Carbon Budget Proposal Report

2024

CLIMATE CHANGE ADVISORY COUNCIL

Carbon Budget Proposal Report 2024

Climate Change Advisory Council
McCumiskey House
Richview, Clonskeagh Road, Dublin 14, D14 YR62

Tel: 01 2680180

Email: info@climatecouncil.ie

www.climatecouncil.ie

ISBN: 978-1-80009-228-0

How to cite:

Climate Change Advisory Council (2024), *Carbon Budget Proposal Report 2024.* https://www.climatecouncil.ie/councilpublications/

Acknowledgements

The Climate Change Advisory Council would like to acknowledge the significant contributions of the Secretariat of the Climate Change Advisory Council to the drafting of the Carbon Budget Proposals for Carbon Budget 3 (2031–2035) and provisional Carbon Budget 4 (2036–2040), especially:

George Hussey

Gina Kelly

Meabh Gallagher

Kieran Craven

Philip O' Brien

Jodie Colgan

The Climate Change Advisory Council also acknowledges the contributions from the members of the Carbon Budgets Working Group and all the other contributors to the work of the group and would like to thank them for their excellent scientific support in the preparation of this proposal.

The Climate Change Advisory Council would also like to thank Prepress Projects for their copy-editing, proofreading, design and typesetting of this report.

Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
BAU	business as usual
BECCS	bioenergy with carbon capture and storage
CB1, 2, 3, 4	Carbon Budget 1, 2, 3, 4
CBWG	Carbon Budgets Working Group
CDR	carbon dioxide removal
EPA	Environmental Protection Agency
ESRI	Economic and Social Research Institute
EV	electric vehicle
FaIR	Finite Amplitude Impulse Response
FERS	Forest, Environmental Research and Services
GDP	gross domestic product
GHG	greenhouse gas
GOBLIN	General Overview for a Back-casting approach of Livestock Intensification and land use
GWP_{100}	average global warming potential over 100 years
IPCC	Intergovernmental Panel on Climate Change
LED	low energy demand
LTTG	long-term temperature goal
LULUCF	Land Use, Land Use Change and Forestry
MACC	marginal abatement cost curve
NESC	National Economic and Social Council
NTA	National Transport Authority
PV	photovoltaic
SEAI	Sustainable Energy Authority of Ireland

SLCF	short-lived climate forcer
SSP	shared socioeconomic pathway
TIM	TIMES-Ireland Model
UCC	University College Cork
UNFCCC	United Nations Framework Convention on Climate Change
WAM	with additional measures
WEM	with existing measures

Contents

1. Introduction

Ireland has committed to transition to a climate-resilient, biodiversity-rich, environmentally sustainable and climate-neutral economy by 2050[a] (the 'National Climate Objective'). To help achieve this challenging but necessary objective, the Climate Action and Low Carbon Development (Amendment) Act 2021 (the 2021 Amended Act) mandates the Climate Change Advisory Council to propose carbon budgets. These carbon budgets must set Ireland on a pathway consistent with furthering the achievement of the National Climate Objective.

Meeting the National Climate Objective will deliver significant opportunities for Ireland in terms of maximising employment, the attractiveness of the State for investment and the long-term competitiveness of its economy. There is huge potential for Ireland to become a global leader in the generation of renewable electricity and there are numerous geopolitical and economic benefits to ending its dependency on imported fossil fuel.[b] [1,2] Achieving the National Climate Objective will increase national energy security as well as enhancing the health and well-being of Ireland's citizens through improved air quality and a healthier, safer and nature-rich environment. Realising these benefits requires interlinked planning across all sectors of the economy. Innovation and the development of capacity across sectors will be critical to achieving the National Climate Objective. At the same time, the delivery of an equitable and Just Transition requires inclusive decision-making and engagement with stakeholders.

In 2021, the Council submitted its first programme of carbon budgets to the Minister for the Environment, Climate and Communications, which included an upper limit of 295 Mt CO_2 eq in emissions for the period 2021–2025 (Carbon Budget 1 (CB1)); 200 Mt CO_2 eq for the period 2026–2030 (Carbon Budget 2 (CB2)); and a provisional budget of 151 Mt CO_2 eq for the period 2031–2035 (Carbon Budget 3 (CB3)). The Oireachtas adopted the Council's proposed carbon budgets without revision in April 2022.

In accordance with the 2021 Amended Act, not less than 12 months prior to the expiry of the first carbon budget the Climate Change Advisory Council is required to prepare and submit proposed amendments to CB3 (2031–2035) and propose a provisional Carbon Budget 4 (CB4) (2036–2040). The Council's proposal for this second programme of carbon budgets is outlined in **Section 2**. In preparing this carbon budget proposal, the Council has reflected on the National Climate Objective and been guided by the objectives of the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement's long-term temperature goal (LTTG) to limit global warming to well below 2°C and pursue efforts to limit warming to 1.5˚C.[3]

The Council's carbon budget proposal does not address the potential of carbon budget debt rollover between carbon budget periods. The 2021 Amended Act mandates that exceedance of carbon budgets is carried over at the point of concluding the finalisation of emissions inventories for each carbon budget period. Furthermore, it should be noted that sectoral emissions ceilings are a matter

a The Climate Action and Low Carbon Development Act 2015 sets out the National Climate Objective, which commits to pursue and achieve, no later than 2050, Ireland's transition to a climate-resilient, biodiversity-rich, environmentally sustainable and climate-neutral economy.

b The Intergovernmental Panel on Climate Change Sixth Assessment Report Working Group I glossary defines fossil fuels are carbon-based fuels from fossil hydrocarbon deposits, including coal, oil and natural gas.

for Government decision and the carbon budgets proposed here do not pre-empt the Minister's and Government's decision on how sectoral emissions ceilings are allocated, which will set out the maximum amount of GHG emissions that are permitted in different sectors of the economy during carbon budget periods.

The Environmental Protection Agency (EPA) adopts the best available, peer reviewed science to prepare its national inventory and projections. As such, updates and revisions are a routine occurrence. In its Annual Review 2024,[4] the Council has recommended that Government commit to a scheduled technical re-assessment of carbon budgets to take account of significant revisions due to our changing understanding of the science.

Finally, estimates of emissions and removals associated with the Land Use, Land Use Change and Forestry (LULUCF) sector in the national inventory remain highly uncertain. Significant advances have been made in recent years and further refinements are expected to be ongoing. In addition, although LULUCF is included within the carbon budgets, a sectoral emissions ceiling has not been agreed, and the contribution of the sector to climate action will need to be reviewed as our understanding of the science improves.

2. Carbon budget proposal

The Council's carbon budget proposal outlined here includes a final proposal for CB3 (2031–2035) of 160 Mt CO_2 eq, and a provisional proposal for CB4 (2036–2040) of 120 Mt CO_2 eq, with overall indicative emission reductions of 68% by 2040, relative to 2018. Consistency with the cumulative carbon budgets, including the agreed CB1 and CB2 and the proposed CB3 and CB4, will require the equivalent of annual emissions reductions of 6.3% year on year in the period 2024–2040. **Table 1** shows our carbon budget proposal.

Table 1: Carbon budget proposals and associated indicative emissions reductions relative to 2018

	CB3 (2031–2035)	Provisional CB4 (2036–2040)
Carbon budget (Mt CO_2 eq)*	160	120
Total emissions reduction relative to 2018**	56%	68%

* Emissions are evaluated using the average global warming potential over 100 years (GWP_{100}) from the Intergovernmental Panel on Climate Change Fifth Assessment Report.

** The total emissions reduction, relative to 2018, in 2035 and 2040, respectively.

Figure 1 shows the proposals for CB3 (2031–2035) and a provisional CB4 (2036–2040) in the context of the adopted CB1(2021–2025) and CB2 (2026–2030). These carbon budget proposals exclude emissions from international aviation and shipping and (as mandated under S.I. 531 of 2021) are calculated based on global warming potential values evaluated over 100 years (GWP_{100}) published in the Intergovernmental Panel on Climate Change Fifth Assessment Report[5] in line with UNFCCC and

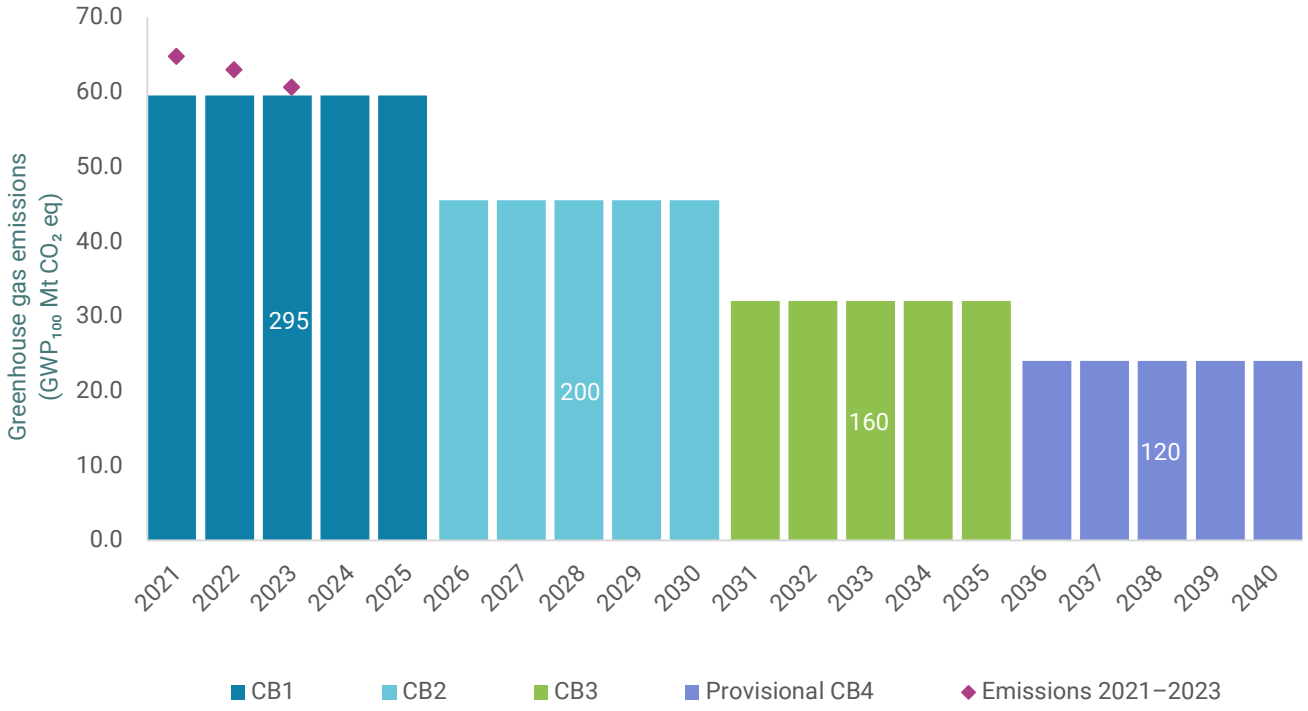

Figure 1: Carbon budgets 2021–2040. The Council's proposal for CB3 (2031–2035) of 160 Mt CO_2 eq and a provisional CB4 (2036–2040) of 120 Mt CO_2 eq using GWP_{100} in the context of the agreed CB1 (2021–2025) and CB2 (2026–2030) and the EPA provisional estimates of total emissions in the years 2021–2023.[7]

EU reporting requirements.[c] [6] Before finalising these carbon budget proposals an assessment was undertaken of whether they met the criteria under the 2021 Amended Act in line with the legislation (see **Section 3**).

The provisional CB3 (2031–2035) was a linear interpolation to meet net zero in GWP_{100}[d] by 2050. Updated analyses of mitigation options were used for the new proposal, in which the Council considered temperature neutrality pathways rather than constraining Ireland to meeting net zero emissions in GWP_{100}.[d] This has resulted in a 9 Mt CO_2 eq increase in the Council's final proposal for CB3.

The Council established the Carbon Budgets Working Group (CBWG)[8] in early 2023 and tasked the group with assisting and advising the Council in the development of the evidence basis for this carbon budget proposal. An overview of the CBWG's pathways development and modelling is provided in the Carbon Budgets Working Group Outputs Report,[9] and summaries of the core scenarios that were developed are outlined in **Section A** and **Section B** of the **Technical Appendix**. The Council assessed 1,196 scientifically based greenhouse gas (GHG) emissions scenarios that were developed

c The Intergovernmental Panel on Climate Change Sixth Assessment Report (AR6) has updated the values for GWP_{100} for all GHGs. However, no changes to the reporting requirements have been made at UNFCCC, EU or at national level to adopt the revised AR6 values for reporting. It is also worth noting, ahead of commencement of the CB3 period, that the Intergovernmental Panel on Climate Change Seventh Assessment Report will likely provide additional revisions to GWP_{100} values.

d Emissions are evaluated using the average global warming potential over 100 years (GWP_{100}) from the Intergovernmental Panel on Climate Change Fifth Assessment Report.

by the CBWG for consistency with the National Climate Objective. The Council also assessed the implications of the different pathways in terms of feasibility and the challenges associated with the transformations implied. This assessment of the carbon budget scenarios is outlined in **Section C** of the **Technical Appendix**.

The Council has considered multiple definitions of climate neutrality (see **Technical Appendix Section C**) and has interpreted climate neutrality to be the stabilisation of Ireland's contribution to global warming. The National Climate Objective states that Ireland must achieve climate neutrality by 2050. An alternative definition of climate neutrality is the achievement of net zero GHG emissions on the basis of GWP_{100}. However, none of the scenarios modelled by the CBWG achieve net zero GHG emissions by 2050, on the basis of GWP_{100}. This is because the modelling avoided overreliance on CO_2 removal technologies in an Irish context and considered emissions reduction scenarios for agriculture within a range consistent with European and international assessment of mitigation potential within the sector.

The Council believes that an appropriate response to the Paris Agreement requires consideration of global emissions pathways consistent with the most ambitious aspects of the temperature goal, that is the shared socioeconomic pathway (SSP) 1-1.9 scenario, which constrains global warming to 1.5°C. The analysis identified 15 pathways consistent with the national climate neutrality objective in the context of global action consistent with SSP1-1.9. It is important to note that an additional nine pathways were identified that are consistent with climate neutrality in the context of global action under the SSP1-2.6 scenario, which constrains global warming to less than 2.0°C.

The Council decided to base its carbon budget proposal on the shortlist of the 15 pathways consistent with Ireland achieving climate neutrality by 2050, against a backdrop of global efforts to limit global warming to 1.5°C. The range of carbon budgets derived from the emissions associated with each of these 15 scenarios is provided in **Table TA1** of the **Technical Appendix**.

The Council has not chosen a preferred scenario for this carbon budget proposal. Instead, the Council used all 15 of the shortlisted scenarios to calculate the carbon budget proposal by averaging the carbon budgets from the shortlist and rounding to the nearest 10 Mt. These scenarios are illustrative and, while they demonstrate pathways based on individual models to inform the carbon budgets, further work is required as part of the process of deciding sectoral emissions ceilings and developing future climate action plans to develop specific emissions reduction measures. Overall, this analysis highlights that, while a range of options exist to meet the proposed carbon budgets, it will be necessary for all sectors covered to realise significantly increased ambition in both the period to 2030 and the period between 2030 and 2040.

