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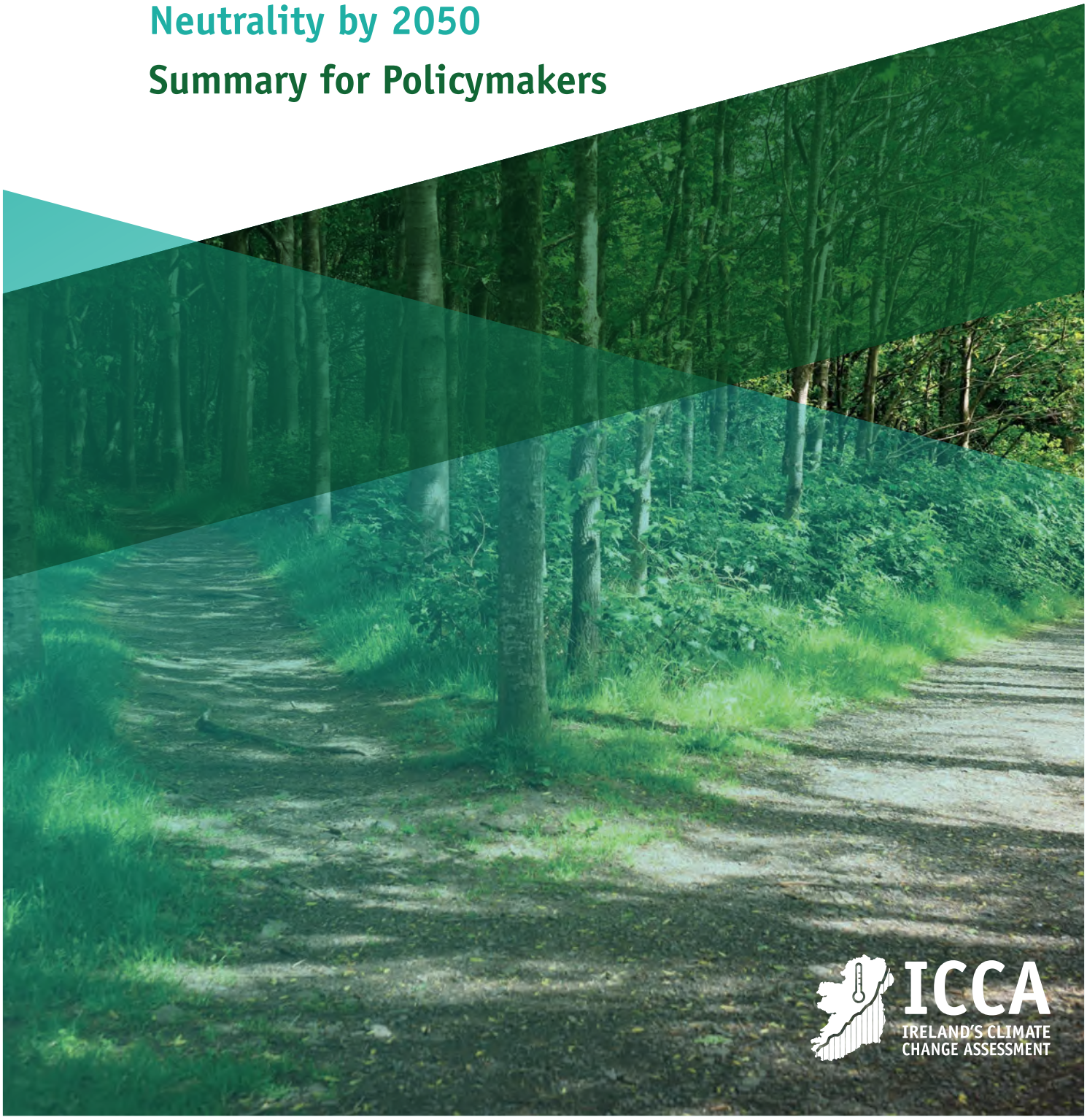
An Ghníomhaireacht um Chaomhnú Comhshaoil

IRELAND'S CLIMATE CHANGE ASSESSMENT

Volume 2: Achieving Climate Neutrality by 2050

Summary for Policymakers



ICCA
IRELAND'S CLIMATE CHANGE ASSESSMENT

Ireland's Climate Change Assessment 2023

Environmental Protection Agency

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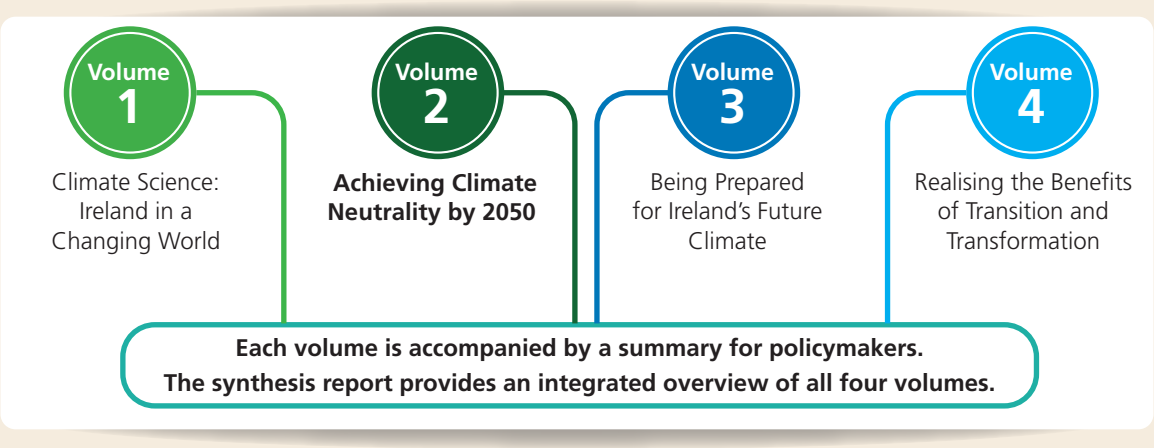
Introduction

