CORA Cork Open Research Archive
Cartlann Taighde Oscailte Chorcaí

Title	The role of carbon budgets in translating the Paris Agreement into national climate policy
Authors	McGuire, Jason;Rogan, Fionn;Daly, Hannah;Glynn, James;Balyk, Olexandr;Ó Gallachóir, Brian P.
Publication date	2020-10-01
Original Citation	McGuire, J., Rogan, F., Daly, H., Glynn, J., Balyk, O. and Ó Gallachóir, B. (2020) The role of carbon budgets in translating the Paris Agreement into national climate policy, Discussion paper, MaREI Centre, University College Cork.
Type of publication	Report
Link to publisher's version	https://www.marei.ie/wp-content/uploads/2020/10/Discussion-Paper_The-role-of-carbon-budgets-in-translating-the-Paris-Agreement-into-national-climate-policy.pdf, https://www.marei.ie/project/capacity/
Download date	2026-11-17 03:38:40
Item downloaded from	https://hdl.handle.net/10468/11172

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

A World Leading SFI Research Centre

Science Foundation Ireland sfi For what's next

MaREI

Energy · Climate · Marine

The role of carbon budgets in translating the Paris Agreement into national climate policy

Discussion Paper

Jason Mc Guire, Fionn Rogan, Hannah Daly, James Glynn, Olexandr Balyk and Brian Ó Gallachóir

HOST INSTITUTION

UCC
University College Cork, Ireland
Coláiste na hOllscoile Corcaigh

PARTNER INSTITUTIONS

CIT Cork Institute of Technology · DCU · DIAS · Dundalk Institute of Technology · ESRI Economic & Social Research Institute · Maynooth University · NUI Galway OÉ Gaillimh · Trinity College Dublin · DUBLIN · Tyndall National Institute · University College Dublin An Coláiste Ollscoile, Baile Átha Cliath · University of Limerick Ollscoil Luimnigh

Key Messages

- A Global Carbon Budget is the total estimated cumulative CO2 that the world can emit while staying within a certain global temperature target, e.g. 1.5C, 2C
- To align national climate ambition with both Article 2 (1.5C & 2C temperature target) and Article 4 (carbon neutrality by 2050) of the Paris Agreement, countries can develop a national carbon budget consistent with a Global Carbon Budget, based on an "effort sharing methodology"
- On its own, a net-zero emission target (e.g. in 2050) may not align with a Global Carbon Budget
- For governance purposes, national carbon budgets can be sub-divided into time periods (e.g. 5 years) and allocated to sectors (e.g. transport, buildings, public sector, etc.). This allocation process needs to be analytically robust, transparent, and involve wide stakeholder consultation
- In this document, we propose an approach to building a national carbon budget for Ireland based on this framework, compare with international experience and discuss open issues.

Executive Summary

Two articles of the Paris Agreement are particularly relevant to countries as they seek to mitigate their impact on global warming. Article 2 sets a target for long-term temperature stabilisation, seeking to hold the increase in global average temperature to "well below 2 °C above pre-industrial levels, while pursuing efforts to limit the temperature increase to 1.5 °C". Article 4 includes a target to "peak greenhouse gases (GHGs) as soon as possible" and thereafter to achieve "rapid reductions" in emissions so that sources of emissions are balanced by sinks (i.e. achieving net zero emissions) in the second half of the 21st century. Despite the ratification of the Paris Agreement, there is no political or scientific consensus on precisely how these targets should be translated into national decarbonisation trajectories. As a result, countries are developing and setting their own carbon reduction strategies in different ways: increasingly, countries are implementing net-zero targets for mid-century. Although consistent with Article 4, given the linear relationship between warming and cumulative net emissions of long-lived GHGs, net-zero target dates only specify when temperatures are stabilised, but not at what temperature. To comply with Paris Agreement temperature goals, international and national climate action policy must have regard to cumulative reductions in GHG emissions, not just single year targets. Broadly, this requires a carbon budget approach.

In this discussion paper we review some of the ways that a carbon budget approach has been used in climate action policy. One approach is based on developing a so-called Climate Science Carbon Budget derived from a Global Carbon Budget (GCB) associated with a particular temperature goal and an equitable effort-sharing approach to share the GCB. This is contrasted with other approaches including national frameworks for climate policy such as the UK's net zero emissions by 2050 where the carbon budgets are for a shorter time period (i.e. 5 years). We call this latter approach Climate Policy Carbon Budgets, that is carbon budgets that aren't derived from a global temperature target, but instead from national decarbonisation trajectories. This discussion paper also explores approaches to developing decarbonisation pathways for Ireland which are consistent with the Paris Agreement using a carbon budget approach. This discussion paper outlines a broad approach to generating a national long-term climate science carbon budget for Ireland and translating it into five-year sectoral carbon budgets. The process for developing such carbon budgets will require an appropriate set of robust energy system modelling tools, that are iteratively developed and examined, together with an extensive stakeholder engagement process. This discussion paper concludes with some reflections on the governance arrangements for setting, monitoring, and reviewing carbon budgets.