3. Consistency of the proposed carbon budgets with legislated-for considerations

Based on the scenarios presented in the **Technical Appendix** and building on the results of the modelling, the Council's final proposal for CB3 (2031–2035) of 160 Mt CO_2 eq and a provisional proposal for CB4 (2036–2040) of 120 Mt CO_2 eq were assessed against the criteria laid out under the legislation.[10]

3.1. Ireland's National Climate Objective

The Council is required to propose a carbon budget that is consistent with furthering the achievement of Ireland's National Climate Objective.[e] The Council has identified a shortlist of 15 scenarios that directly inform the Council's carbon budget proposal and has outlined possible pathways to achieving the emissions reductions necessary for Ireland to achieve climate neutrality by 2050 (see the **Technical Appendix** for further details). In this assessment, the Council has interpreted the achievement of climate neutrality as being consistent with stabilising Ireland's warming impact as a result of net zero CO_2 emissions, along with prescribed deep cuts in methane and nitrous oxide emissions, i.e. temperature neutrality. The proposed carbon budgets highlight the urgent need for ambitious actions across all sectors to address climate change, with opportunities to achieve improvements in climate resilience, environmental sustainability and biodiversity.

In terms of the three main GHGs, fossil fuel use in the Energy sector is the dominant source of carbon dioxide (CO_2) emissions, while the Agriculture sector is the dominant source of methane (CH_4) and nitrous oxide (N_2O) emissions. The 15 scenarios considered in calculating the carbon budgets are consistent with net CO_2 emissions from energy reaching zero between 2039 and 2048, along with significant reductions in other GHG emissions, including rapid and sustained reductions of between 22% and 30% in the rate of methane emissions and a 66–69% reduction in the rate of nitrous oxide emissions from agriculture by 2040, relative to 2018. All selected scenarios require the deployment of carbon dioxide removal (CDR), including nature-based and technological solutions, as well as mitigation within the LULUCF sector in the period to 2050 and beyond.

There are implicit implications for trade-offs between the Energy sectors and Agriculture, Forestry and Other Land Use (AFOLU) sectors inherent in the range of emissions reductions for CH_4 and N_2O, and the time frame for achieving net zero CO_2 emissions (see the **Technical Appendix** for an overview of the impact of different combinations of scenarios on additional warming). Targeting the lower end of ambitions in each case would not be sufficient to realise the ambition of these carbon budget proposals. Instead, these ranges illustrate the need for a government-wide cross-sectoral approach to assigning levels of effort sharing between the Energy and AFOLU sectors within the limits of the proposed carbon budget. This will be for consideration as part of the Minister's and Government's roles in the preparation of sectoral emissions ceilings, which will set out the maximum amount of GHG emissions that is permitted in different sectors of the economy during carbon budget periods, with different ceilings applying to different sectors.

3.2. The objectives of the UNFCCC and the Paris Agreement

The 2021 Amended Act requires that the Council carries out its functions in respect of the preparation of carbon budgets in a manner that is consistent with the ultimate objective specified in Article 2 of the UNFCCC[11] and the matters specified in Articles 2 and 4(1) of the Paris Agreement (see the **Technical Appendix Section D**).[3] In preparing this carbon budget proposal, the Council has reflected Ireland's National Climate Objective and been guided by the LTTG of the UNFCCC Paris Agreement to limit global warming to well below 2°C and pursue efforts to limit warming to 1.5°C. The Council conducted a comprehensive assessment of 1,196 national GHG emission scenarios developed

e The 2021 Amended Act defines the National Climate Objective as the following: 'The State shall, so as to reduce the extent of further global warming, pursue and achieve, by no later than the end of the year 2050, the transition to a climate resilient, biodiversity rich, environmentally sustainable and climate neutral economy'.

by the CBWG for achieving climate neutrality by 2050 in line with the Paris Agreement LTTG (see **Technical Appendix Section C**). A shortlist of 15 scenarios was identified by the Council as being consistent with setting Ireland on an emissions trajectory that is compatible with Ireland's emissions contributing to no further global warming by 2050, against a backdrop of global efforts to limit global warming to 1.5°C in line with the Paris Agreement. The proposals for CB3 (2031–2035) and the provisional CB4 (2036–2040) are based on a calculated sum of the average annual emissions of the 15 shortlisted scenarios outlined in the **Technical Appendix** of this report.

3.3. Ireland's obligations under EU legislation

The European Commission recently recommended a 2040 climate target of a 90% reduction in net GHG emissions by 2040 relative to 1990 levels.[12] The EU has not formally adopted this target, nor has it indicated how Member States will be allocated different targets, or whether sectors will be treated differently. Ireland's GHG emissions profile is distinctive, with a higher share of gases such as methane and nitrous oxide from agriculture than most of the EU.[13] To be consistent with expected EU policy, only scenarios for the energy system that meet a 90% reduction target by 2040 or earlier were considered for the Council's carbon budget proposal. The scenarios assessed in the European Scientific Advisory Board on Climate Change's scientific advice report,[14] on which its EU 2040 target proposal is based, generally achieve Agriculture sector methane emissions reductions of 15–40% between 2019 and 2040. Analysis of the scenarios directly informing the Council's carbon budget proposal are within this range, achieving Agriculture sector methane emissions reductions of 22–30% between 2018 and 2040.

These proposals and decisions on sectoral emissions ceilings also need to be cognisant of the revised Energy Efficiency Directive (Directive (EU) 2023/1791) as part of the European Green Deal package and the requirement under Article 4 of the directive to reduce final energy consumption across the EU by 11.7% by 2030, including the national energy efficiency targets set out for Ireland in its National Energy and Climate Plan.[15]

3.4. The use of the latest inventories, projections and best practice reporting of emissions and removals

In its deliberations the Council has considered the most recent national GHG inventory and projections of future GHG emissions, along with international best practice on the reporting of GHG emissions and removals. The inventory undergoes continual updates and revisions to take account of improved scientific understanding and improved activity data. As referenced in Box 1 of our 2024 Annual Review,[4] there needs to be a programmed re-evaluation of the levels of the carbon budgets so that they remain coherent with Ireland's emissions statistics, which are constantly being improved and updated. The Council therefore considers that a scheduled technical re-assessment of carbon budgets based on inventory methodological changes only should become routine on a 5-yearly basis, in line with practice at EU level. The 2021 Amended Act envisages the potential for such reviews but without specifying a time frame. To avoid undermining the carbon budgeting approach mandated under legislation, a technical review of current carbon budgets should be scheduled to occur at a minimum in tandem with the end of the previous carbon budget period review.

As the Annual Reviews of the Council have made clear,[4,16,17] all involved will need to significantly increase their efforts to deliver on the necessary ambition in the current decade out to 2030, as the

requirement to carry over exceedances of carbon budgets, particularly in respect of CB2 (2026–2030), now looks increasingly certain.[18] Government will need to consider the implications of this exceedance and implement the corrective action necessary to address the shortfall in the target set out in the Act for a 51% reduction in emissions by 2030, relative to 2018.

Without immediate measures to bring the Climate Action Plan in line with CB2, the feasibility of delivering overall carbon budgets between 2024 and 2040 will become significantly more challenging, with steeper emissions reductions required in CB3 and CB4 periods along with greater reliance on CDR measures. These negative emissions will be generated in the Land sector via afforestation, in the Built Environment sector via harvested wood product carbon storage, and in the Energy sector via bioenergy with carbon capture and storage (BECCS) or other forms of CDR.

The EPA also produces national GHG emission projections on an annual basis. These projections are compiled in line with EU guidelines to meet EU reporting obligations.[18] At a national level this assessment informs policy and the monitoring and reporting of Ireland's climate action performance to Government under the 2021 Amended Act and to the public, as outlined in the 2024 Climate Action Plan.[19] It also provides an assessment of Ireland's progress towards achieving its EU emissions reduction targets for 2030 as set out under the Effort Sharing Regulation.[20] In so far as is possible, the policies and measures contained in the 2024 Climate Action Plan are included in these projections. However, there are a number of exceptions where policies and measures were not included, as the EPA could not see an implementation pathway to merit their inclusion in its 2024 projections. Nevertheless, the EPA notes that, even with full implementation of the measures identified in the Climate Action Plan 2024, economy-wide emissions reductions of only 42% by 2030, relative to 2018, would be achieved. As part of the CBWG, the University College Cork (UCC) Energy Policy and Modelling Group undertook a sensitivity analysis of the energy system to assess the scale of mitigation action required post 2030 should Ireland maintain the emissions trajectories implied in the EPA projections analysis, which currently exceed those of CB1 and CB2. On the basis of the modelling outcomes, the Council concluded that these emissions scenarios, constrained to the EPA projections analysis, are not consistent with the National Climate Objective, and so they were excluded from consideration for the Council's carbon budget proposal (see the **Technical Appendix** for more details).

3.5. Scientific advice, including with regard to the distinct characteristics of biogenic methane

In its deliberations, the Council has considered scientific advice regarding the distinct characteristics of biogenic methane in recognition of its behaviour as a short-lived climate forcer (SLCF) with ongoing, albeit substantially reduced, emissions compatible with climate stabilisation at global scales.[21] Ireland's emissions profile includes significant methane emissions, with methane the second most significant contributor to GHG emissions because of Ireland's large numbers of ruminant livestock. In its guidance to the CBWG, the Council requested the development of scenarios that achieve a range of 30–60% reduction in GHG emissions for the Agriculture sector by 2050.

Furthermore, while the scenarios informing the carbon budgets include negative emissions associated with afforestation, harvested wood product carbon storage and BECCS, the modelling does not rely on other novel CDR options, given their currently very low deployment levels around the world.[22] Very few CDR methods are represented in models to date, with many novel technologies

at low technology readiness levels. It is very difficult to assess which type and what volume of CDR, including direct air carbon capture and storage, for example, can be deployed in Ireland specifically. As a result, none of the modelled scenarios achieve net zero GHG emissions by 2050, on the basis of GWP_{100}, when methane is included. This is in contrast with the global integrated assessment modelling outputs assessed by the Intergovernmental Panel on Climate Change (IPCC), which includes significant roll-out of CDR, which would allow for scenarios where ongoing, residual emissions of GHGs, including methane, can be balanced by negative emissions. The Council intends to revisit this issue and available technologies when finalising provisional CB4.

As set out in the EPA's report for the CBWG,[23] the question of whether SLCFs, specifically methane in Ireland's case, should be part of a target to achieve net zero GHG emissions target by 2050 remains a key point to be addressed, as it has implications for the carbon budgets and amount of CDR that would be required. While the European Climate Law targets include SLCFs in the 2050 net zero GHG target, Ireland's latest long-term strategy does not.[24] The IPCC's special report on global warming of 1.5°C indicates that significant reductions to global agricultural methane emissions (–24% to –47%) will be required by 2050 in scenarios that keep warming below 1.5˚C. It should be noted that the IPCC considered modelling of global average reductions, and the expectations for individual countries would vary for reasons including current production efficiency and ability to pay for offsets and local technical and behavioural opportunities for mitigation action.[25] As outlined in **Section 3.3**, analysis of the scenarios directly informing the Council's carbon budget proposal are within the range of Agriculture sector reductions in methane emissions on which the EU 2040 target proposal is based. While an EU-wide target and individual Member State targets for 2040 have not yet been agreed, the significance of the Agriculture sector in Ireland, in particular livestock agriculture, will be a consideration in determining Ireland's individual 2040 target.

3.6. Biodiversity

As part of the preparation of its carbon budget proposals, the Council commissioned a working paper on the assessment of biodiversity considerations in this process.[26] This study builds on previous work by Gorman et al.,[27] funded by the EPA, on the impacts of climate change mitigation measures on biodiversity. The changes required to achieve these ambitious carbon budget proposals will necessarily entail significant changes in land and sea use in the coming years, particularly in the areas of agriculture, energy and forestry. This will have implications for habitats and species in these areas. The research highlighted the need to achieve statutory obligations for biodiversity protection and restoration and to align policies and targets for both climate and biodiversity. It also called for the development of a national integrated land use strategy to inform on-the-ground actions and for this to be underpinned by a spatial planning framework, given that impacts on biodiversity are highly context and location specific.

A separate report prepared for the CBWG looked at the potential biodiversity impacts from various scenarios considered for the carbon budget proposals.[28] In relation to agriculture and biodiversity risks for land and water, the scenarios consistent with CB3 and provisional CB4 imply targeted intensification of dairy in certain areas, with conversion of land to various lower emissions or negative emissions land use diversification options in other areas. A reduction in the number of livestock and improved efficiencies assumes lower nutrient inputs on farms and has the potential to reduce risks to freshwater and transitional/coastal water biodiversity while maintaining sustainable agriculture and land use. This highlights the need for an integrated spatial strategy

recognising trade-offs at catchment scale to realise benefits for terrestrial and aquatic biodiversity. In relation to forestry, the report notes that opportunities for positive versus negative impacts on biodiversity associated with an expansion in afforestation is dependent on site location, species choice, establishment, ongoing management and harvesting practices adopted. In relation to energy system decarbonisation, improved spatial targeting of renewable energy generation must endeavour to avoid further habitat loss/fragmentation, species loss and degradation of ecosystem quality and function.

3.7. Maximising employment, the attractiveness of the State for investment and the long-term competitiveness of the economy

Under the legislation, the Council's carbon budget proposals are required to take into account, as far as is practicable, the need to maximise employment, the attractiveness of the State for investment and the long-term competitiveness of the economy. These have been given due consideration from a macroeconomic perspective, including the impact of a number of scenarios on investment and competitiveness (see **Section 4.3**) and consideration of specific impacts on employment (see **Section 4.4**).

3.8. Climate justice

On a per capita basis, Ireland's historical warming impact is significant and comparable to other developed countries, with half the warming impact having arisen since 2000. If the rest of the world's population had contributed to emissions to the same extent as Ireland, current global warming would be approximately 3.6°C (within a likely range of 3.2–3.9°C).[29] The Council has previously used the 'Paris Test' to constrain carbon budgets in line with a 1.5°C global temperature ceiling.[30] Passing the test necessitates the use of a reference year more recent than the 1851–1900 reference period used in this assessment of Ireland's historical global warming impact.[29] Instead, the Council has taken the approach of assessing Ireland's projected future warming impact and constraining carbon budgets based on climate neutrality by ruling out scenarios incompatible with climate neutrality, in which Ireland's warming impact is still increasing in 2050. This is a deliberately minimalist interpretation, which solely ensures adherence with the 2021 Amended Act as stipulated. A report for the CBWG[31] discussing the moral considerations of what would be a fair or just contribution from Ireland to global emissions reductions with regard to a national carbon budget highlights that alternative approaches would lead to more stringent carbon budgets. For example, the inclusion of more equity and justice considerations, such as adopting burden-sharing principles or non-egalitarian distributional justice patterns would almost certainly increase Ireland's responsibility and decrease its carbon budget.[31] Furthermore, the Council's carbon budget proposal is not consistent with an overall emissions trajectory towards achieving net zero GHG emissions overall as a result of ongoing, albeit reduced, methane emissions from the Agriculture sector in Ireland. Thus, the carbon budgets proposed here should be considered as upper bounds.