Ireland's Climate Change Assessment (ICCA) delivers a comprehensive, Ireland-focused, state of scientific knowledge report on our understanding of climate change, its impacts on Ireland, the options to respond to the challenges it poses, and the opportunities from transitions and transformations to a climate-neutral, climate-resilient and sustainable economy and society. This serves to complement and localise the global assessments undertaken by the Intergovernmental Panel on Climate Change (IPCC) reports (see www.ipcc.ch). The findings presented build upon these global assessments and add important local and national context.

The report is presented in a series of four thematic volumes accompanied by an overarching synthesis report. The volumes are as follows:



Volume 2

The Summary for Policymakers (SPM) provides key insights from Volume 2 of Ireland's Climate Change Assessment: *Achieving Climate Neutrality by 2050*. Volume 2 introduces our current best understanding of how to mitigate climate change with a central focus on Irish literature seeking to inform the pathway to a climate-neutral Ireland. The SPM is organised as follows. Section A sets out the current position in relation to greenhouse gas emissions and climate policy in Ireland. Section B outlines our options to achieve climate neutrality with a focus on future energy systems and greenhouse gas emission choices. Section C provides key insights for policy and Section D outlines key recommendations for future research investment.

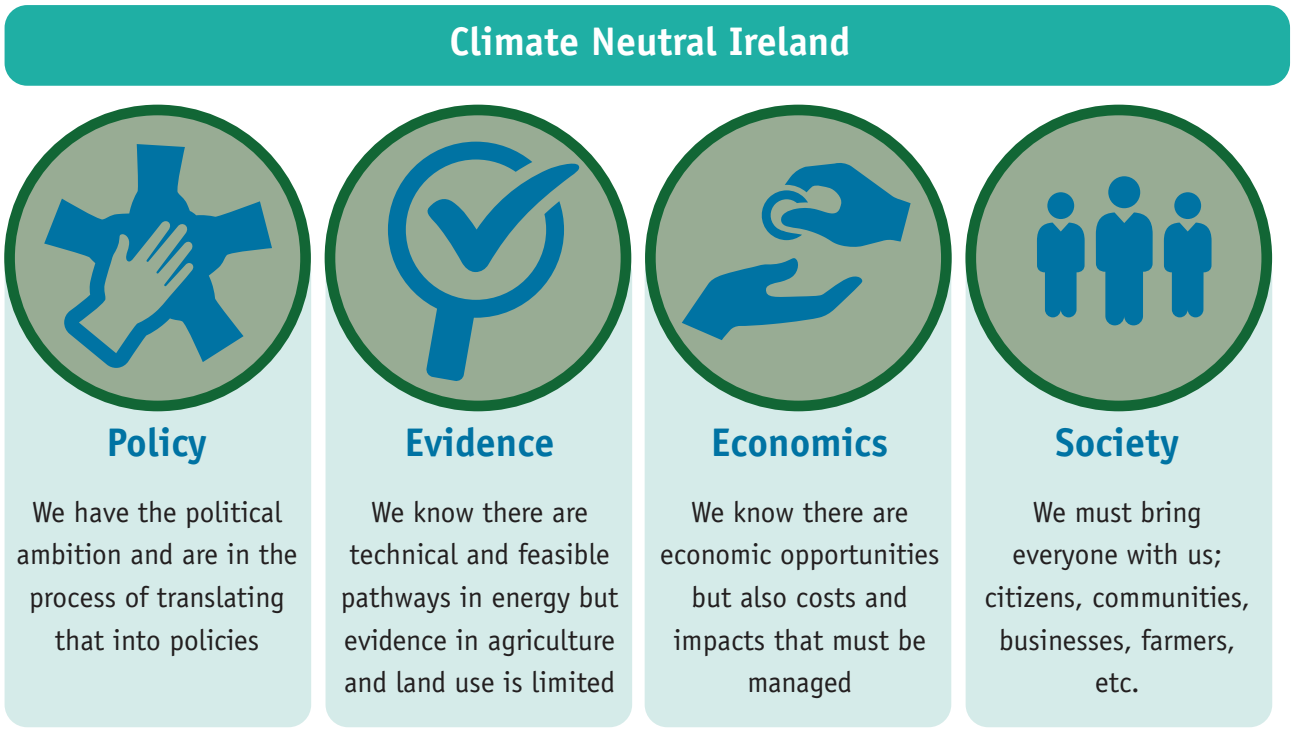


Figure SPM.1 Ireland's strategy towards climate neutrality[1].

A. The starting point: greenhouse gas emissions and climate policy in Ireland

Since the Industrial Revolution, enhanced levels of atmospheric greenhouse gases, particularly carbon dioxide, have changed the Earth's energy balance, resulting in less heat being lost to space. This is causing global warming, which is observed as increased global average temperatures, changes in precipitation patterns, mean sea level rise and changes in the character of weather extremes.