1 Introduction

The near linear relationship between cumulative CO2 emissions and global temperature warming, means that the remaining cumulative amount of CO2 which can be emitted to stay within a global temperature limit can be quantified. This is the Global Carbon Budget (GCB) (see Table 1) and this forms the scientific basis of Article 2 of the Paris Agreement, that is keeping global average temperatures "well below 2 °C above pre-industrial levels, while pursuing efforts to limit the temperature increase to 1.5 °C".

Article 4 adds to Article 2 of the Paris Agreement, while both aim to limit global warming, Article 4 is focused upon the net-zero target, by stating that global peaking of GHGs should be as soon as possible, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of this century. Article 4 also states that this target should be achieved on the basis of equity and that developed countries should take the lead in climate mitigation.

The Paris Agreement does not prescribe a single GCB, nor does it indicate how countries should determine their national carbon budgets. Adherence with both Articles 2 and 4 of the Paris Agreement will require a transparent and equitable method for developing a national carbon budget as an allocation from the GCB, notwithstanding the challenges that "the more a national target is derived from the global situation, the less it will take account of national circumstances, and vice versa" [1].

Box 1: What is the Global Carbon Budget and how is it related to global warming?

The Global Carbon Budget (GCB) is defined as the *future* (or remaining) *cumulative CO_2 emissions consistent with a given warming limit* [2]. Climate modelling studies have established a robust near-linear relationship between global warming and cumulative carbon dioxide (CO_2) emissions since industrialization [2]. The Transient Climate Response to cumulative carbon Emissions (TCRE) metric was developed to represent this connection. Essentially, the TCRE estimates for every 42 $GtCO_2$ (approx. the global annual CO_2 emissions) emitted, the global temperature will increase by between 0.009°C to 0.011°C [3].

Since the Paris Agreement, a lot of analysis has been undertaken to understand what the remaining GCB is, consistent with a given warming limit. The TCRE was used in the IPCC 1.5°C Special Report in 2018 to develop Table 1. To have a 67% chance of limiting temperatures to 1.5°C, the remaining global carbon budget from 2018 onwards is between -500 and 1,340 $GtCO_2$, with 420 $GtCO_2$ the most probable GCB. The uncertainty is largely due to climate cycle feedbacks, and non-CO_2 GHG emissions. The quantity of the GCB is also dependent on the amount of overshoot (if any) towards a temperature warming limit. Table 1 assumes no overshoot, as the TCRE is only applied up to peak warming temperature.

Temperature limit target	Probability of remaining below limit	Remaining Carbon Budget ($GtCO_2$)
1.5°C	67%	**420 (-500 to 1,340)**
1.5°C	50%	**580 (-340 to 1,500)**
2°C	67%	**1,170 (250 to 2,090)**
2°C	50%	**1,500 (580 to 2,420)**

Table 1: Global Carbon Budgets and Uncertainties [3] Remaining Global Carbon Budgets from 2018 with associated probability of remaining within the given temperature limit. Given values are centre estimate, bracket values represent minimum and maximum (i.e. uncertainty range). Negative values indicate CO_2 emission limits reached

The conceptual simplicity of TCRE and of carbon budgets led to the prominent presentation of these concepts in the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) [4], [5].

Looking ahead, the Sixth Assessment Report (AR6) of the IPCC will again review the GCB and perform a "global stocktake" in 2023, to inform and support nations as they update and enhance their mitigation actions, and to enhance international cooperation for climate action [6]. The latest climate models suggest higher climate sensitivity than previously thought, meaning additional warming is expected over the twenty-first century [7].

This paper grapples with the challenge of formulating a national decarbonisation strategy for Ireland, which is consistent with the two relevant Paris Agreement articles. Section 2 of this paper expands on the science of carbon budgets and discusses the allocation of the GCB to different countries (so-called effort-sharing approaches). Section 3 contrasts this approach with one where short-term carbon budgets are determined by long-term decarbonisation targets, specifically net-zero targets. Section 4 analyses a number of country case studies for their approach to setting mitigation targets and carbon budgets. Section 5 then discusses an approach to setting a long-term carbon budget for Ireland, and a methodology for translating this into five-year carbon budgets and allocating carbon budgets to different sectors. Finally, Section 6 discusses open questions and factors relating to the science-policy interface.