4. Implications for the transformation of key sectors

It is useful to illustrate what range of likely actions will be required across different sectors to meet the carbon budgets being proposed here. While the exact actions required and implications for each sector will depend on the eventual sectoral emissions ceilings to be determined by the Government of the day, the pathways modelled give some indication of likely actions required, were these carbon budget proposals to be enacted, and potential implications and benefits.

4.1. Energy system

Emissions from Ireland's energy system need to reach net zero well before 2050 and become negative thereafter. CO_2 emissions from energy consumption (e.g. electricity, transport, industry and heating) must fall to zero between 2039 and 2048, alongside the delivery of significant cuts in non-CO_2 emissions. **Figure 2** illustrates the trajectories for emissions in the energy system in megatonnes of CO_2 equivalent (Mt CO_2 eq) under each of the scenarios used to inform the Council's carbon budget proposals (for further details on the assessment of carbon budget scenarios, see the **Technical Appendix**).

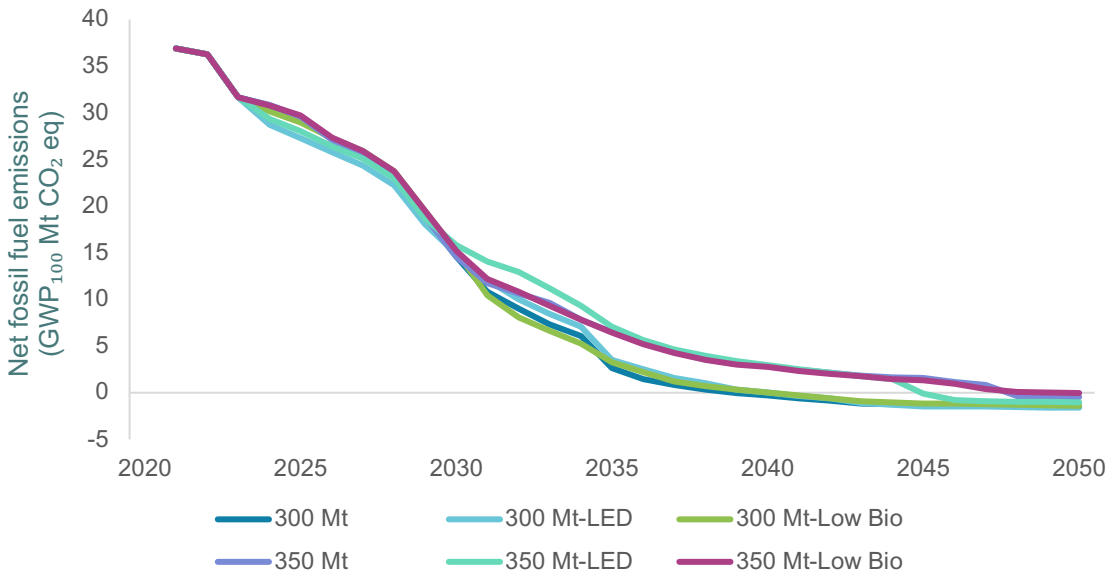

Figure 2: Emissions pathways out to 2050 for the six energy system scenarios that were considered in the calculation of the carbon budget proposal are illustrated here in Mt CO_2 eq using GWP_{100}. This includes emissions associated with fossil fuel combustion across Ireland's energy system (covering power, buildings and transport) plus industrial process emissions and excludes international aviation and shipping. The more ambitious 300 Mt scenarios are consistent with net CO_2 emissions from energy reaching zero as early as 2039, while the less ambitious 350 Mt scenarios are consistent with net CO_2 emissions from energy reaching zero by 2048. Further details on the TIM modelling of Ireland's energy system and the scenarios referenced here can be found in the Technical Appendix.

The most ambitious energy scenarios informing the Council's carbon budget proposal involve an effective phasing out of fossil fuel use by 2039 within Electricity, Industry, Buildings and Transport sectors, with limited to no opportunity for new investments in fossil fuel systems (e.g. the 300 Mt scenarios modelled by the TIMES-Ireland Model (TIM)). A number of scenarios for the energy system also rely on final energy demand reduction as a lever to meet carbon budgets (i.e. low energy demand (LED) scenarios modelled by TIM), leading to less rapid deployment of low-carbon technologies or reliance on measures such as BECCS or hydrogen deployment.

As set out in the EPA's report for the CBWG,[23] given the latest energy demand trajectory, there is little evidence to suggest that energy demand moderation will be achieved in the short term, as there is currently little (implemented or planned) policy that is likely to reduce energy demand significantly prior to 2030. However, the energy modelling presented to the CBWG indicates that moderating final energy demand is necessary to meet most carbon budget scenarios, particularly in the event of an exceedance of CB1 and CB2. This will present a significant challenge to achieve in a country experiencing significant economic and population growth as well as fast-growing energy demand from large energy users such as data centres.

Key implications for each of the sectors within Ireland's energy system, arising from the TIM scenarios that directly informed the Council's Carbon Budget proposal, are described below. It is important to note that TIM produces technology-explicit pathways on the future evolution of Ireland's energy system but does not take account of all potential policies and measures that could impact on emissions across each sector. The model chooses the 'optimal' level of technology deployment across sectors to meet specific carbon budgets and energy demands, incorporating constraints.

All energy sector scenarios underlying the Council's CB Proposal require unprecedented rates of technology change, but mainly rely on technologies that are mature, cost-effective and well-tested. While they are not explicitly modelled, all scenarios have important benefits across society and are expected to have a positive impact on health and well-being. The main challenges are associated with the timing of deployment and capacity. There are also a number of technical and societal challenges:

- There is uncertainty regarding the operation of the power system post 2030 in terms of storage technology and back-up generation, for example, along with the lead times for the deployment of new installed capacity, increased interconnection, large-scale storage and transmission and distribution system reinforcement.
- Reliance on reducing final energy demand makes more ambitious scenarios more feasible but requires regulation, development of new policies and measures and behaviour change beyond what has currently been developed and achieved.
- Many energy sector scenarios modelled in TIM rely on BECCS or other forms of CDR. There is greater reliance on these technologies for scenarios that impose more stringent carbon budgets on the energy system and less reliance on these technologies for scenarios associated with lower final energy demand. For comparison, the scenarios modelled by the Sustainable Energy Authority of Ireland (SEAI) do not include any CDR technologies out to 2040 at present.
- While the Act excludes emissions from Aviation and Maritime sectors from our carbon budgets, aviation and maritime emissions have continued to increase at global and national levels. In its Annual Review, the Council highlighted the need for policy development in this area, specifically the publication of the Sustainable Aviation Fuel Policy Roadmap[32] Ireland should also remain attentive to opportunities to support EU and international action to reduce both aviation and maritime emissions.

4.1.1. Electricity sector

Electrification and decarbonisation of power generation is the main decarbonisation lever in all scenarios for the energy system.[f] Electricity demand as a share of total final energy consumption will grow due to the electrification of transport, buildings and industry, with strong growth in wind and solar photovoltaic (PV) power across all scenarios. The scale of renewable installations comprising offshore wind, onshore wind and solar PV varies between scenarios. For example, 39 GW of total power generation capacity is installed in the 300 Mt scenario versus 30 GW in the 300 Mt-LED scenario in 2050, as the LED scenarios require lower power generation capacity (see the **Technical Appendix** for more details). As set out in the macroeconomic analysis carried out for these carbon budget proposals (**Section 4.3**), a significant benefit associated with the deployment of renewables in this sector is the expected long-term savings from reduced fossil fuel imports, along with the benefits of increasing Ireland's energy independence and improving energy security.

4.1.2. Transport sector

The Transport sector decarbonises rapidly in all scenarios considered, with limited to no carbon budget remaining for further sales of fossil fuel vehicles. The scenarios modelled involve full electrification of all vehicles by 2040, with an end to sales of new internal combustion engine vehicles by 2025 for private vehicles and by 2027 for freight vehicles in the business as usual (BAU) energy demand scenarios, as the model finds full vehicle electrification to be the lowest cost energy system response. LED scenarios, which lower the dependence on private cars and reduce freight movements, allow a later phasing out of new fossil fuel vehicles (see the **Technical Appendix** for more details). The TIM scenarios focus on technology deployment (including vehicle sales, overall stock and passenger-kilometres), but do not include modelling of broader policy measures to reduce emissions in transport, such as the roll-out of public transport modes, demand management or benefits from improved spatial planning and placemaking, which would need to be accounted for in the development of sectoral emissions ceilings.

Analysis by SEAI[33] has highlighted the challenges associated with the rate of electric vehicle (EV) uptake and overall EV sales volumes. A comparison carried out by the National Transport Authority (NTA) found good alignment with TIM data for passenger-kilometres, tonne-kilometres and fleet mix, but potential differences related to the projected increase in passenger-kilometres in active transport modes, and the projected changes in freight tonne-kilometres.[34] In addition, the NTA Car Stock scenario development process was not able to develop a scenario that projected a fleet decline.

The model also does not account for expected co-benefits from reduced noise and air pollution, reduced congestion, increased connectivity between people and places and wider health benefits, for example. It is important to note that international aviation and maritime emissions are not included in the modelled scenarios or in the carbon budgets proposed.

f Some additional emissions in electricity may be expected compared with modelled TIM scenarios due to requirements for back-up gas generation during the third carbon budget period and balancing of the electricity system, for example, which are not accounted for in the model. TIM is not designed to model in detail power system operation, including the investment in grids, storage and flexibility in the most ambitious National Energy Projections scenario. With current planned policy (with additional measures), there is still over 2 Mt of electricity generation emissions projected in 2040, primarily from the gas generation required.

4.1.3. Built Environment sector

Scenarios for the Built Environment sector involve rapid deployment of heat pumps with targeting of the most carbon-intensive buildings for retrofitting first, ending the use of coal and peat and mostly phasing out kerosene for heating by 2030. In more ambitious scenarios, natural gas is phased out in the early 2030s, but with a higher carbon budget for the energy system some fossil natural gas remains until 2040 (see the **Technical Appendix** for more detail). District heating also plays an important role post 2030 in apartments and attached homes. Analysis carried out by SEAI has pointed to the increased support for homes and businesses that would be required to increase the pace of uptake of heat pumps and retrofitting measures.[33] In the TIM modelling report for the CBWG,[35] recent research carried out on lowering the threshold for heat loss required for heat pump grant support is highlighted as a potential mechanism for facilitating a more rapid transition in the sector at a lower cost.[36] The Council's 2024 Sectoral Review of the Built Environment also considered a range of opportunities to further incentivise the uptake of heat pumps.[37] Lastly, while not explicitly modelled, the phasing out of fossil fuel heating in the sector would be expected to have significant co-benefits, including better air quality and health, reduced energy poverty and improved levels of comfort across all households.

4.1.4. Industry sector

Industry relies on direct electrification for the majority of its processes, apart from high-temperature processes that rely on biomass and wastes. Fuel switching from fossil natural gas to biogas and from solid fuels to solid biomass are transitional measures in the short and mid-term. In addition, BECCS installation in cement manufacturing is expected to be deployed from 2030 to decarbonise emissions from this process. This is an important assumption and, as highlighted by SEAI, BECCS is not assumed to be adopted in the National Energy Modelling Framework based on current planned policy. This points to the need to develop appropriate policy support for this as part of a broader range of measures required in the Industry sector, as set out in the Council's 2024 Industry and Waste Sectoral Review.[38] Supporting decarbonisation of the Industry sector would have important co-benefits in lowering the carbon intensity of production and achieving compliance under the EU Emissions Trading Scheme.

4.2. Agriculture and Land Use

Achieving substantial reductions in agricultural GHG emissions by 2050 necessitates very ambitious adoption of mitigation measures in agriculture. High levels of mitigation measure uptake would allow the Agriculture sector to contribute significantly to Ireland's national climate goals, including the 25% reduction target for agriculture by 2030 and further reductions by 2050, with potential reductions in agricultural emissions of between 38% and 48% by 2050 relative to 2018.[39] **Figure 3** provides a trajectory for emissions in the Agriculture sector under each of the scenarios used to inform the Council's carbon budget proposals (for further details on the selection process for these scenarios, see the **Technical Appendix**).

Scenarios in which livestock agricultural activity is relatively stable (S1) or reduced (S2) yield the largest GHG emissions reductions relative to the 2018 level, particularly when coupled with very ambitious mitigation measures (P2) (see **Figure 3**). The combined agricultural activity and mitigation scenarios informed the Council's carbon budget proposal (see the **Technical Appendix** for more details). A wide range of GHG mitigation measures can contribute to reducing agricultural emissions,

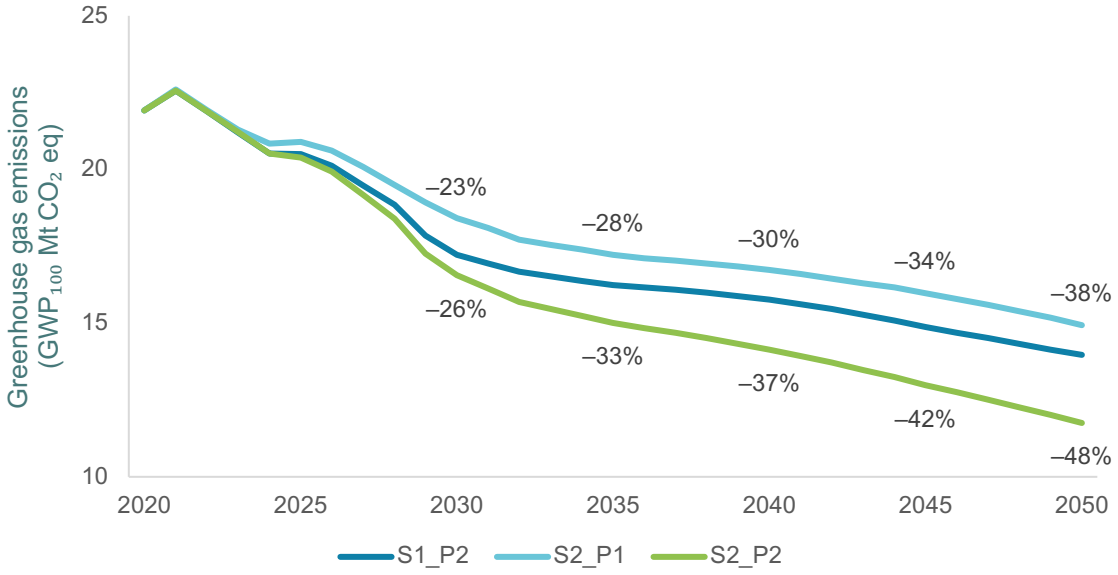

Figure 3: Emissions pathways out to 2050 for the three Agriculture sector scenarios considered in calculating the carbon budget are illustrated here in Mt CO_2 eq using GWP_{100}. The more ambitious S2_P2 scenario is consistent with a 37% and 48% reduction in emissions from agriculture by 2040 and 2050, respectively, while the less ambitious S2_P1 scenario is consistent with a 26% and 37% reduction in emissions from agriculture by 2040 and 2050, respectively. Further details on the FAPRI-Ireland modelling of Ireland's Agriculture sector and the scenarios referenced here can be found in the Technical Appendix.

with no single measure providing a dominant share of the mitigation potential. Key contributors include reducing the age of cattle finishing, using feed additives, protected urea fertilisers and improved breeding practices. Farmers must be financially supported to implement these measures. The future level of GHG emissions from the Agriculture sector is difficult to anticipate, reflecting uncertainties around future livestock numbers and the dairy-to-beef cow ratio, as emissions vary between these production systems.