Greenhouse gases are composed of several different heat-trapping gases, with carbon dioxide being the largest and most important contributor to climate change. Methane, nitrous oxide, industrial gases and ozone are also important greenhouse gases. The influence of these greenhouse gases and other climate forcers (e.g. aerosols) on the Earth's energy balance are detailed in Ireland's Climate Change Assessment (ICCA) Volume 1.

To address climate change, both Ireland and the EU are Parties to the United Nations Framework Convention on Climate Change and the 2015 Paris Agreement. The Paris Agreement entered its implementation phase in 2020 as the global framework for addressing climate change. The Paris Agreement established goals relating to temperature, climate resilience and financial flows. Specifically, these are to hold the global average temperature increase to well below 2°C and pursue efforts to limit the increase to 1.5°C. {Chapter 1}

Ireland and other Parties to the Paris Agreement have committed to collectively reaching a global 'balance' of greenhouse gas emissions and removals during the second half of this century on the basis of equity, reflecting common but differentiated responsibility in light of different national circumstances. Ireland's commitments have been agreed with EU partners and submitted as a collective EU nationally determined contribution under the Paris Agreement. These are framed by national long-term emissions reductions strategies.

[1] There are different interpretations of the term climate neutrality. The EU Climate Law aligns it with achieving net zero greenhouse gas emissions by 2050. The Climate Action and Low Carbon Amendment Act 2021 interprets a "climate neutral economy" as a "sustainable economy and society where greenhouse gas emissions are balanced or exceeded by the removal of greenhouse gases". This is the interpretation used in this report that draws on the long-term mitigation analysis published for Ireland. Evolving interpretations of climate neutrality include adopting separate approaches for long- and short-lived greenhouse gas emissions and the need to include the roles of short-lived climate forcers.

Collective global progress in achievement of the goals of the Paris Agreement and the scale of stated collective ambition are assessed under the Paris Agreement global stocktake every 5 years, starting from 2023.

Ireland is ranked second highest across the EU when all greenhouse gas emissions are considered on a per person basis. Compared with other EU Member States, Ireland has higher than average emissions of methane and nitrous oxide because we have the highest agriculture emissions contribution to our national total emissions. A similar pattern can be seen in New Zealand, where agriculture is also an important part of the economy.

Ireland's greenhouse gas emissions increased by 29% in the period from 1990 to 2001, the year in which emissions peaked. In the period since 2001, Ireland's emissions have reduced by 14%.

A.1. Ireland has made limited progress in reducing greenhouse gas emissions but there is a very long way to go

Ireland's greenhouse gas emissions peaked in 2001. Greenhouse gas emissions per capita have decreased from 18 tonnes in 2001 to 12 tonnes per person in 2021. Carbon dioxide is the most significant contributor to the greenhouse gas emissions in Ireland. Ireland's energy system is heavily dependent (86%) on fossil fuels. Carbon dioxide emissions in the transport sector have doubled since 1990. Ireland's large livestock population is the main driver of methane and nitrous oxide emissions, the second and third most significant contributors to greenhouse gas emissions in Ireland. Land use, land use change and forestry (LULUCF) in Ireland is a source of greenhouse gas emissions rather than a sink. {Chapter 2}

A1.1	Having peaked in 2001, Ireland's greenhouse gas emissions reduced in all sectors except agriculture[2]. In 2021, Ireland's total greenhouse gas emissions are estimated to be 62 million tonnes carbon dioxide equivalent[3] (69 million tonnes including LULUCF[4]), which is approximately 11% higher than emissions in 1990 and 14% lower than emissions in 2001. Greenhouse gas emissions per capita increased from 16 tonnes carbon dioxide equivalent per person in 1990 to 18 tonnes in 2001, and reduced to 12 tonnes per person in 2021.
A1.2	Carbon dioxide is the most significant contributor to greenhouse gas emissions in Ireland at 60.5% of total greenhouse gas emissions excluding LULUCF. The electricity and transport sectors were responsible for 27% and 29% of total carbon dioxide emissions (excluding LULUCF) in 2021, respectively. There was a 14% increase in carbon dioxide emissions from 1990 to 2021, due to a doubling of emissions from fossil fuel combustion in the transport sector over the period. Ireland's energy system is heavily dependent (86%) on fossil fuels.
A1.3	Methane is the second most significant contributor to greenhouse gas emissions in Ireland (28.4% of total greenhouse gas emissions excluding LULUCF) and is due to the large livestock population. Emissions of methane increased from 1990, reaching a peak in 1998, then decreased due to falling livestock numbers and returned to near record levels again in 2021. The main contributor to the methane trend is the agriculture sector, and in 2021 this sector accounted for 94% of the methane emissions.
A1.4	Nitrous oxide emissions (10.3% of total greenhouse gas emissions excluding LULUCF) increased during the 1990s to peak in 1998, reflecting the increased use of synthetic fertilisers and increased amounts of animal manures associated with increasing animal numbers. Emissions subsequently showed a downwards trend followed by an increase in the period 2015–2021, as the dairy sector expanded and nitrogenous fertiliser use increased.

[2] EPA (2023). Ireland's National Inventory Report 2023: Greenhouse Gas Emissions 1990–2021.

