Joint Committee on Environment and Climate Action, 2022), (5) the importance of tackling climate and biodiversity together (e.g. Joint Committee on Environment and Climate Action, 2022) and (6) the importance of taking a transformative approach to land-use and food systems (e.g. DCHG, 2019; Biodiversity Working Group, 2020; EPA, 2020; DHLGH, 2022a).

It is not surprising that integration, to varying degrees, occurring in strategy, policy design and planning is emerging first across departments with responsibility for climate, environment and biodiversity (DECC, 2021; DHLGH, 2022a; Government of Ireland, 2022). The Department of Agriculture, Food and the Marine also has responsibilities for these areas; however, historically, there has been less integration of environmental policy within this 'closed policy community'[24] (Adshead, 1996; Fahy, 2020). Agricultural strategy to date demonstrates that when there is a choice to be made between environmental sustainability and economic growth, growth is prioritised (Fahy, 2020). In October 2022, the Department of the Environment, Climate and Communication published the *National Implementation Plan for the Sustainable Development Goals 2022–*

[24] In such a community, policymaking happens in a closed discussion between interest groups, ministers and senior civil servants with similar priorities and ideology, and it is difficult for groups outside this circle to become part of the discussion (Adshead, 1996; Fahy, 2020).

2024, which aims to embed these in the work of government departments and local authorities (DECC, 2022c). In terms of planning, the foundations of strategic land management are being put in place through the work of the Land Use Review and improvements in land cover mapping. Both will provide the evidence to inform the development of integrated policy and implementation.

While transformation is not explicitly mentioned in the Climate Action and Low Carbon Development (Amendment) Act 2021, the need for transformative change across all of society is recognised as central to delivering the fourth National Biodiversity Plan Action Plan (DHLGH, 2022a) and originates from the international post-2020 Global Biodiversity Framework (Convention on Biological Diversity, 2021). The National Landscape Strategy sets forth an integrated approach to landscape that recognises, characterises, utilises, develops and protects all dimensions of landscape, urban and rural, including cultural dimensions (DAHG, 2015). While integration of policy across departments with responsibility for climate and the environmental is important, wider integration, across health, nutrition and trade, for example (Babiker et al., 2022), is required to identify potential synergies and trade-offs (iPES Food, 2019), and take advantage of spill-over effects (Kanter et al., 2020; OECD, 2021). This is key to achieving a transformative approach (Sachs et al., 2019).

From a public perspective, the Citizens' Assemblies on Climate Action and Biodiversity Loss demonstrate that there is an appetite for transformative change in Ireland, making progressive recommendations on the type of actions they determined necessary if these issues are to be tackled in Ireland (see Chapter 8).

While there is evidence of transformative thinking in relation to some aspects of landscapes emerging in Ireland, other relevant areas, including just transition, equity and justice and the underlying drivers of climate change and biodiversity loss, need more attention if the depth, scale and speed of change required is to be achieved. A holistic, long-term systems approach will be necessary to tackle overexploitation of natural resources and land-use change so that nature can be protected and restored, and the myriad synergies for the environment, climate, society and the economy identified and made the most of while managing any trade-offs.

2.5. Research gaps

Transformative approaches to food and land systems. The necessity for transformation originates in the dual crises of biodiversity loss and climate change, and in the urgency that is required to address them. Climate, biodiversity and society are interdependent, and treating them as such is necessary for successful policy intervention (Pörtner et al., 2021). Tackling the direct drivers of climate change and biodiversity loss does not result in change in the speed, scale or depth that is required if Ireland is to deliver on its climate and biodiversity goals. Research on the underlying drivers of climate change and environmental degradation is only beginning (Chan et al., 2020) and is essential if transformational change is to be achieved. The food systems approach is considered to be transformative (EEA, 2017). It is a holistic approach that considers all aspects of the food system from nature's contribution to all those who work the land, process, ship and sell food, and wider issues related to health and waste. Establishing this approach and integrating it with the wider land systems will require further research.

Ireland's role in the global food system. Ireland's role in global food production is likely to evolve as the global population grows and climate change and related pressures affect global food production. Will Ireland need to increase the amount of food it produces? If so, will this require a move to less resource-intensive food production systems to maximise calorie output? If so, what would be the implications for the land transition?

Comparative efficiency of agriculture production systems. As part of establishing a food systems approach in Ireland, research on the comparative efficiency of agricultural production systems will be required to better understand the efficiencies of these systems. Research on carbon leakage is also required as part of determining the most emissions-intensive and environmentally damaging food and materials.

Feasibility of land-use change. Phase 2 of the National Land Use Review will involve consultation with a wide variety of stakeholders and will gauge the appetite for the type and level of change, as it currently stands, with regard to changing land-use patterns in Ireland. While the options for land-use change are 'technically' feasible, research will be required to understand how individuals, households, rural communities, wider society and the economy can assist in enhancing the feasibility and implementation of the change necessary to deliver on Ireland's national climate objective.

Enabling afforestation, peatland and nature restoration. Further research on enabling afforestation, peatland rewetting and restoration and nature restoration, particularly in relation to sustainable livelihoods, supporting rural communities and all those who work and steward the land, will be required in order to maximise synergies between mitigation and adaptation actions and the wellbeing of those on the front lines of climate action.

Research will be required to ensure that policies and measures are fair and that an undue burden is not placed on rural dwellers. Research will be necessary to establish the magnitude of the land carbon sink in Ireland.

Implementation of nature-based approaches. Nature-based approaches have the potential to be transformative, as they can tackle climate change (mitigation and adaptation) while delivering benefits for nature and human wellbeing simultaneously. How nature-based approaches can be implemented in Ireland requires further study.

Clean air and fresh water. There is little research available on the co-benefits of mitigating greenhouse gas emission in agriculture, for example the benefits for air and water pollution, flood protection and amenity. Research will be necessary if wider co-benefits are to be identified, especially those that can benefit human health and wellbeing and the protection of nature.

Bioenergy. To date, research on bioenergy has been concentrated on interactions between fuel, food and feed. Research in this area may be expanded to consider interactions with biodiversity, mitigation and adaptation action, to bring a fuller understanding of the interconnections and potential for synergies and trade-offs in the landscape.

Carbon dioxide removal. 'Novel' methods of CDR, such as bioenergy carbon capture and storage and direct air capture, will become more important for carbon removal towards the middle of this century. Research is required to assess the feasibility of developing, financing and deploying these and other 'novel' CDR technologies in Ireland so that the synergies and trade-offs associated with these technologies can be assessed and these technologies can become part of a long-term integrated strategy for land use.

Integrated strategies, design and planning. Of all transformations, transforming landscapes has the greatest possibility for trade-offs. For example, interventions to make space for nature could mean increased intensification of agriculture and associated environmental impacts that result in damaging ecosystems further (EEA, 2017; Sachs et al., 2019; Haughey et al., 2023). Integrated strategies, design and planning are required to anticipate and minimise such trade-offs, alongside maximising the synergies (Sachs et al., 2019; Schmidt-Traub et al., 2019). It is clear that a long-term integrated plan for land use is required in Ireland and that the groundwork to establish this is ongoing. However, given the potential negative impacts for climate, biodiversity and society, research is required on how to achieve integration to maximise synergies and manage trade-offs.

References