All forestry scenarios include a reduced rate of harvest, closer to the economic optimum, compared with the current trend towards shorter harvest intervals, which would apply to both existing and new forests.[40] **Figure 4** shows that the forestry scenarios informing the Council's carbon budget proposal represent a significant increase in the rate of afforestation relative to recent history[41] (for further details on the selection process for these scenarios, see the **Technical Appendix**).

The lower forestry ambition scenario (L1) represents the current policy target for afforestation rates of 8,000 ha per year being achieved in 2027 and continued thereafter. L1 envisages an extended period of net GHG emissions due to land use, returning to a net removal in around 2045. The L1 comprises a 50:50 split between slower growing (but more biodiverse) broadleaf species and faster growing conifer species. The soil type is split 15:85 organic to mineral soils, with significant CO_2 emissions incurred from planting on organic soils (this is accounted for within the forest net GHG emission flux results from the carbon budget model used by Forest, Environmental Research and Services (FERS)).

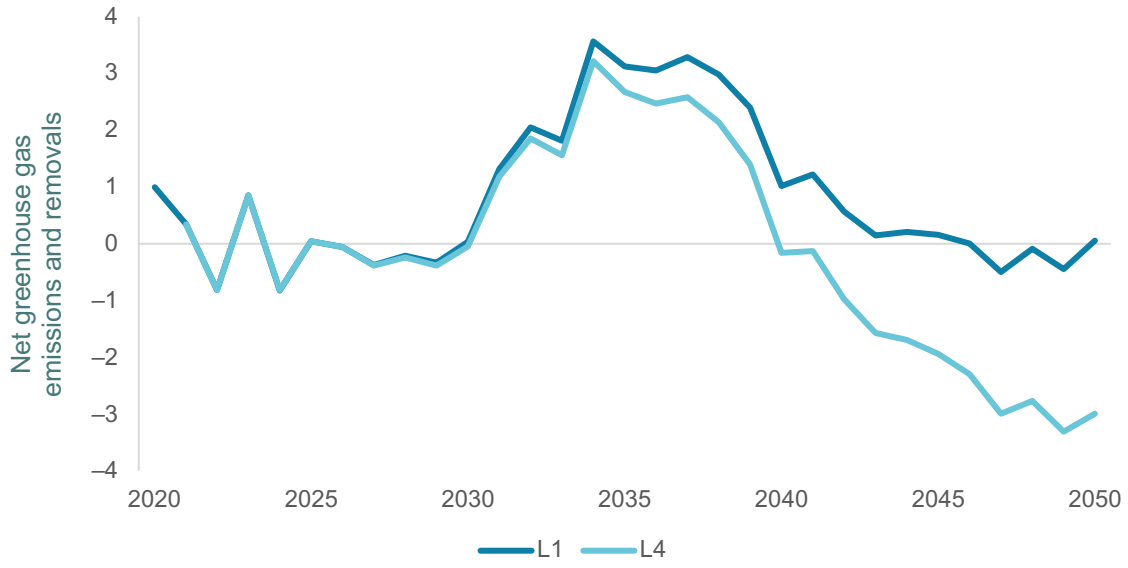

Figure 4: Emissions pathways out to 2050 for the Land Use sector scenarios considered in calculating the carbon budgets are illustrated here in Mt CO_2 eq using GWP_{100}. The more ambitious L4 scenario is consistent with net zero emissions from land use by 2040, while the L1 scenario is consistent with net zero emissions from land use by 2046. Further details on the GOBLIN modelling of Ireland's Land Use sector and the scenarios referenced here can be found in the Technical Appendix.

The higher forestry ambition scenario (L4) envisages afforestation rates of 17,500 ha per year, split 70:30 coniferous to deciduous species with the species mix, where planting on organic soils with the associated GHG emissions is avoided entirely. The L4 scenario would see an earlier return to significant net removals for the sector (see the **Technical Appendix** for more details).

Across all land use scenarios, it is assumed that there will be ambitious levels of improved management of drained organic soils, including improved water table management, rewetting and nature restoration where appropriate. Recently revised organic soil and wetland areas and emission factors from the 2024 National Inventory Report[42] were incorporated into the land use modelling. Management of the water table to protect the carbon in peat soils was assumed to occur on 90% of the remaining drained organic soil area under grass by 2050.[g] Similarly, 90% of remaining drained industrial and domestic exploited wetlands was assumed to be rehabilitated by 2050. A time series was generated for rewetting and restoration effects, based on linear progress towards, and from, 2030 waypoints corresponding with Climate Action Plan targets.[h] It was assumed that mineral soil carbon sequestration would decline to zero by 2050 as grassland improvement effects drop out of the inventory. Thus, in a simplified and conservative approach, a

g As of 2022 according to the National Inventory Report.

h Climate Action Plan targets referenced here include 80 kha of 'reduced management intensity' (assumed full rewetting) on organic soils under grassland; 33 kha of restoration on industrial exploited wetlands; and 30 kha of restoration on domestic exploited wetlands.

zero net flux was assumed for mineral soil carbon in 2050, with a linear reduction in the current 1.7 Mt CO_2 eq sink between 2030 and 2050. Management options have been identified that can enhance the sequestration of these soils further and may provide additional mitigation options for policy development.[43]

Projections of agricultural land use and agricultural activity levels for the extended time horizon of 2050 are conditional on underlying (long-term) projections of agricultural input and output prices and forecasts of macroeconomic indicators, such as per capita income and general price levels as well as international energy prices. There is very significant uncertainty regarding the level of economic activity in the Agriculture sector and its composition over this time frame. This includes fundamental uncertainty relating to the economic drivers of international agricultural markets and input and output prices over the medium to long term. Further areas of uncertainty include future decisions relating to food and agricultural policy, trade policy and environmental policy. The future rate of uptake of the mitigation measures in the AFOLU sectors is also uncertain. Assumptions of uptake rates were made in the FAPRI-Ireland model and the General Overview for a Back-casting approach of Livestock Intensification and land use (GOBLIN) model analyses, as were assumptions about the efficacy of existing measures. Achievement of the emissions mitigations modelled using the FAPRI-Ireland and GOBLIN models will thus be conditional on both policy and market signals as well as on support for agricultural and other advisory activities. Ongoing research and innovation activity in Ireland and elsewhere may offer scope for an expanded set of mitigation measures that might be applicable in the Irish Agriculture and Land Use sectors.

4.3. Macroeconomic impacts

Analysis carried out by McInerney and Fitzgerald[44] found that, overall, the long-term costs of reaching the National Climate Objective are expected to be relatively limited, as future savings in imports of fossil fuels will largely offset the long-term costs of making the change. While achieving carbon budgets will involve significant upfront investment costs, delayed action will impose a greater financial burden on society in the longer term from continued fossil fuel dependence, with greater and more costly impacts expected with additional warming. This needs to be compared with the baseline level of investment that would have taken place without the proposed carbon budgets.

In relation to energy, the macroeconomic impact of different carbon budgets has been assessed using the Central Bank of Ireland's semi-structural model of the Irish economy, considering the paths for investment and final energy consumption corresponding to the '300 Mt' and '350 Mt' carbon budgets for the energy system. The additional investment required across these scenarios is up to 1.4% of gross national income in the 2026–2030 period. The response of investment in both scenarios is similar in the short term, with investment front loaded in both scenarios and rising by 9.5–11% above the baseline level of investment in the period to 2030. This drives additional labour demand, putting upward pressure on wages, and a deterioration in Ireland's competitiveness relative to its trading partners, as indicated by the significant fall in the output of the Trade sector up to 2040.

Overall, the analysis finds that the biggest burden of adjustment, which will have a medium-term negative impact on living standards, will be between 2025 and 2035. However, even at its peak, the reduction in living standards will be limited, probably amounting to between 0.5% and 1% of national income. For comparison, in studies estimating the cost of the transition for France[45] or for the wider world economy,[46] medium-term costs were estimated to fall between 2% and 3% of national income but the longer-term effects, after the adjustment is completed, were estimated

to be lower than the upfront costs, as in the Irish case. McInerney and Fitzgerald also consider a number of further scenarios and their overall macroeconomic impact, including where labour constraints are binding in the short run, where the implementation of carbon budgets results in a reduction in productivity, and finally a scenario with higher global interest rates. The detailed results from these scenarios can be found in their report. McInerney and Fitzgerald conclude that, while the costs of decarbonising the economy by 2050 seem limited overall, the major constraint now is the restrictions imposed on new climate-related investment by the regulatory system (including physical planning).

In relation to agriculture, Lanigan et al.[39] provide a range of scenarios for emissions reductions in the sector combining estimates of emissions and of agricultural output and income. Teagasc considered three agricultural output scenarios S1 – the base case, S2 – lower output and S3 – higher output. They also consider two scenarios on emissions reduction: the ambitious (P1) and the very ambitious mitigation scenarios (P2) (see the **Technical Appendix** for more details). This analysis considered the mitigation costs across each scenario modelled, based on the estimated technical costs and benefits of the mitigation measures at the farm level, on a partial budget basis. It concluded that Government and industry support for farmers will be required to achieve very ambitious rates of adoption of mitigation measures.

In order to assess the macroeconomic impact of these scenarios, the difference between the base case scenario (S1) and the lower output scenario (S2) was considered (McInerney and Fitzgerald, 2024). The difference in the growth rate of GVA (farm income) in the base case and the lower output scenario would amount to around 0.65% a year. The significant cost of implementing mitigation measures would need to be accounted for in addition to costs arising from reduction in output.

The reduction in output of beef cattle and milk in the lower output scenario, compared to the base case, would have implications for the food processing sector. By 2050 milk output under the lower output scenario would be 7% below what it would be in the base case and beef cattle output would be 17% below the base case. In turn, this reduction in inputs would reduce the output of the meat processing and the dairy processing sectors. The analysis suggests that significant agricultural land would become available for other uses under this scenario (c. 400,000 hectares). The research undertaken using GOBLIN[40] suggests that extensive planting of trees between now and 2050 could sequester a substantial amount of CO_2 out of the atmosphere. In the long term, the harvesting of this timber would also provide a potential income stream.

While significant in terms of the individual sectors and individuals, because today they account for 1% of gross national income, the overall macroeconomic impact of their reduced output on the economy as a whole would be more limited. Just Transition challenges would be likely if agricultural activity outcomes akin to this more ambitious emissions reduction scenario (i.e. S2) were to arise with significant supports required for farmers. The very steep reduction in suckler cow production, given its spatial concentration, would pose large societal challenges in some regions of the country.[47] Overall, under this more ambitious emissions reduction scenario (S2_P2), Teagasc's modelling suggests that agricultural emissions would be reduced by 48% by 2050.

A second, less ambitious, agricultural emissions reduction scenario considered in the carbon budget proposal (S1_P2) would involve a larger total bovine herd, but mitigation measure adoption rates would remain the same as in the more ambitious scenario (i.e. P2). Under a less ambitious agriculture scenario, emissions would be reduced by only 38% by 2050. This scenario (S1_P2) would involve less dramatic changes in agricultural output and Food Processing sector output than those in the more ambitious agriculture scenario (S2_P2). The less ambitious agriculture scenario (S1_P2) envisages

slightly less change in the area of grassland for livestock (about 370,000 ha), but not on a scale that would constrain land availability for diversification.

This analysis did not account for the macroeconomic impact of the costs of adapting the Irish economy to the problems arising from climate change over the period to 2050. It also did not consider the numerous co-benefits that accrue from mitigating climate change, such as lower air pollution, higher life expectancy and reduced biodiversity loss. The Council supported a fellowship through the Economic and Social Research Institute (ESRI) to assess the economic costs of climate change impacts and adaptation in Ireland, which is summarised in a working paper published on the Council's website.[48] The working paper considered the costs of the impacts of climate change from an economic perspective in five areas, without adaptation measures in place. It found that, under the representative concentration pathway (RCP) 4.5 scenario, coastal flooding has the largest negative impact on gross domestic product (GDP) in 2030, 2040 and 2050, with further secondary impacts for the wider economy. This initial study also found that adaptation can significantly reduce the real GDP losses associated with a given level of climate change. In 2040, for example, gross damages of over 2.7% of GDP can be reduced to residual damages of less than 1% at protection costs of 0.25% by applying adaptation policies.[48] Adaptation can significantly reduce the negative effect of climate change impacts on real GDP.

4.4. Impacts on employment

The journey to climate neutrality will require significant societal change. For many, these changes will be positive and beneficial; however, there will be significant changes to job markets and livelihoods, and it is critical to acknowledge that many individuals will face challenges as part of the transition. The Organisation for Economic Co-operation and Development notes the importance of skills policies to facilitate the movement of workers from sectors with high GHG emissions, which are likely to shrink, into growing sectors aligned with low-carbon goals.[49]

Although there is a commitment to a Just Transition in Irish climate governance and some early embedding of the concept in policy, no one approach to applying it to the carbon budget process exists. Considerations in relation to a Just Transition were provided throughout the development of the carbon budget proposal by reflecting on the Just Transition Principles Framework.[19] The outcome of this process highlighted Just Transition considerations for future climate policy development. The importance of enabling people to benefit from the opportunities of the transition was emphasised. Furthermore, the costs must be shared so that the impact is equitable and existing inequalities are not exacerbated. This can be done by considering the full range of distributional impacts on demographics, locations, sectors and the wider environment. Identifying the potential impacts on vulnerable groups can allow Government to prepare and develop targeted policy supports.

A number of studies carried out at EU level have assessed the impact of EU climate policy in terms of aggregate employment effects,[50–53] with the overall impact estimated to be slightly positive or with job losses in specific sectors balanced by emerging opportunities in other sectors. This depends on the level of employment concentrated in 'brown' sectors across Member States.[54] A study by the Joint Research Centre[55] found that overall projected shifts in sectors would not lead to systematically different 'green jobs' versus 'brown jobs' in terms of the overall quality of employment.

In terms of the jobs and skills required, a recent report by the Irish Fiscal Advisory Council estimated that 25,000 additional workers will be needed to meet renewable energy targets.[56] Skills will be needed particularly in the Offshore Energy sector, including marine construction, assembly,

installation, operation, maintenance and administration.[57] ESRI has estimated a mean value of 14,720 construction workers required to meet the target of deploying 9 GW of onshore wind by 2030, not including indirect or induced employment, with a further 10,280 workers required to meet the target of 5 GW of offshore wind. The current deficit in skilled construction workers and building professionals requires an estimated 50,000 new entrants across all skill levels over the period 2023–2030 to deliver on Government targets for housing and retrofitting.[58,59] In the area of energy efficiency, ESRI has estimated an additional requirement of 22,779 workers to upgrade 500,000 dwellings to B2 Building Energy Rating status by 2030.[60] As set out in the Council's Technical Report accompanying its proposals for carbon budgets in 2021, an effective training and reskilling infrastructure will be crucial to deliver the skilled workers required in sectors such as the construction and trades industries, otherwise supply constraints and inflationary pressures may impact the ability to implement the carbon budgets.