[3] Greenhouse gases other than carbon dioxide (i.e. methane, nitrous oxide and fluorinated gases) can be aggregated as carbon dioxide equivalents using their global warming potentials from the Intergovernmental Panel on Climate Change Fifth Assessment Report. Here, the global warming potential of a gas is a measure of the cumulative warming over a specified time, usually 100 years, by a unit mass of this gas. More detail on global warming potential is available in ICCA Volume 1.

[4] Unless stated, all national greenhouse gas numbers exclude the LULUCF sector, which covers the following categories: forest land, cropland, grassland, wetlands, settlements, other land and harvested wood products. This sector has historically not been included in the published national emission totals unless explicitly stated but is reported in submissions to the EU and UN. Its recent inclusion in the published national emission totals reflects national policy, specifically arising from the inclusion of LULUCF in Ireland's 2030 greenhouse gas emission reduction target and in carbon budgets. This sector is a net source of greenhouse gas emissions.

A.2. Irish and European climate ambition has significantly increased since 2019

Climate policy at national and EU and UN levels has evolved rapidly since the adoption of the Paris Agreement. Ireland has established a statutory target for a 51% reduction in total greenhouse gas emissions (including LULUCF) by 2030, compared with 2018 and has legislated for a long-term national climate objective of climate neutrality by 2050 at the latest. The European Climate Law establishes a legislative framework for the EU to become climate neutral by 2050 and sets the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared with 1990 levels. {Chapter 2}

A2.1	The Climate Action and Low Carbon Development Act (Amendment) 2021 (Climate Act 2021) establishes a target for a 51% reduction in total greenhouse gas emissions (including LULUCF) by 2030, compared with 2018, and a long-term national climate objective of climate neutrality by 2050 at the latest. The Climate Act also provides for the establishment of carbon budgets[5] as a legislative framework for achieving Ireland's climate ambition. The 51% target, relative to 2018, is the primary constraint on carbon budgets over the course of the first two budget periods, ending on 31 December 2030.
A2.2	The European Climate Law establishes a legislative framework for the EU to become climate neutral by 2050. This enshrines the European Green Deal, which provides for investing in green technologies and protecting the natural environment in order to achieve net zero greenhouse gas emissions by 2050. The law also sets the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared with 1990 levels, under the EU Fit for 55 legislative package[6]. {Chapter 2}

Ireland's 2030 target under the EU's Effort Sharing Regulation is to limit its greenhouse gas emissions by at least 42% by 2030 in the areas mainly outside electricity generation[7]. The 42% reduction defines the trajectory with annual binding emission limits over the period to 2030. Ireland has access to EU-wide flexibilities to allow for a fair and cost-efficient achievement of the target. These flexibilities include intra-EU trading of Member State emissions allowances, the use of EU Emissions Trading System allowances and credit from action undertaken in the LULUCF sector. {Chapter 2}

5 Ireland's carbon budgets provide a maximum 5-yearly total for greenhouse gas emissions based on all emissions aggregated in terms of carbon dioxide equivalents determined by their 100-year global warming potential as provided in the Intergovernmental Panel on Climate Change Fifth Assessment Report.

6 The EU Fit for 55 legislative package has been submitted to the United Nations Framework Convention on Climate Change as the EU nationally declared contribution to the Paris Agreement.

7 Greenhouse gas emissions reductions in the electricity sector, large industry and intra-EU aviation are legislated for separately under the EU Emissions Trading System.

A.3. Additional policies and actions are required to meet legally binding targets

Large-scale and immediate greenhouse gas emissions reductions are needed across energy, agriculture and land use to meet Ireland's legally binding targets. Ireland has the high-level political climate ambition, and the necessary technologies, but there is a disconnect between this and the delivery of political, financial, societal and industry climate action. {Chapter 2}

A3.1	Greenhouse gas emission estimates for 2021 and 2022 indicate that 47% of Ireland's first carbon budget has been emitted within 40% of the budget time frame[8].
A3.2	Ireland's first two carbon budgets (2021–2030) under the Climate Act 2021 are projected[9] to be exceeded by a significant margin of between 24% (117MtCO_2-eq) and 34% (170MtCO_2-eq). In addition, any shortfall in the first carbon budget will be carried over to the second carbon budget period.
A3.3	Current polices are not sufficient to meet the legally binding national carbon budgets for 2021–2025 and 2025–2030.

A.4 Achieving Ireland's climate goals will be challenging and will need to take account of our global responsibilities

A4.1	Achieving net zero carbon dioxide emissions by 2050 requires significant and unprecedented changes to our energy system. In addition, implementation of emissions mitigation strategies across agriculture and land use sectors, including diversification, has not been achieved to date. Achieving net zero greenhouse gas emissions (or achieving climate neutrality[10]) by 2050 is very challenging.
A4.2	To date, climate mitigation research has not identified technically feasible scenarios in which Ireland can remain within its population-weighted share of the remaining global carbon budget for 1.5°C. It is Ireland's cumulative emissions in the period to 2050, rather than meeting net zero by 2050, that determine Ireland's contribution to climate change.
A4.3	Current energy systems modelling shows that achieving net zero carbon dioxide emissions by 2050 requires unprecedented changes and in itself is not sufficient to achieve climate neutrality. {Chapter 3}
A4.4	Estimating how to equitably distribute remaining global carbon budgets has legal, ethical and practical dimensions. Addressing such equity issues is central to implementation of the Paris Agreement and will be considered by governments during the 5-yearly global stocktake of climate action that begins in 2023.
A4.5	The energy scenarios modelled to date as being technically feasible exceed Ireland's population-weighted share of the remaining 1.5°C cumulative emissions trajectories.
A4.6	Apportioning the global carbon budget using different approaches informed by other ethical principles (such as ability to pay or historical emissions) will produce different estimates of equitable share.
A4.7	Modelling of agriculture emissions and the projected impact of mitigation measures indicates that there are a range of measures that can be taken. {Chapter 6}
A4.8	Significant implementation of mitigation measures, including diversification, has not been achieved in Ireland to date, making the achievement of climate neutrality more challenging.
A4.9	Research on what is required to achieve climate neutrality across the agriculture and land use sectors is at an early stage and more analysis on what levels of agriculture emissions can feasibly be balanced with land use removals is urgently needed. {Chapter 7}

[8] EPA (2023). *Ireland's National Inventory Report 2023: Greenhouse Gas Emissions 1990–2021*.

[9] EPA (2023). *Ireland's Greenhouse Gas Emissions Projections 2022–2040*.

[10] This volume interprets achieving climate neutrality by 2050 as achieving net zero greenhouse gas emissions in Ireland by 2050. The Climate Act 2021 interprets a "climate neutral economy" as a "sustainable economy and society where greenhouse gas emissions are balanced or exceeded by the removal of greenhouse gases".

B. The options to achieve climate neutrality: future energy system and greenhouse gas emission choices

In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change highlighted the existence of technological, political and economic solutions to achieve rapid and widespread emission reductions. Projected cumulative future carbon dioxide emissions from current and planned energy infrastructures worldwide would, over their lifetime and without additional abatement, likely exceed the cumulative global budget for limiting warming to 1.5°C.

Similarly, studies suggest that Ireland's future energy-related emissions would exceed a per capita share of the global 1.5°C budget, without additional unprecedented carbon dioxide emission reductions and/or reliance on large-scale carbon dioxide removals.

Large-scale and immediate greenhouse gas emissions reductions are needed across the whole energy system (electricity, heat and transport), agriculture and land use to meet Ireland's legally binding targets. The range of technical mitigation options available in agriculture are still in nascent stages (requiring more research and investments) than those within the energy sector. There are a growing number of options for mitigating methane and nitrous oxide emissions in agriculture that are at different stages of development. Although there is international research on how reductions in energy and livestock challenge the current economic growth paradigm, this research is limited to date in Ireland.

B.1. Features of net zero carbon dioxide energy systems

There are well-established 'no-regret options' that must happen now, which can get us most of the way to net zero carbon dioxide emissions. Beyond that, there are 'future energy choices' relating to the scale and magnitude of technologies that will help get us all the way. Energy demand reduction is the replacement of fossil fuels with renewable energy is necessary, but carbon dioxide removal from the atmosphere is also required. Electrification of heating and transport is necessary but not sufficient to achieve a net zero energy system. Ireland will need new energy carriers in the form of bioenergy or hydrogen for heavy transport and high-grade heat in industry, and should also look at alternatives such as district heating for urban areas. {Chapters 3, 4, 5}

B1.1	There are well-established 'no-regret options' that must happen now, which can get us most of the way. These are **demand reduction** (e.g. through energy efficiency and reduced consumption), **electrification** (e.g. electric vehicles and heat pumps), **deployment of market-ready renewables** (e.g. wind and solar) and **low-carbon heating options** (e.g. district heating).
B1.2	Beyond that, there are **future energy choices** relating to the scale and magnitude of technologies that will help get us to net zero emissions. These technologies include hydrogen, carbon capture and storage, nuclear energy[11] and electrofuels. While the scale and mix of these specific technologies are currently unclear, it should not be and is not a barrier to action.
B1.3	A benefit of a net zero energy system is **a significant reduction in the import of fossil fuels into Ireland** to meet our energy needs, from 70% today to less than 5% in the future, according to the literature to date. There are many additional societal co-benefits, including human health and air quality.
B1.4	Figure SPM.2 provides one indicative pathway for Ireland to achieve a net zero energy system by 2050.

[11] Developing nuclear energy or carbon storage would require legislative changes.