According to research by the National Economic and Social Council (NESC),[57] the sectors most vulnerable to the transition in Ireland are those engaged in the supply of fossil fuels and generation of electricity from peat and coal, transport, parts of manufacturing and agriculture. Within sectors further job losses might be expected. For example, in electricity job losses might occur due to the closure of fossil fuel-based generation plants but this may be balanced by significant expansion in the area of renewable energy. The phasing out of peat-generated electricity in Ireland and the harvesting of peat for this purpose has already had significant economic and social impacts in Ireland. Specific occupations will also be impacted, for example for engineers in the transition from oil and gas boiler maintenance to heat pump systems and for mechanics who require upskilling in the transition to EVs. A paper by the Nevin Economic Research Institute[61] identified six sectors accounting for 90% of emissions in Ireland – those that would be expected to be the most at risk from the climate transition. These represent approximately 9% of total employment, which aligns with a number of sectors identified as at risk by the European Commission.[52] Research carried out by EnvEcon has also noted the indirect and induced employment effects associated with direct job losses.[62] As part of this research, EnvEcon has produced an index of jobs at risk at a small area level, outlining the distribution of workers in Ireland at risk from policies, strategies and actions to reduce GHG emissions primarily linked to fossil fuels.

Research from NESC has identified the Agri-food sector as one of those most impacted by the low-carbon transition in terms of employment.[57] In all the mitigation scenarios modelled by Teagasc for the carbon budgets, diversification options are important measures for reducing emissions, for which Government and industry support will be crucial. Considering the scenarios modelled by Teagasc and analysis carried out on the overall impact of these for the Agriculture sector by McInerney and Fitzgerald,[44] particularly vulnerable areas of employment have been identified in the Meat Processing sector (which had 21,000 people in direct employment in 2022 – 0.81% of total employment), with a significant multiplier effect for employment across the wider economy reported by the sector.[63] As set out in the Council's 2024 Sectoral Review for Agriculture,[64] knowledge transfer and skills training will be required to implement the specific technical measures necessary to address GHG emissions and to implement appropriate adaptation measures.

The research undertaken using GOBLIN[40] suggests that extensive planting of trees between now and 2050 could sequester a substantial amount of CO_2 from the atmosphere, accelerating Ireland's progress towards reaching climate neutrality. In the long term, the harvesting of this timber would also provide a potential additional income stream and increased source of employment.

Impacts will differ by sector in Ireland, with increased demand for some jobs and decreased demand for others. This points to a need to conduct more detailed sector-specific analysis for Ireland and prepare adequate education, training and employment policies to align workers with required skills and successfully redeploy people from vulnerable sectors as the changes required across sectors become clearer through the next allocation of sectoral emissions ceilings. The Council emphasises in its 2024 Annual Review that individuals and their communities impacted by these changes will require targeted policy support and assistance from Government to ensure a Just Transition.[65]

5. Conclusions

The Council has proposed what it believes to be the maximum level of emissions allowable in the decade 2031–2040 consistent with setting Ireland on a pathway to achieve its National Climate Objective and to make a significant contribution to the Paris Agreement aim to limit global warming to well below 2°C and pursue efforts to limit warming to 1.5°C. In doing so, there is a realisation that this calls for a significant ramping up of ambition and delivery across all sectors, well beyond what has already been demonstrated. The challenges that this will pose are manifold, but the scientific imperative to respond to these challenges is becoming ever more evident. The scenarios considered in calculating the Council's carbon budget proposal include implicit trade-offs between the energy system (including the Electricity, Built Environment, Transport and Industry sectors) and AFOLU sectors that will need to be considered when assigning levels of effort sharing between sectors within the limits of the proposed carbon budget. This will be for consideration as part of the Minister's and Government's role in the preparation of sectoral emissions ceilings, which will set out the maximum amount of GHG emissions that is permitted in different sectors of the economy during carbon budget periods, with different ceilings applying to different sectors. In this regard, the changes implied by the low-carbon transition will require a further strengthening of the whole-of-Government approach to achieving the National Climate Objective.

Technical Appendix

Section A of the Technical Appendix describes how readers should interpret the different elements of the scenario labels using **Box TA1** and **Box TA2**. **Section B** and **Section C** of the Technical Appendix present further detail on the models used and the decision-making process regarding the scenarios that were eventually identified as part of the final calculations for this carbon budget proposal.

Section A: Understanding the scenario labels used in this report

Box TA1: How to parse and interpret a scenario label used in this report

The CBWG created a number of future scenarios that can be combined in a large number (1,196) of different ways. To aid understanding of scenarios that are being combined, a labelling system is applied. The following example, picked from the list in **Box TA2**, shows how to read one of these labels:

300 Mt-LED L4-S1_P2

- This relates to the total **carbon budget for CO_2** emissions implied for Energy sectors. See second row of TIM scenarios.
- This is a **variant** on the main 300 Mt scenario, and detail of that variation is available in the LED row of the TIM scenarios .
- This relates to the **afforestation** scenario. These are differentiated by the volume and/or planting mix. See the fourth row of GOBLIN scenarios for detail on the L4 scenario.
- This relates to which **agricultural activity** scenario is being used. See the first row of the FAPRI-Ireland scenarios.[i]
- This relates to the **rate of adoption** of potential measures in the Agriculture sector. See the last row of the FAPRI-Ireland model.

Further information about each sub-component of the label can be found in the relevant row of the summary descriptions in **Box TA2** (per the instructions above). Parts of the text of this document may provide some insights that compare the options in the different sub-components of the modelling combinations, but the same labelling convention is used throughout.

i There are also scenarios in the dialogue tool which end with the letter A–E instead of the 'S1_P2' convention illustrated in the example. In these cases, no data from the FAPRI-Ireland model were used and projections data for agriculture were extracted directly from the GOBLIN model. See rows 1 to 5 of the Agriculture sub-set of the GOBLIN scenarios for further details.

Box TA2: Summary descriptions of the scenarios developed by the CBWG

FAPRI-Ireland scenarios		
Agricultural activity	**S1** (base case)	In the base case agricultural activity scenario (S1), by 2050 dairy cow numbers are projected to rise by 14%, increasing total milk production by 38% relative to 2022 due to higher milk yields. Total cattle inventories are projected to decrease by 7%, while beef production declines by 11% due to the projected contraction of the beef (suckler) cow herd. Fertiliser use is projected to rise by 10%, and cropland area shrinks by 16% as grassland farming, especially dairying, becomes more profitable. Sheep numbers are projected to drop by 25%, while pig and poultry production grows by 25% and 30%, respectively.
	S2 (lower agricultural activity)	In the lower agricultural activity scenario (S2), with reduced economic incentives for dairy and beef cow production projected in this scenario, by 2050 total cattle inventories are projected to drop by 22% relative to 2022, driven by an 84% decline in beef cow numbers. Dairy cow numbers still increase by a projected 7% and, with higher milk yields, milk production increases by 28%, but beef production is projected to fall by 26% by 2050. Fertiliser use decreases by 12%, cropland contracts by 14%, and sheep numbers drop by 25%. Pig and poultry production are projected to grow by 25% and 35%, respectively.
	S3 (higher agricultural activity)	Higher milk prices and support for beef farmers lead to a 22% increase in dairy cow numbers by 2050 and a slower decline in beef cow numbers than in the other two scenarios. Total cattle inventories grow by 1%, milk production rises by 47% and beef production drops by less than 5%, a smaller decrease than for S1 and S2. Fertiliser use rises by 22%, cropland area contracts by 24%, and sheep numbers decline by 25%. Pig and poultry production grow by 24% and 34%, respectively.
MACC adoption rate	**BAU** (no mitigation)	No mitigation (BAU): The projected emissions in 2050 for S1, S2 and S3 without any emissions mitigation in 2050 are 23,171, 20,227 and 25,118 kt CO_2 eq, respectively. Emissions without any mitigation are projected to decrease by 0.7% under S1 and by 4.2% under S2. Emissions from agriculture without any mitigation are projected to decrease by 3.0% under S3.
	P1 (ambitious adoption rates)	Pathway 1 (P1) assumes an ambitious adoption rate following the 2023 Teagasc MACC.
	P2 (very ambitious adoption rates)	Pathway 2 (P2) assumes very ambitious adoption rates, with many measures extended close to the maximum potential rate to 2050. Achieving substantial reductions in agricultural GHG emissions by 2050 necessitates very ambitious adoption of mitigation measures (P2). High levels of uptake would allow the Agriculture sector to contribute significantly to Ireland's national climate goals, including the 25% reduction target for agriculture by 2030 and further reductions by 2050, with potential reductions in agricultural emissions of between 38% and 48% by 2050 relative to 2018.

GOBLIN scenarios		
Forestry	**L1**	Forest management: More sustainable management (longer rotations, more continuous cover forestry). Afforestation: BAU mix (50:50 conifer:broadleaf), 15% on organo-mineral soils: 8 kha per year 2030–2080.
	L2	Forest management: More sustainable management (longer rotations, more continuous cover forestry). Afforestation: BAU mix (50:50 conifer:broadleaf), 15% on organo-mineral soils: 25 kha per year 2030–2080.
	L3	Forrest management: More sustainable management (longer rotations, more continuous cover forestry). Afforestation: 70:30 conifer:broadleaf mix, 100% on mineral soils: 25 kha per year 2030–2080.
	L4	Forest management: More sustainable management (longer rotations, more continuous cover forestry). Afforestation: 70:30 conifer:broadleaf mix, 100% on mineral soils: 17.5 kha per year 2030–2080.
Agriculture	**A**	Current herd structure: Current cattle herd and sheep flock structure is maintained. Constant level of bovine protein production in Ireland is maintained to minimise the risk of carbon leakage. MACC+: High rates of deployment of efficient management practices and abatement technologies, proxying maximum deployment of existing proven practices and technologies by 2050. Agriculture sector emissions reductions of 34% vs 2020 by 2050.
	B	Intermediate herd structure: Assumes a shift out of suckler beef and towards milk plus more dairy beef. Average dairy and beef cow productivity scales up from current performance (scenario A) to intermediate performance. MACC+: High rates of deployment of efficient management practices and abatement technologies, proxying maximum deployment of existing proven practices and technologies by 2050. Agriculture sector emissions reductions of 40% vs 2020 by 2050.
	C	Agriculture sector emissions reductions of 45% vs 2020 by 2050.
	D	Dairy specialisation, high yield: Reduces dairy cow numbers needed to maintain bovine protein output owing to an average increase in milk productivity. Average dairy and beef cow productivity scales up from current performance (scenario A) through intermediate performance (scenario B) to higher levels of performance. MACC+: High rates of deployment of efficient management practices and abatement technologies, proxying maximum deployment of existing proven practices and technologies by 2050. Agriculture sector emissions reductions of 52% vs 2020 by 2050.
	E	Scales down animal numbers and production from scenario D to achieve Agriculture sector emissions reductions of 60%. Average dairy and beef cow productivity scales up from current performance (scenario A) through intermediate performance (scenario B) to higher levels of performance. MACC+: High rates of deployment of efficient management practices and abatement technologies, proxying maximum deployment of existing proven practices and technologies by 2050. Agriculture sector emissions reductions of 60% vs 2020 by 2050.

TIM scenarios			
Energy	**250 Mt**		A carbon budget of 250 Mt CO_2 eq is imposed as a constraint on total GHG emissions from the sectors covered in TIM fossil fuel combustion across Ireland's energy system (covering power, buildings, transport) plus industrial process emissions and excluding international aviation and shipping. A BAU energy demand is projected.
	300 Mt		A carbon budget of 300 Mt CO_2 eq is imposed as a constraint on total GHG emissions from the sectors covered in TIM fossil fuel combustion across Ireland's energy system (covering power, buildings, transport) plus industrial process emissions and excluding international aviation and shipping. A BAU energy demand is projected.
	350 Mt		A carbon budget of 350 Mt CO_2 eq is imposed as a constraint on total GHG emissions from the sectors covered in TIM fossil fuel combustion across Ireland's energy system (covering power, buildings, transport) plus industrial process emissions and excluding international aviation and shipping. A BAU energy demand is projected.
	400 Mt		A carbon budget of 400 Mt CO_2 eq is imposed as a constraint on total GHG emissions from the sectors covered in TIM fossil fuel combustion across Ireland's energy system (covering power, buildings, transport) plus industrial process emissions and excluding international aviation and shipping. A BAU energy demand is projected.
	450 Mt		A carbon budget of 450 Mt CO_2 eq is imposed as a constraint on total GHG emissions from the sectors covered in TIM fossil fuel combustion across Ireland's energy system (covering power, buildings, transport) plus industrial process emissions and excluding international aviation and shipping. A BAU energy demand is projected.
	Energy scenario sensitivity cases	**WEM**	An additional scenario run for a sensitivity analysis which does not impose carbon budgets and instead aligns each sector's GHG emissions with the EPA WEM scenario for 2024–2050.
		WAM	An additional scenario run for a sensitivity analysis which does not impose carbon budgets and instead aligns each sector's GHG emissions with the EPA WAM scenario for 2024–2050.
		No mitigation	No carbon budget or GHG target is imposed in this scenario.
		LED	The low energy demand case increases the feasibility of faster emissions reductions, particularly in the first and second carbon budget periods (2021–2030), and allows more ambitious carbon budgets to be met and mitigation to be achieved with less rapid deployment of mitigation measures and with lower reliance on more speculative measures or those that have a higher risks of negative trade-offs, such as BECCS and hydrogen.
		Low Bio	A sensitivity case, Low Bio, is also included where there is no increase in bioenergy demand relative to 2020 in order to explore the implications across the energy system of limiting bioenergy imports.
		High Solar PV	A sensitivity case, High Solar PV, is also included, which enables greater levels of solar PV capacity than is assumed in core scenarios.

MACC, marginal abatement cost curve; WAM, with additional measures; WEM, with existing measures.

Section B: Development of carbon budget scenarios

The Council established the CBWG[10] in early 2023 and tasked the group with assisting and advising the Council in developing the evidence base for this second carbon budget proposal. In particular, the CBWG provided a wealth of modelling and analytical support, without which these proposals would not have been possible. The CBWG consisted of a wide range of relevant experts and held monthly meetings from March 2023 to September 2024. The CBWG membership included experts in modelling for energy, agriculture and land use, with additional expertise in economics, macroeconomics, biodiversity, philosophy, climate justice and emissions projections. The Carbon Budgets Working Group Outputs Report[9] provides a detailed overview of the activities of the CBWG, synthesising the outputs and providing links to each of the relevant CBWG final output reports that assisted the Council in proposing CB3 (2031–2035) and the provisional CB4 (2036–2040). The existence of the CBWG did not diminish the overall responsibility of the Council in taking the final decision on the carbon budget proposal submitted to Government. The Council would like to take this opportunity to thank the members of the CBWG and all the other contributors to the work of the group for their excellent scientific support in the preparation of this proposal.

A unified model that provides analysis across all sectors of the economy is not available. However, Ireland maintains a range of sector-specific modelling and analysis expertise hosted within Government agencies and third-level institutes and the private sector. The CBWG drew on this expertise to build a robust evidence base to enable an integrated assessment across the whole economy to inform the Council's development of the carbon budget proposal. Three core models covering the Energy (TIM),[j] Agriculture (FAPRI-Ireland)[k] and Land Use (GOBLIN) sectors[l] were each used to perform three modelling iterations from September 2023 to August 2024 to inform the carbon budget programme. The final iteration of core modelling resulted in 1,196 scientifically based GHG emission scenarios that were developed by the CBWG. Several additional models (National Energy Modelling Framework, National Transport Agency's (NTA's) model, Central Bank of Ireland's semi-structural model) supported the assumptions and outputs of the core models, and expertise from the CBWG refined the modelling and output process. An overview of the CBWG pathways development and modelling is provided in Section 4.2 of the Carbon Budgets Working Group Outputs Report,[9] and a summary of the core scenarios developed is provided here.

UCC's Energy Policy and Modelling Group applied the TIM model[35] to develop multiple scenarios for Ireland's energy system, which include fossil fuel combustion across the energy system (covering power, buildings, transport) plus industrial process emissions, but excluding international aviation and shipping, from now until 2050. Varying levels of climate action ambition were modelled by imposing a range of carbon budgets as a constraint on total GHG emissions on the Energy sector from 2021 to 2050. In summary, the TIM scenarios developed were centred around five different carbon budgets for the energy system from 2021 to 2050: 250 Mt CO_2 eq, 300 Mt CO_2 eq, 350 Mt CO_2 eq, 400 Mt CO_2 eq and 450 Mt CO_2 eq (all using GWP_{100}). These carbon budgets were imposed as a constraint on total

j TIM is being developed at UCC to inform future possible decarbonisation pathways for the Irish energy system.

k FAPRI-Ireland is a country-specific instance of the Food and Agricultural Policy Research Institute model maintained by Teagasc.

l The GOBLIN model is a biophysical national model of the AFOLU sector in Ireland led by the University of Galway.

GHG emissions from the sectors covered in TIM. All five carbon budgets were modelled under two distinct demand projection scenarios, BAU and LED. A sensitivity case, Low Bio, was also included, in which there is no increase in bioenergy demand relative to 2020, to explore the implications across the energy system of limiting bioenergy imports. The final report from the UCC team[35] details the necessary investments, mitigation measures and choices to be made across the Energy, Electricity, Transport, Heating, and Industry sectors under carbon budgets of different stringency.

Scenarios for agricultural GHG emissions in Ireland were developed using the FAPRI-Ireland model and the 2023 Teagasc marginal abatement cost curve (MACC) model.[39] In summary, this modelling work examined potential future GHG emissions under three agricultural activity scenarios with different levels of animal numbers, land use and input use. These were scenario 1 (S1), a base case agricultural activity projection; scenario 2 (S2), a lower agricultural activity projection; and scenario 3 (S3), a higher agricultural activity projection. These three activity level projections were modelled alongside two GHG mitigation pathways. Pathway 1 (P1) assessed an ambitious adoption rate of mitigation measures following the 2023 Teagasc MACC. Pathway 2 (P2) assessed very ambitious mitigation measure adoption rates, with many measures extended close to the maximum potential rate of adoption to 2050. The final report from the Teagasc team outlines these scenarios, modelled using the FAPRI-Ireland model and the Teagasc MACC, in full detail.[39]

Researchers from the University of Galway and FERS modelled land use and land use change to 2100 using GOBLIN and other models[40] In summary, four forestry scenarios were developed, all of which represent a reduced rate of harvest, closer to the economic optimum, compared with the current trend towards shorter harvest intervals. Scenario L1 represents the current policy target for afforestation of 8,000 ha per year being achieved from 2027 to 2100. Scenario L2 represents an ambitious afforestation rate of 25,000 ha per year from 2031 to 2080. Scenario L3 represents a maximum forest carbon sink, with afforestation rates the same as for scenario L2 but the species mix weighted in favour of fast-growing conifers and planting on organic soils, which include peatland, avoided entirely. Scenario L4 is a 70% scaled version of scenario L3, derived from the scenarios modelled by FERS to achieve a net zero GHG balance (excluding methane) coupled with a 50% reduction in agricultural emissions. As a result, scenario L4 represents an afforestation rate of 17,500 ha per year from 2031 to 2080 with the species mix weighted in favour of fast-growing conifers and planting on organic soils, which include peatland, avoided entirely. The GOBLIN team also set out five scenarios outlining the emissions associated with modelled mitigation levels for the Agriculture sector. Three scenarios (a, c & d) approximated Agriculture sector emissions reductions of 30% (a), 45% (c) and 50% (d). Interpolation and downscaling were used to derive two additional scenarios (b & e) corresponding to emissions reductions of 40% (b) and 60% (e). The final report from the GOBLIN team[40] sets out scenarios for possible pathways for Ireland's Agriculture and Land Use sectors in the period out to 2050 (and extended to 2100) under varying levels of climate action ambition in full detail.

Additional modelling and analysis supporting the assumptions and outputs of the core models using SEAI's National Energy Modelling Framework, the NTA's model and the Central Bank's semi-structural model is summarised in Section 4.4 of the Carbon Budgets Working Group Outputs Report.[9] SEAI's Energy Modelling Team provided views based on its own analysis and performed additional testing of Energy sector carbon budget scenarios produced by UCC's Energy Policy and Modelling Group. The final report from SEAI's Energy Modelling Team[33] presents key findings from SEAI analysis of the carbon budget scenario outputs from UCC's TIM, and addresses risks and critical actions regarding the feasibility of adhering to the existing budgets and possible new budgets to 2040.

Review and input from the NTA Transport Modelling Team[34] helped inform the assumptions for and constraints on the final iteration of energy modelling work, focusing on a number of key transport indicators, namely person-kilometres, tonne-kilometres and vehicle fleet projections for cars, light goods vehicles and heavy goods vehicles. In addition, an assessment of the macroeconomic impact of carbon budgets[44] was carried out using the Central Bank's semi-structural model, which detailed potential consequences for the macroeconomy and investment. These models do not explicitly model important aspects of climate action, including Just Transition, biodiversity impacts, climate justice, and broader EU and international climate policy. The modelled scenarios provided a quantitative basis for the CBWG analyses of these aspects of climate action, which are discussed in Sections 4.5–4.11 of the Carbon Budgets Working Group Outputs Report.[9]

Section C: Assessment of carbon budget scenarios

Warming impact analysis

To assess the warming impact of the scenarios developed by the CBWG, Dr Joseph Wheatley, UCD Energy Institute and School of Economics, carried out an assessment of emissions scenarios using the FaIR Simple Climate Model framework.[29] FaIR is the Finite Amplitude Impulse Response Simple Climate Model. It is a reduced complexity climate model that is useful for scenario assessment and idealised climate runs. This analysis is summarised here, and a more detailed overview can be found in Section 4.3 of the Carbon Budgets Working Group Outputs Report.[9] Quantifying the national contribution to global warming is key to assessing adherence to the National Climate Objective of attaining a climate-neutral economy by 2050. Ireland's GHG emissions profile is distinctive, having a higher share of shorter-lived gases such as methane, along with emissions of nitrous oxide from agriculture, than most other developed nations. To address this complexity and reflect the specific nature of biogenic methane emissions, the warming impact of future emission scenarios can be analysed using simple climate models,[m] which reflect the latest understanding of climate parameters, processes and uncertainties and are widely used in IPCC assessments. For the CBWG warming analysis, FaIR was applied to analyse 1,196 emission pathways for Ireland, developed by CBWG modelling teams. A brief summary of these scenarios is outlined in **Section B** of the **Technical Appendix**, with further detail available in Sections 4.2 and 4.3 of the Carbon Budgets Working Group Outputs Report.[9] Based on this analysis,[29] it was found that:

- Ireland's historical contribution to global warming from the pre-industrial era to 1990 is of the order of 0.9 m°C.[n] By 2020, Ireland's contribution had increase to an estimated 2.0 m°C.
- On a per capita basis, Ireland's historical contribution to global warming is significant and comparable to that of other developed countries. Half the national contribution to warming is due to activities since 2000.
- If the rest of the world's population had contributed to emissions to the same extent as Ireland, current global warming would be approximately 3.6°C (likely range 3.2–3.9°C). Equivalent estimates for other developed countries are as follows: United States 5.7°C, Germany 4.0°C, UK 4.2°C.[66] The unexpectedly high per capita warming estimate for Ireland, despite relatively

m Also known in the literature as climate model emulators.

n Ireland's contribution to global warming is indicated in thousandths of degrees Celsius, i.e. m°C.

low level of industrialisation, may be explained by net positive land use emissions and a large contribution from ruminant agriculture.

- Without strong mitigation of non-CO_2 GHG emissions, Ireland's warming impact will continue to grow to 2050 even if net zero CO_2 emissions are achieved in the 2040s.
- Agricultural activities are the dominant source of non-CO_2 GHG emissions. Therefore, mitigation of the Agriculture sector will be very effective in limiting Ireland's future warming impact.

All 1,196 scenarios considered result in additional warming in 2050 relative to 2020. Ongoing CO_2 emissions are the dominant source of this additional warming even as the economy embarks on rapid decarbonisation. Climate neutrality is a key component of the National Climate Objective. There are different interpretations of what it means for a country to be climate neutral, including:

- net zero GHG emissions on the basis of GWP_{100} metrics,
- net zero-CO_2 emissions combined with deep cuts in other, non-CO_2, GHG emissions,
- stabilisation of the country's contribution to global warming – also known as temperature neutrality,
- reversal of the country's historical contribution to the increased atmospheric concentration of GHGs above pre-industrial levels.

While ambitious, none of the 1,196 scenarios modelled for the CBWG achieve climate neutrality by the first of the interpretations of a climate-neutral economy, i.e. net zero GHG emissions by 2050. All scenarios include significant reduction in emissions of non-CO_2 GHGs. However, none of scenarios achieve a reversal of Ireland's historical contributions to global warming by 2050 because of the large amounts of CO_2 removal that would be required. A number of scenarios achieve temperature neutrality by 2050. It is reasonable to assert that achieving temperature neutrality by 2050 is a threshold, minimum criterion consistent with the National Climate Objective. However, additional consideration is required to assess consistency with the Paris Agreement LTTG.

A scenario in which Ireland's warming impact is still increasing in 2050 is incompatible with the National Climate Objective. The warming analysis conducted identified scenario combinations of the energy system and AFOLU sectors considered by the CBWG emissions scenarios teams that achieve climate neutrality with a threshold probability of greater than 67% in the context of internationally recognised global 'pathways'. The warming analysis was undertaken using SSP1-1.9 with emission reductions that limit global warming to below 1.5°C and the SSP1-2.6 with emissions reductions that limit warming to approximately 1.8°C.[o] These global scenarios are considered consistent with the Paris Agreement LTTG, and all remaining global scenarios exceed 2°C warming.

Therefore, provided the rest of the world follows an emissions pathway that can be considered compliant with the Paris Agreement LTTG, the temperature neutrality of modelled scenarios can be assessed against the National Climate Objective of climate neutrality. **Figure TA1** and **Figure TA2** show the national emissions scenarios consistent with climate neutrality in the context of SSP1-1.9 and SSP1-2.6. As can be seen, a larger number of national scenarios fulfil the climate neutrality

o Shared socioeconomic pathways are climate change scenarios of projected socioeconomic global changes up to 2100 as defined in the IPCC Sixth Assessment Report on Climate Change. In the pathway labels (e.g. SSP1-1.9), the first number (e.g. 1) refers to the assumed shared socioeconomic pathway, and the second (e.g. 1.9) refers to the approximate level of global effective radiative forcing in 2100.

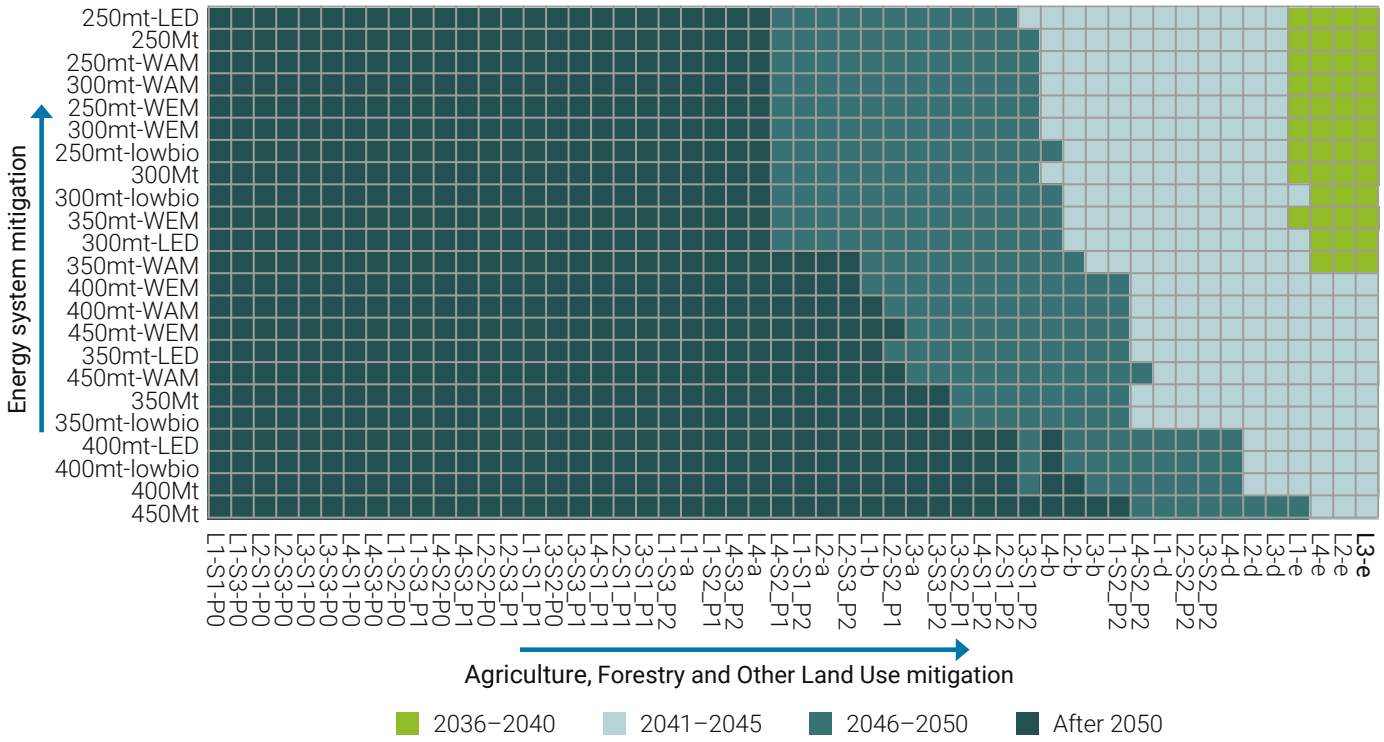

Figure TA1: Timing of temperature neutrality for given scenario combinations with a global shared socioeconomic pathway SSP1-2.6, with emissions reductions that limit warming to approximately 1.8°C. AFOLU scenarios are arranged along the x-axis in order of increasing mitigation strength. Energy system scenarios are arranged in order of increasing mitigation level along the y-axis so that the strongest mitigation scenarios occur in the top right-hand corner of the map. The probability threshold for neutrality was set at 67%. The Irish scenario codes are explained in Section A of the Technical Appendix.

condition under SSP1-2.6 than under the SSP1-1.9 global pathway. However, SSP1-2.6 carries with it a global context that has a higher risk of not achieving the Paris Agreement LTTG. The Council subsequently determined that the only those national scenarios consistent with climate neutrality in the context of SSP1-1.9 would be considered in the final shortlisted analysis for the carbon budgets, and therefore Ireland's level of ambition is consistent with high levels of ambition globally. In addition, **Figure TA3** shows the output from the warming analysis for an indicative national scenario, SSP1-1.9 350 Mt L1-S2_P2 broken down by GHG. Of note here is the evolution of the impact of aerosols from 1990, contributing to rapid warming. Also of note is the relatively stable contribution of methane and nitrous oxide emissions and the dominance of the fossil fuel-derived CO_2 component. The analysis extends to the year 2100, showing peak net warming before 2050 and a very gradual decline thereafter.