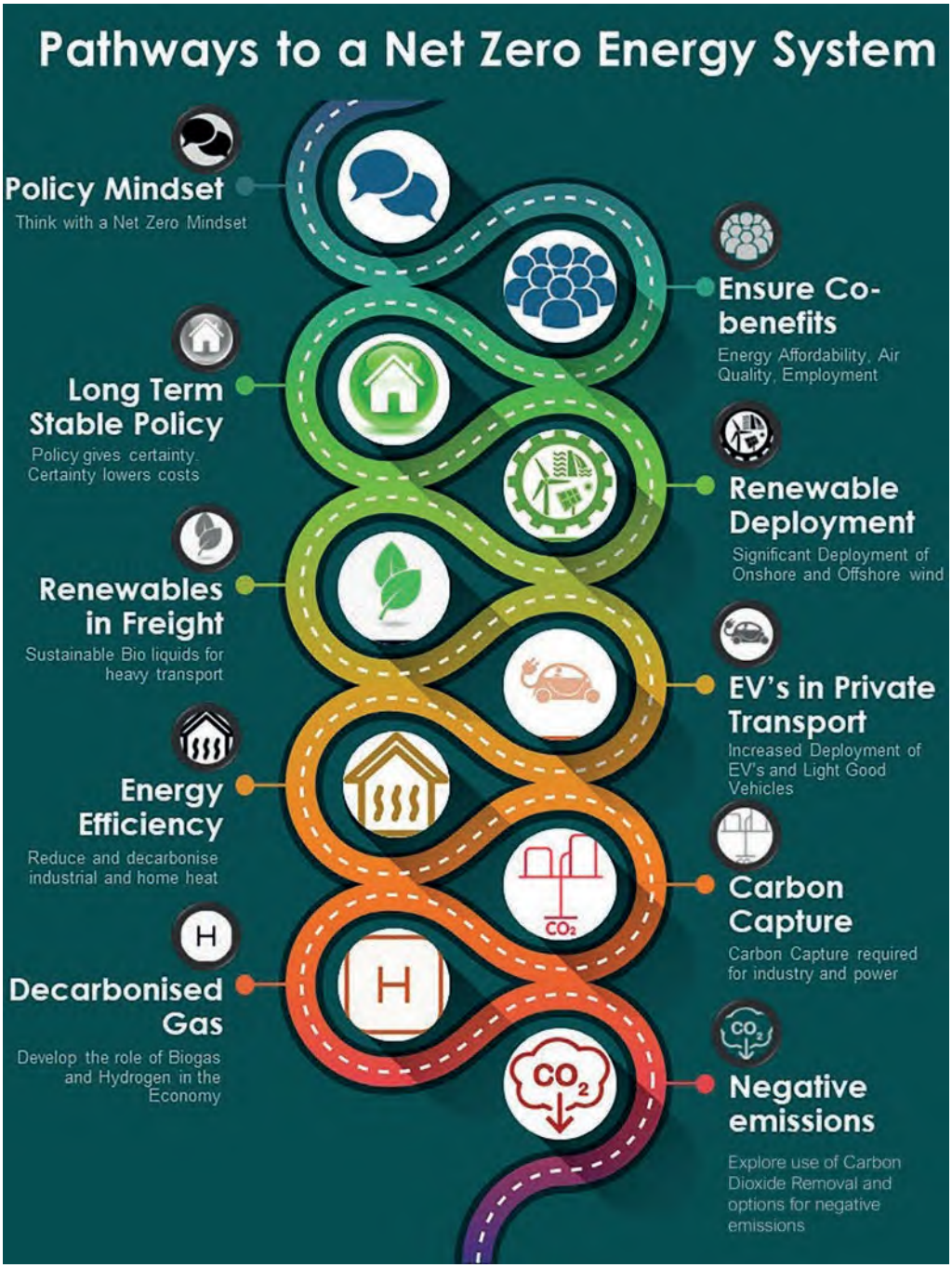


Figure SPM.2 An indicative pathway to achieve a net zero energy system in Ireland. (Source: MaREI Centre)

B.2. A wide range of interventions is needed to transform Ireland's energy system away from fossil fuels

Significant reductions if not complete elimination in fossil fuel usage is required. Avoid–shift–improve is a useful framework emanating from mobility research that should be applied across all sectors. Transformative system-wide changes across the energy system can deliver multiple co-benefits, including in the areas of health, air pollution and energy justice.

B2.1	Significant reductions if not complete elimination in fossil fuel usage is required. Avoid–shift–improve[12] provides a framework to deliver the necessary transformations across all sectors, including industry, transport, residential and services sectors.
B2.2	Planning compact development within urban areas will be important to reduce greenhouse gas emissions associated with land use change and urban sprawl. This would also help in reducing emissions in transport in particular, but also in reducing infrastructural costs and losses in biodiversity and vegetated land.
B2.3	Reducing emissions in homes is essential. Where homes also use solid fuels as their main fuel source, and these can be replaced with low-carbon alternatives, this can have the added benefit of improving local air quality.
B2.4	Retrofitting the homes of those experiencing energy poverty should be a priority, as it is crucial for a just transition. The share of households experiencing energy poverty has grown from 16% in 2013 to an estimated 40% at the end of 2022: almost double its previously recorded high of 23% in 1994/95.

B.3. Ireland needs to transition to a renewables future but will also need carbon dioxide removals

Wind energy and solar photovoltaics can provide the backbone of Ireland's future electricity system, but additional options are also required to ensure security of supply. Ireland's renewables success to date has been with renewable electricity (primarily wind energy, which increased from 36.4% of Ireland's electricity in 2021 to 36.8% in 2022). Renewable heating and transport are lagging far behind. Bioenergy, other renewables and hydrogen will be needed in sectors not currently suited to electrification. The literature to date also concludes that some levels of carbon capture, storage and removal across the economy will likely be needed.

B3.1	Offshore/onshore wind and solar photovoltaics can provide the backbone of Ireland's future electricity system. However, it will not be enough. To ensure grid stability and security of supply, the system will also require other options, such as increased interconnection, demand flexibility, storage and zero emission back-up generation. {Chapter 4}
B3.2	Alternatives such as bioenergy, other renewables and hydrogen will be needed in sectors not currently suited to electrification, such as heavy transport and industry, and to balance a grid based on variable renewable electricity technologies. These require further investigation. {Chapter 4}
B3.3	Renewable energy can increasingly provide our future energy needs but will need to be complemented with carbon dioxide removals to achieve a net zero energy system in hard-to-abate sectors. The literature to date concludes that some levels of carbon capture, storage and removal across the economy will likely be needed. {Chapter 4}

[12] Avoid–shift–improve is a demand-side focused approach designed to improve the efficiency of the transport system. This approach would enable significant reductions in greenhouse gas emissions and reduced energy consumption and congestion and would create a more liveable urban infrastructure.