From this assessment, certain conclusions can be reached:

- A reasonably broad range of combinations of ambitious Energy and AFOLU sector mitigation scenarios could lead to temperature neutrality by 2050, and therefore they cannot be ruled out as being incompatible with achieving climate neutrality.
- A broader set of AFOLU options could contribute to temperature neutrality by 2050 when total energy system CO_2 emissions over 2021–2050 are 300 Mt or lower.

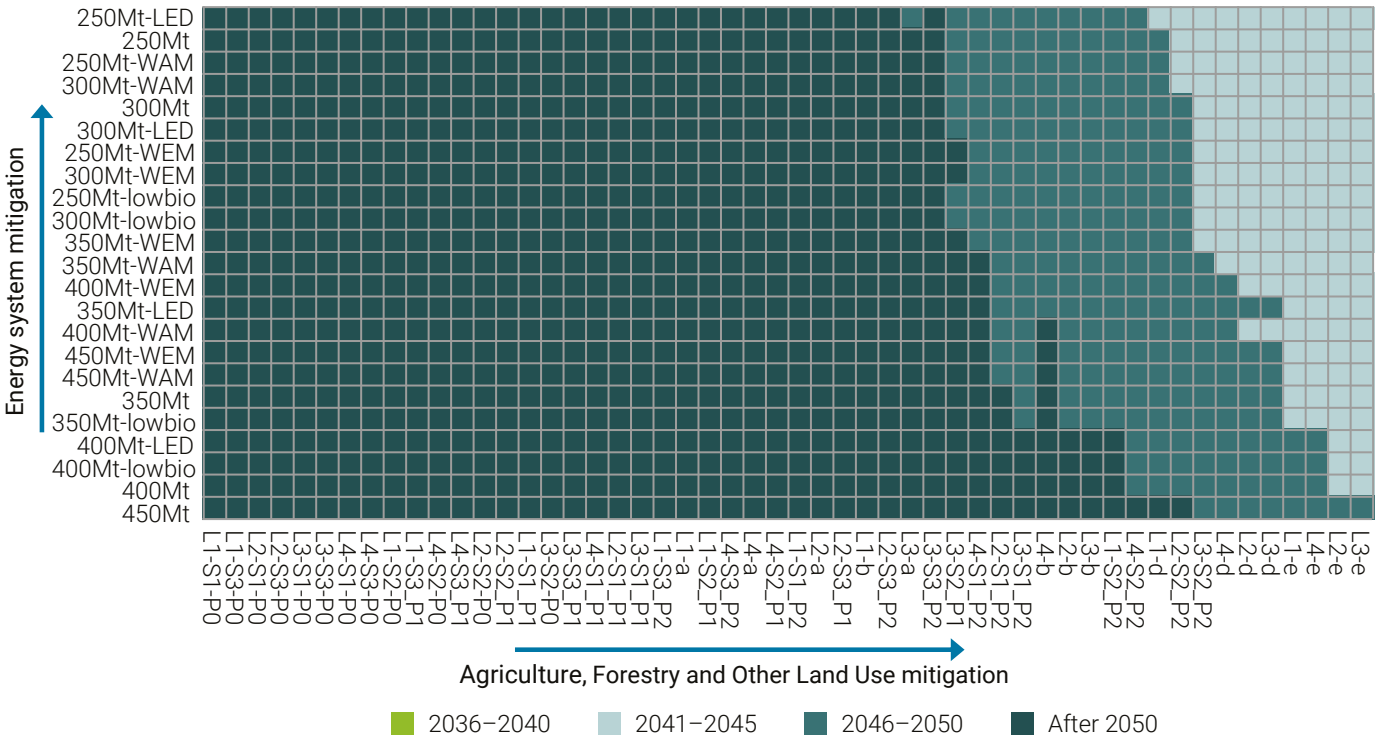

Figure TA2: Timing of temperature neutrality for given scenario combinations with a global shared socioeconomic pathway SSP1-1.9, with emission reductions that limit global warming to below 1.5°C. AFOLU scenarios are arranged along the x-axis in order of increasing mitigation strength. Energy system scenarios are arranged in order of increasing mitigation along the y-axis so that the strongest mitigation scenarios occur in the top right-hand corner of the map. The probability threshold for neutrality was set at 67%. The Irish scenario codes are explained in Section A of the Technical Appendix.

- Only very ambitious Agriculture sector mitigation scenarios (in which the very ambitious mitigation measure adoption pathway P2 is assumed) are likely to contribute to temperature neutrality by 2045 when 2021–2050 energy system CO_2 emissions are allowed to exceed 300 Mt.

Scenarios informing the development of the carbon budget proposal

While CO_2 emissions from the Energy sector could reach net zero as early as 2039, none of the modelled scenarios achieve net zero GWP_{100} for the AFOLU sector by 2050 when all gases are included. Methane is the second most significant contributor to GHG emissions in Ireland because of the high numbers of ruminant livestock. The Council requested that the CBWG develop scenarios that achieve a range of 30–60% reduction in GHG emissions for the Agriculture sector by 2050. Furthermore, while the scenarios informing the carbon budgets include negative emissions associated with afforestation, harvested wood product carbon storage and BECCS, the modelling does not rely on other novel CDR options, given their current very low deployment levels around the world.[22] As a result, none of the modelled scenarios achieve net zero GHG emissions by 2050, on the basis of GWP_{100}, when methane is included. A long list of 522 scenarios was identified as being consistent with Ireland achieving temperature neutrality by 2050 when combined with SSP1-2.6 (**Figure TA1**). Under a more ambitious global shared socioeconomic pathway, SSP1-1.9, just 377 of these scenarios are consistent with Ireland achieving temperature neutrality by 2050 (**Figure TA2**).

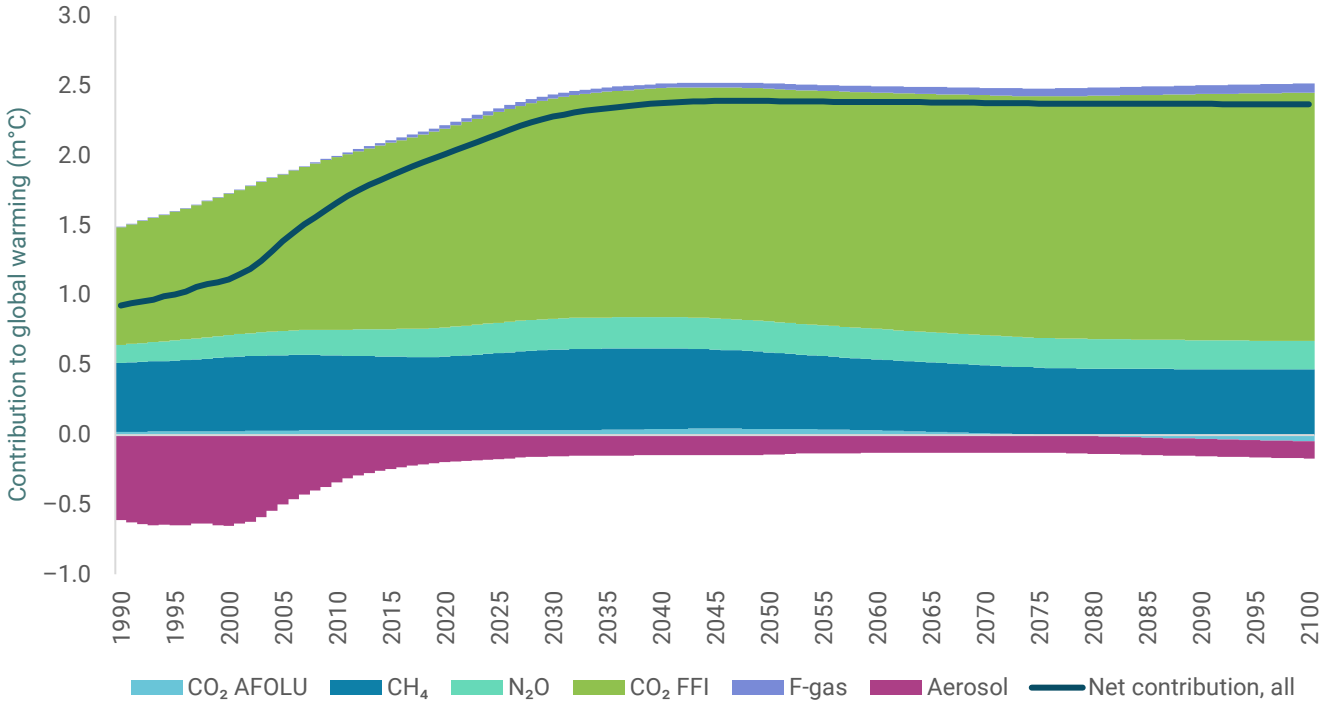

Figure TA3: Ireland's estimated net contribution to global warming relative to the pre-industrial era based on historical emissions 1750–2022, and indicative scenario SSP1-1.9 350 Mt L1-S2_P2. CO_2 AFOLU, contribution from CO_2 emissions and removals due to agricultural activities, land use and land use change; CH_4, methane emissions, largely due to livestock farming; N_2O, nitrous oxide emissions largely due to agricultural activities; CO_2 FFI, CO_2 emissions due to the use of fossil fuels and industrial processes; F-gas, industrial gases; Aerosol, direct and indirect impact on climate of small particles largely due to combustion.

The Council also excluded several energy scenarios from consideration in the carbon budget proposal. Some of these energy scenarios were excluded because they involved a sensitivity analysis for each of the energy system carbon budget cases modelled by TIM. This sensitivity analysis imposed carbon budgets aligned with current WEM and with additional measures (WAM) projections in the period to 2030 that currently do not align with CB1 and CB2.[p] This analysis highlighted that a failure to deliver on CB1 and CB2 will lead to even smaller carbon budgets in the 2030–2040 period, which is a major threat to the feasibility of CB3 and provisional CB4. Following a WEM or WAM pathway leaves vanishingly small carbon budgets after 2030 and would require both infeasibly steep mitigation in the 2030s and significant CDR. Furthermore, those energy scenario sensitivity cases ending in 'WEM' or 'WAM' that were constrained to the EPA projections analysis are not consistent with the National Climate Objective and were excluded from consideration for the Council's carbon budget proposal. In addition, the Council ruled out the most stringent 250 Mt CO_2 eq scenario for the energy system due to significant emissions overshoot and associated higher abatement costs stemming from the requirement to invest in a backstop carbon removal technology under this level of ambition for the energy system. Lastly, the Council also ruled out the least stringent 400 Mt CO_2 eq and 450 Mt CO_2 eq energy system scenarios due to their failure to meet a 90% reduction in net GHG emissions by 2040 relative to 1990 levels when benchmarked against the European Commission's

p The EPA's WEM scenario is a projection of future emissions based on the measures currently implemented and actions committed to by Government, while the WAM scenario includes all policies and measures included in the WEM scenario, plus those included in Government plans but not yet implemented.

recently recommended 2040 climate target.[q] These energy system scenarios are described in further detail in **Section A** and **Section B** of the **Technical Appendix**.

Similarly, the Council was able to rule out a number of Agriculture and Land Use sector scenarios from consideration in the carbon budget proposal. While agricultural emissions were modelled by both the GOBLIN and FAPRI-Ireland models, and the results showed good alignment between the models, the Council decided to focus on the agriculture scenarios from FAPRI-Ireland in combination with land use scenarios from GOBLIN in its deliberations. As a result, the agriculture scenarios modelled by the GOBLIN model (scenarios a–e) were excluded from consideration in the carbon budget proposal. Furthermore, two of the four forestry scenarios (L2 and L3) are based on a highly ambitious 25,000 ha per year afforestation rate, which approximates to the maximum rate achieved in the early 1990s in Ireland. These higher rates of afforestation are technically feasible based on the area of mineral soil spared from agriculture but would require further investigation regarding the exclusion criteria currently applied in forest licensing. As a result, the Council decided to focus on the two less ambitious forestry scenarios, one of which represents the current policy target of an afforestation rate of 8,000 ha per year (L1) and another, more ambitious, scenario representing 17,500 ha per year (L4). These Agriculture and Land Use sector scenarios are described in further detail in **Section A** and **Section B** of the **Technical Appendix**.

Finally, the Council identified a shortlist of 15 illustrative scenarios that are consistent with setting Ireland on an emissions trajectory that is compatible with the country's emissions contributing to no further global warming by 2050, against a backdrop of global efforts to limit global warming to 1.5°C in line with the Paris Agreement. It is worth noting that an additional nine pathways were identified that are consistent with climate neutrality in the context of global action under the SSP1-2.6 scenario, which constrains global warming to less than 2.0°C. The council decided to base its proposed carbon budgets on the shortlist of 15 scenarios (**Table TA1**). While the modelling of these 15 scenarios provides quantified solutions, the modelling groups added serious caveats to the practical feasibility of these scenarios. Overall, this analysis highlights that, while a range of options exist to meet the carbon budget targets, it will be necessary for all sectors covered to realise significantly increased ambition in both the period to 2030 and the period between 2030 and 2040.

A description of each of the scenarios listed in **Table TA1** is available in **Section 4** of this report and in the accompanying Carbon Budget Member Output Reports compiled by the modelling teams. The Council has not chosen a preferred scenario for this carbon budget proposal. Instead, the Council used all 15 of these scenarios to inform the carbon budget proposal by averaging the carbon budgets associated with each of the 15 scenarios to calculate the Council's carbon budget proposal outlined in **Section 2** above. The 15 scenarios considered in calculating the Council's carbon budget proposal include trade-offs between the Energy and AFOLU sectors that will need to be considered when assigning levels of effort sharing between sectors within the limits of the carbon budget. These 15 scenarios outline possible pathways to achieving the emissions reductions necessary if Ireland is to achieve temperature neutrality by 2050, and they highlight the urgent need for ambitious action to deliver the National Climate Objective.

q The EU has set a target to reduce net GHG emissions by at least 55% relative to 1990 levels for 2030. Recently, the European Commission recommended a 2040 climate target, proposing a 90% reduction in net GHG emissions by 2040 relative to 1990 levels. The EU has not formally adopted this target, nor has it indicated how Member States will be allocated different targets, or whether different sectors will be treated differently.

Table TA1: The proposed carbon budgets based on the average of the 15 shortlisted scenarios with a > 66% probability of achieving climate neutrality by 2050 with a global SSP1-1.9 and emissions reductions that limit warming to approximately 1.5°C. The scenario labels for each of the 15 shortlisted scenarios detailing the specific energy and AFOLU scenarios considered are provided, along with the indicative carbon budgets associated with each. Also shown is the estimate of Ireland's contribution to global warming since the pre-industrial era (1750–2050) and the proportion of that warming associated with combustion of fossil fuels

Scenario	Energy	Agriculture and Land Use	Mt CO_2 eq		Estimate of Ireland's contribution to global warming 1750–2050 (m°C)	Proportion of warming associated with fossil fuels
			CB3	Provisional CB4		
Scenario 1	300 Mt-Low Bio	L4-S1_P2	154	121	2.40	68%
Scenario 2	300 Mt-Low Bio	L1-S2_P2	150	118	2.37	69%
Scenario 3	300 Mt-Low Bio	L4-S2_P2	149	113	2.36	70%
Scenario 4	300 Mt	L4-S1_P2	156	119	2.40	68%
Scenario 5	300 Mt	L1-S2_P2	153	115	2.37	69%
Scenario 6	300 Mt	L4-S2_P2	151	111	2.36	70%
Scenario 7	300 Mt-LED	L4-S1_P2	162	122	2.40	68%
Scenario 8	300 Mt-LED	L1-S2_P2	158	119	2.37	69%
Scenario 9	300 Mt-LED	L4-S2_P2	162	128	2.36	70%
Scenario 10	350 Mt	L1-S2_P2	163	132	2.39	70%
Scenario 11	350 Mt	L4-S2_P2	162	128	2.38	70%
Scenario 12	350 Mt-Low Bio	L1-S2_P2	163	132	2.39	70%
Scenario 13	350 Mt-Low Bio	L4-S2_P2	162	128	2.39	70%
Scenario 14	350 Mt-LED	L1-S2_P2	171	134	2.39	70%
Scenario 15	350 Mt-LED	L4-S2_P2	170	130	2.38	70%
Average of 15 shortlisted scenarios	N/A	N/A	159	123	2.38	69%
Proposed carbon budgets rounded to the nearest 10 Mt	N/A	N/A	160	120	–	–

Note: Additional data can be found in the carbon budgets scenario digest (https://www.climatecouncil.ie/carbonbudgets/).

Section D: Article 2 of the United Nations Framework Convention on Climate Change and Articles 2 and 4(1) of the Paris Agreement

United Nations Framework Convention on Climate Change[11]

Article 2

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

The Paris Agreement[3]

Article 2

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

    a. holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change,

    b. increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production, and

    c. making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

2. This Agreement will be implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances.

Article 4 (1)

In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.

References

1. EY (2024). Renewable Energy Country Attractiveness Index. [online] https://www.ey.com/content/dam/ey-unified-site/ey-com/en-gl/insights/energy-resources/documents/ey-gl-recai-63-final-07-2024.pdf

2. BVG Associates (2024). Offshore Renewable Energy Export Potential for Ireland. [online] https://assets.gov.ie/281435/8d698eac-0112-4058-9524-e43d1668e979.pdf

3. Paris Agreement to the United Nations Framework Convention on Climate Change, 12 December 2015, T.I.A.S. No. 16-1104. [online] https://unfccc.int/documents/184656

4. Climate Change Advisory Council (2024). Annual Review 2024: Cross-sectoral Review. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/AR2024-Cross-sectoral-Review-FINAL.pdf

5. Intergovernmental Panel on Climate Change (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [online] https://www.ipcc.ch/report/ar5/wg1/

6. Intergovernmental Panel on Climate Change (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. [online] https://www.ipcc.ch/report/ar6/wg1/

7. Environmental Protection Agency (2024). Ireland's Provisional Greenhouse Gas Emissions 1990–2023. [online] https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/irelands-provisional-greenhouse-gas-emissions-1990-2023.php

8. Climate Change Advisory Council (2022). Terms of Reference of Carbon Budgets Working Group. [online] https://www.climatecouncil.ie/media/climatechangeadvisorycouncil/contentassets/documents/governance/Carbon%20Budgets%20Working%20Group%20Terms%20of%20Reference_Final.pdf

9. Climate Change Advisory Council (2024). Carbon Budgets Working Group Outputs Report. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

10. Government of Ireland (2021). Climate Action and Low Carbon Development (Amendment) Act 2021. [online] https://www.irishstatutebook.ie/eli/2021/act/32/section/15/enacted/en/html

11. United Nations (1992). United Nations Framework Convention on Climate Change. [online] https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

12. European Commission (2024). Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. [online] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2024%3A63%3AFIN

13. European Environment Agency (2024). EEA greenhouse gases – data viewer. [online] https://www.eea.europa.eu/en/analysis/maps-and-charts/greenhouse-gases-viewer-data-viewers [accessed 20.11.2024].

14. European Scientific Advisory Board on Climate Change (2023). Scientific Advice for the Determination of an EU-wide 2040 Climate Target and a Greenhouse Gas Budget for 2030–2050. [online] https://climate-advisory-board.europa.eu/reports-and-publications/scientific-advice-for-the-determination-of-an-eu-wide-2040

15. Department of the Environment, Climate and Communications (2024). National Energy and Climate Plan 2021–2030. [online] https://www.gov.ie/en/publication/0015c-irelands-national-energy-climate-` plan-2021-2030/

16. Climate Change Advisory Council (2023). Annual Review 2023. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/CCAC-AR-2023-postfinal.pdf

17. Climate Change Advisory Council (2022). Annual Review 2022. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/Annual%20Review%202022%20Web%20Version.pdf

18. Environmental Protection Agency (2024). Ireland's Greenhouse Gas Emissions Projections 2023–2050. [online] https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/irelands-greenhouse-gas-emissions-projections-2023-2050.php

19. Government of Ireland (2024). Climate Action Plan 2024. [online] https://www.gov.ie/pdf/?file=https://assets.gov.ie/296414/7a06bae1-4c1c-4cdc-ac36-978e3119362e.pdf#page=null

20. EUR-Lex (2028). Regulation (EU) 2018/842 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement. [online] https://eur-lex.europa.eu/eli/reg/2018/842/oj

21. Climate Change Advisory Council. CCAC Secretariat Note on Methane: Meeting 4. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

22. Geden, O. (2024). Carbon Budgets Working Group Report on the Role of Carbon Dioxide Removal. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

23. Department of the Environment, Climate and Communications (2023). Ireland's Long-term Strategy on Greenhouse Gas Emissions Reduction 2024. [online] https://www.gov.ie/en/publication/e4e81-long-term-strategy-on-greenhouse-gas-emissions-reductions/

24. Environmental Protection Agency (2024). EPA Report to Carbon Budget Working Group Secretariat. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

25. Intergovernmental Panel on Climate Change (2019). Special Report: Global Warming of 1.5 ºC. [online] https://www.ipcc.ch/sr15/

26. Molloy, A. et al. (2024).Working Paper No. 33: Assessment of Biodiversity Considerations in the Carbon Budgets Process. Climate Change Advisory Council. [online] https://www.climatecouncil.ie/councilpublications/councilworkingpaperseries/WP33%20Biodiversity%20for%20web.pdf

27. Gorman, C. et al. (2023). Reconciling climate action with the need for biodiversity protection, restoration and rehabilitation. *Science of the Total Environment*, 857, 159316. [online] https://www.sciencedirect.com/science/article/abs/pii/S0048969722064154

28. Moran, J. (2024). Biodiversity Considerations in the Carbon Budgets 2031–2040. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

29. Wheatley, J. (2024). Ireland's Warming Impact. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

30. Climate Change Advisory Council (2021). Carbon Budget Technical Report. [online] https://www.climatecouncil.ie/media/climatechangeadvisorycouncil/Technical%20report%20on%20carbon%20budgets%2025.10.2021.pdf

31. Climate Change Advisory Council (2024). Annual Review 2024: Transport. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/AR2024-Transport-final.pdf

32. Mintz-Woo, K. (2024). Irish Carbon Budgets: Some Moral Considerations. Climate Change Advisory Council. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

33. Sustainable Energy Authority Ireland (2024). Carbon Budgets Modelling Review: 2024 Report of SEAI Analysis for Carbon Budgets Working Group. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

34. National Transport Authority (2024). Report on review by the NTA for Carbon Budgets Working Group. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

35. Daly, H. et al. (2024). Pathways for Ireland's Energy System to 2050: Modelling Analysis to Support the Climate Change Advisory Council on the Second Carbon Budget Programme. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

36. McGuire, J. et al. (2024). Advancing cost-optimal residential decarbonisation pathways: an examination of heat pumps and thermal efficiency. *Energy and Buildings*, 317, 114383. [online] https://www.sciencedirect.com/science/article/pii/S0378778824004997

37. Climate Change Advisory Council (2024). Annual Review 2024: Built Environment. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/AR2024-Built%20Environment.pdf

38. Climate Change Advisory Council (2024). Annual Review 2024: Industry and Waste. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/AR2024-IndustryWaste-FINAL.pdf

39. Lanigan, G.J. et al. (2024). Modelling Irish Agricultural GHG Emissions and Mitigation to 2050: Scenarios for the Carbon Budgets Working Group. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

40. Styles, D. et al. (2024). GOBLIN Scenarios to Support Ireland's Carbon Budgets 3 & 4. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

41. Central Statistics Office (2023). Afforestation area. [online] https://data.cso.ie/ [accessed 20.11.2024].

42. Environmental Protection Agency (2024). Ireland's National Inventory Report 2024: Greenhouse Gas Emissions 1990–2022. [online] https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/Ireland's-NIR-2024_cov.pdf

43. Lanigan G., et al. (2023). MACC 2023: An Updated Analysis of the Greenhouse Gas Abatement Potential of the Irish Agriculture and Land-Use Sectors Between 2021 and 2030. Teagasc. [online] https://www.teagasc.ie/environment/climate-centre/publications/marginal-abatement-cost-curve-2023/

44. Mclnerney, N. and Fitzgerald, J. (2024). Assessing the Macroeconomic Impact of Carbon Budgets. [online] https://www.climatecouncil.ie/carbonbudgets/carbonbudgetsworkinggroup2023-2024/

45. Pisani-Ferry, J. and Mahfouz, S. (2023). The Economic Implications of Climate Action. France Stratégie. [online] https://www.piie.com/sites/default/files/2023-11/2023-11-08-pisani.pdf

46. Pisani-Ferry, J. (2021). Climate Policy is Macroeconomic Policy, and the Implications Will Be Significant. [online] https://www.piie.com/sites/default/files/documents/pb21-20.pdf

47. Central Statistics Office (2024). AAA09 number of livestock. [online] https://data.cso.ie/ [accessed 20.11.2024].

48. De Bruin, K. et al. (2024). Working Paper No. 32: Policy Brief on Economic Costs of Climate Change Impacts and Adaptation in Ireland: A Sectoral Analysis on Five Climate Change Impacts. Climate Change Advisory Council. [online] https://www.climatecouncil.ie/councilpublications/councilworkingpaperseries/Policy%20Brief%20Economic%20Costs%20Climate%20Impacts%20and%20Adaptation%20in%20Ireland%20for%20web.pdf

49. Borgonovi, F., et al. (2023). The effects of the EU Fit for 55 Package on Labour Markets and the Demand for Skills. Organisation for Economic and Social Development. [online] https://www.oecd-ilibrary.org/social-issues-migration-health/the-effects-of-the-eu-fit-for-55-package-on-labour-markets-and-the-demand-for-skills_6c16baac-en

50. European Parliament (2024). Briefing: Social and Labour Market Impact of the Green Transition. [online] https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/762329/EPRS_BRI(2024)762329_EN.pdf

51. Cedefop (2021). The Green Employment and Skills Transformation: Insights from a European Green Deal Skills Forecast Scenario. [online] http://data.europa.eu/doi/10.2801/112540

52. Vandeplas, A. et al. (2022). The Possible Implications of the Green Transition for the EU Labour Market. European Commission. [online] https://economy-finance.ec.europa.eu/system/files/2022-12/dp176_en_green%20transition%20labour.pdf

53. Eurofound (2023). Fit for 55 Climate Package: Impact on EU Employment by 2030. [online] https://www.eurofound.europa.eu/en/publications/2023/fit-55-climate-package-impact-eu-employment-2030

54. European Parliament (2024). Briefing: Social and Labour Market Impact of the Green Transition. [online] https://www.europarl.europa.eu/RegData/etudes/BRIE/2024/762329/EPRS_BRI(2024)762329_EN.pdf

55. Asikainen, T. et al. (2022). The Future of Jobs is Green. Joint Research Centre. [online] https://publications.jrc.ec.europa.eu/repository/handle/JRC126047

56. Conroy, N. and Timoney, K. (2024). Irish Fiscal Advisory Council Working Paper Series No. 23 Ireland's Infrastructure Demands. [online] https://www.fiscalcouncil.ie/occasional-research/#WPs

57. National Economic and Social Council (2020). Addressing Employment Vulnerability as Part of a Just Transition in Ireland. [online] http://files.nesc.ie/nesc_reports/en/149_Transition.pdf

58. SOLAS (2023). National Skills Bulletin 2023. [online] https://www.solas.ie/f/70398/x/2b3fd7d856/national-skills-bulletin-2023.pdf

59. Department of Further and Higher Education, Research, Innovation and Science (2022). Report on the Analysis of Skills for Residential Construction and Retrofitting 2023–2030. [online] https://www.gov.ie/en/publication/10ae6-report-on-the-analysis-of-skills-for-residential-construction-retrofitting-2023-to-2030/

60. Barrett, A. et al. (2024). The National Development Plan in 2023: Priorities and Capacity. Economic and Social Research Institute. [online] https://www.esri.ie/system/files/publications/SUSTAT123_3.pdf

61. Goldrick-Kelly, P. et al. (2019). Working Paper No. 65: Matching Skills Needs with Skills Reserves: Protecting Workers and Communities for a Just Transition. Nevin Economic Research Institute. [online] https://justtransitionforall.com/wp-content/uploads/2022/11/working-paper-series-no-65_final.pdf

62. EnvEcon and AARC (2020). Report on the Transition Process Toward Climate Neutrality. [online] https://www.gov.ie/pdf/?file=https://assets.gov.ie/207785/120570d0-0bed-4377-b752-1992cbd4fdb1.pdf#page=null

63. Ibec (2020). Factsheet: Employment in the Meat Sector. [online] https://cdn.ibec.ie/-/media/documents/connect-and-learn/industries/food-and-drink/meat-industry-ireland/mii-documents/employment-in-the-meat-sector

64. Climate Change Advisory Council (2024). Annual Review 2024: Agriculture and Land Use, Land Use Change and Forestry. [online] https://www.climatecouncil.ie/councilpublications/annualreviewandreport/AR24-Agriculture%20LULUCF.pdf

65. Climate Change Advisory Council (2024). Annual Review 2024: Summary for All. [online] https://www.climatecouncil.ie/councilpublications/

66. Evans, S. (2021). Analysis: Which countries are historically responsible for climate change? Carbon Brief. [online] https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change