B.4. Significant mitigation is needed in agriculture, Ireland's largest sectoral source of greenhouse gas emissions

Ireland has higher than average emissions of methane and nitrous oxide within the EU because of its large livestock sector. Innovations in the development of feed additives to inhibit enteric methane protection are under way and the use of protected urea to reduce nitrous oxide emissions is still in the early stages of implementation. There is currently a key evidence gap in how to achieve climate neutrality in agriculture. Low-emission fertilisers, optimal use of slurry and planting legumes to improve nitrogen use efficiency are recommended. Optimal use of no-regret livestock management measures, such as increasing the dairy Economic Breeding Index, improving herd genetics, improving animal health and promoting efficient feeding strategies, will help in reducing greenhouse gas emissions. Diversification within the sector will be necessary to achieve deep emission reductions. It is very important because this can reduce livestock numbers and enable different land use strategies, such as bioenergy and agroforestry.

B4.1	Beef and dairy farming contribute most significantly to agriculture emissions (in particular methane and nitrous oxide). Innovations such as feed additives to reduce biogenic methane and use of protected urea to reduce nitrous oxide are still in early stages of implementation in Ireland. {Chapter 6}
B4.2	There is a lack of evidence in Ireland on achieving climate neutrality. The literature suggests that a precautionary approach would require adoption of mitigation measures. To reduce nitrous oxide emissions, no-regret mitigation measures include changing to low-emission fertiliser types and optimal use of slurry and legumes to increase nitrogen use efficiency. No-regret mitigation measures for methane include increasing the dairy Economic Breeding Index, beef genomics, improved animal health, extending the grazing season and use of sexed semen within beef and dairy sectors. {Chapter 6}
B4.3	Encouraging and incentivising diversification strategies within the sector are important because reductions in livestock numbers and adopting different land use strategies and bioenergy will likely be necessary to achieve and maintain deep emission cuts. {Chapter 7}

B.5. Land use, land use change and forestry in Ireland is a net source of emissions rather than a net sink

Different combinations of afforestation, rewetting of organic soils and enhancing carbon sequestration in mineral soils are the primary means to achieve net zero emissions within LULUCF. Additional analysis of drainage and the nutrient status of peat soils would help in substantiating the total potential reduced emissions and increased removals that can be achieved via improved land management.

B5.1	Research on LULUCF suggests that the primary means to get to net zero for this sector is through unprecedented rates of afforestation, rewetting in organic soils (including water table management and reduced management intensity), enhanced carbon sequestration in mineral soils and peatland rehabilitation. {Chapter 6}
B5.2	More analysis and interpretation are required within LULUCF, especially in improving the greenhouse gas emissions inventory in Ireland, Europe and globally. This includes increasing use of observational data from soil flux towers and atmospheric sites. Additional analysis of drainage and the nutrient status of peat soils (including agricultural and forested land) would help in understanding the total potential reduced emissions and increased removals that could be achieved through land management. {Chapter 6}

B.6. Common features of climate-neutral pathways

This report interprets 'achieving climate neutrality by 2050' to mean achieving net zero greenhouse gas emissions by 2050. There are no published climate neutrality studies or pathways for Ireland that cover all sources of greenhouse gas emissions in sufficient detail[13]. There are nine existing studies of net zero pathways for Ireland: six covering the energy system and three on agriculture, forestry and land use. Global mitigation pathways show carbon dioxide emissions reaching net zero 10–15 years before other greenhouse gas emissions, and this implies that Ireland should reach net zero carbon dioxide emissions between 2035 and 2040. After reaching net zero carbon dioxide, the energy system would require further negative emissions balance from residual emissions such as methane, nitrous oxide and industrial gases. {Chapter 7}

B6.1	Global mitigation pathways show carbon dioxide emissions going to net zero 10–15 years before other greenhouse gas emissions. Applying that to Ireland, the goal of climate neutrality by 2050 implies reaching net zero carbon dioxide emissions at latest between 2035 and 2040.
B6.2	After reaching net zero carbon dioxide, the energy system will likely need to provide further negative emissions to balance residual greenhouse gas emissions (including industrial process, methane and nitrous oxide emissions).
B6.3	It is not possible for this assessment to provide a clear pathway for climate neutrality or quantify the extent of negative emissions required, as the evidence is currently lacking.
B6.4	Addressing the knowledge gaps including an integrated assessment of agriculture, energy and land use is needed. {Chapter 9}

[13] There is also one study that shows scenarios for the three main greenhouse gases (carbon dioxide, methane and nitrous oxide) but it lacks the necessary sectoral details.

C. Key insights for policy {Chapter 9}

C.1 Climate-neutral pathways for Ireland

There is a significant gap in the literature available for climate-neutral pathways in Ireland. Although there have been studies to incorporate agriculture within the energy models, the mitigation options explored do not achieve net zero. The knowledge gaps, especially in the LULUCF sector, make this more challenging.

C.2 Need for deep emission reductions within the agriculture and land use sectors

Deep emission reductions within the agriculture and land use sectors is a critical aspect of Ireland's efforts to mitigate climate change and transition to a low-carbon economy. The research on LULUCF suggests that the primary means to get to net zero for this sector is through unprecedent rates of afforestation and rewetting of organic soil along with a significant reduction in herd numbers. The majority of the precautionary mitigation options available in Ireland are still in the early implementation stages, and there is an urgent need for Ireland to explore various diversification strategies to enable deep mitigation.

C.3 The energy system post 2030

Policies tailored to suit different stages of technology development are very critical for achieving a net zero energy system. Established technologies such as wind energy, solar photovoltaics and bioenergy will be key in short-term emission reduction targets (i.e. 2030), whereas offshore wind infrastructure is expected to be the backbone of future energy systems. This can only be achieved with appropriate support schemes, regulation and investments for synergistic growth of offshore wind and other renewable technologies. Future energy choices post 2030 need greater exploration to plan for the required transition.

C.4 Ex-post evaluating of policies and measures

A retrospective evaluation of why Ireland has not yet achieved significant emission reductions could provide lessons to guide in designing future mitigation strategies. Also, careful evaluation of existing government-aided support schemes for fair distribution among individuals and businesses is also required.

C.5 Model development priorities

Further analysis is needed to deliver emissions and removals data at subnational levels, e.g. county and local levels. Mappings of energy use and associated emissions can support local authority planning. There is also a need for the industry and services sectors to undertake more detailed analysis and for transport and residential emissions to receive a broader policy analysis, i.e. beyond private car transport and residential retrofitting.

C.6 Enhancing public participation

Public engagement and participation in development and implementation of transition management is essential. Further research is necessary to improve the translation of Citizens' Assembly recommendations and outcomes from subsequent engagement processes into policy, to enhance local deliberative processes, and to inform a just transition that protects and includes vulnerable groups in the shift to a climate-neutral society.

C.7 Enabling climate and energy financing

Further analysis on the impact of financial incentives and drivers, including carbon pricing on behaviour, investment patterns in low-carbon technologies and the use of revenue to drive an efficient, just transition, is necessary. The use of financing, fiscal instruments and governance of climate mitigation is also a critical area that warrants more attention.

C.8	**Alternative economic paradigm** Understanding the potential impacts of alternative economic models, such as degrowth, in the Irish context is crucial for developing sustainable policies and strategies. Understanding the implications and potential impacts of these models, as well as the necessary transformations, can inform policy development and contribute to a more sustainable and resilient future.
C.9	**Bringing mitigation and adaptation actions together** There is a need for a systems approach that integrates both mitigation and adaptation in Ireland's policy responses to climate change. Further research is necessary to explore the co-benefits and future risks, and the resilience of transition pathways, as well as those associated with specific measures. Integrated alignment of planning and implementation of climate actions should support rapid progress in addressing climate change challenges.
C.10	**Deep institutional innovation** There is a need to move beyond a narrow focus on carbon dioxide abatement and consider broader societal and environmental impacts when assessing policies. By considering a wider range of metrics and reimagining institutions, policymakers can make more informed decisions that address the complexities of sustainability, ethics and effectiveness in a holistic manner.

D. Key recommendations for research

D.1	**Improving subnational analysis of greenhouse gas emissions and removals** Research is needed to improve subnational estimates of energy use and associated emissions, as well as emissions and removals from agriculture and land uses, and other emissions, potentially through the development of a distributed analysis system, dashboard or repository for sharing information. This should be linked with and support the official analysis provided by the national inventory system.
D.2	**Energy efficiency and demand-side management** Further research is required to understand the barriers to and drivers of energy efficiency and demand-side management in Ireland. This would help in understanding the enablers required for policymakers and stakeholders to develop targeted strategies to promote sustainable energy practices.
D.3	**Foresight into future technologies** More analysis is required to inform future energy choices beyond 2030 relating to the scale and magnitude of technologies that will help get us to net zero emissions.
D.4	**Quantifying carbon dioxide removals to bridge evidence gap** There is a need to quantify the extent of carbon dioxide removals required to provide a clear pathway for climate neutrality, which should take into account the climate impacts of emissions as well as the risks associated with the adoption of removal solutions, particularly nature-based solutions.
D.5	**Balancing agricultural emissions via management of terrestrial sinks** Despite the recognition of the importance of agricultural emissions and land use removals, there is a critical research gap in determining the specific levels of emissions that can feasibly be balanced with land use practice.
D.6	**Expanding use of observational data** Continued enhancement and development of the national inventory within the LULUCF sector is very important. This can be enabled by increasing use of observational data from soil flux towers and atmospheric sites, as well as the use of remote sensing and enhancing the activity data derived from such observations.
D.7	**Integrated assessments** Addressing the knowledge gaps is essential, including an integrated assessment of whole-of-economy transitions and transformation options. These would apply to agriculture, energy and land use.
D.8	**Mobilising climate action** Research is needed to identify effective strategies and interventions to effectively engage with citizens and communities, build societal capacity, and mobilise society-wide climate action.
D.9	**Integrating mitigation and adaptation** There is a critical need for research to uncover the synergistic co-benefits that can be derived from implementing integrated mitigation and adaptation measures.
D.10	**New economic paradigms: implications of transition to a low-carbon future** Addressing the research gap in Ireland regarding the economic implications of energy and livestock reductions is essential; this will provide policymakers and stakeholders with the insights necessary for evidence-based decision making and the development of targeted policies.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