2 Climate Science Carbon Budgets

A large part of international climate negotiations have revolved around how to equitably share the GCB, or the '*carbon-quota pie',* across countries. We introduce the term *Climate Science Carbon Budgets* as a term to describe this process, starting with a global temperature target and GCB implied from climate science, and using an effort-sharing methodology to allocate a long-term carbon budget to an individual country (See Figure 4). National long-term carbon budgets derived in this way are quantified for CO_2 only, based on the simple linear relationship between cumulative emissions of CO_2 and global temperature (see Box 1). Since all GHGs contribute to global warming [8] two broad methods have been developed to account for non-CO_2 GHG emissions in climate mitigation policy. The established method involves converting other GHGs into a CO_2 equivalent metric (GWP_{100}); however, a more recent metric that treats non-CO_2 GHGs as a separate category (GWP*) has been developed (See Box 2).

Climate change is a classical "commons problem", where the negative effects of emissions are shared across the world. This underlies the historic difficulty in agreeing national climate targets. There are large variations in per-capita CO_2 emissions, both annually and historically, across different nations, with high levels of emissions typically associated with high economic development. However, the negative effects of climate change will be felt at different levels of severity by all nations and the effects are expected to sustain for future generations. This inequality has not been resolved.

Rationing or allocating the remaining GCB between countries can be a sensitive topic – should we focus on the remaining carbon budget only or also take into account historical emissions and fully apply the polluter pays principle? In addition, should we allocate on the basis of a country's wealth or also take into account other factors that determine each country's effort-sharing ability (i.e. should we include differences based on fuel resources, vulnerability to climate change, human rights issues, energy demands and social acceptance)?

Box 2: The Global Warming Potential (GWP) metric

Each GHG has a unique lifetime in the atmosphere and a different warming potential. In an effort to make the global warming potential of different GHGs easily comparable, the Global Warming Potential (GWP) metric is used. The GWP of CO_2 is 1, which is the benchmark that other more or less potent GHGs are measured. The GWP of different gases is commonly compared over 20 years and 100 years.

Emissions reporting under the United Nations Framework Convention on Climate Change (UNFCCC) now requires the use of 100-year Global Warming Potential (GWP_{100}) to account for all gases as carbon dioxide equivalent (CO2eq) quantities. GWP defines the cumulative impacts that the emission of 1 kg CH_4 or N_2O could have on the planetary energy budget relative to 1 kg reference CO_2 gas over a certain period of years [9].

A new usage of GWP, denoted GWP*, allows emissions of short-lived and long-lived climate pollutants (SLCP & LLCPs) to be more consistently expressed within a single metric by equating a change in the emission rate of an SLCP as equivalent to a single emissions pulse of a long-lived pollutant.

When discussing cumulative emissions of CO_2 and non-CO_2 emissions, there is no cumulative GWP metric. The concept of an "emissions budget" cannot be extended to CO2eq emissions as conventionally calculated [10].

The concept of CO2eq emissions is deeply embedded in climate policy. Relating emissions using GWP* allows all emissions to be considered in a common cumulative framework [10], within a given time horizon only.

There are several approaches proposed to determine how to downscale the global carbon budget to determine national carbon emission budgets. Some of the main effort-sharing approaches include the following:

- **Grandfathering or inertia** - prior annual emissions increase future emission entitlements so that a transition is feasible for all countries.
- **Equality** – the remaining global carbon budget is shared equally among the global population.
- **Brazilian Rule Historical** – historical emissions are used in deriving the equitable share of the all-time GCB; some countries are in 'carbon debt' (e.g. Ireland is in debt to a 1.5°C per capita GCB).
- **Contraction & Convergence** - where national per-capita emissions converge to a global average and emissions then contract at the same rate to net zero following global average pathways.
- **Ability to pay** – based on the ability to afford to reduce emissions.
- **Development rights** - considers both responsibility and capability; aims to reach a dignified level of sustainable human development for all.
- **Cost-optimal** – considers the least-cost decarbonisation options for the global energy system [11].

To contribute to international climate negotiations, different effort-sharing approaches (or rules) have been used by researchers to enable an equitable approach to allocate the GCB across countries. Different effort-sharing methodologies influence the resulting carbon budget. Some approaches lead to what might be called politically unlikely outcomes, for example the Brazilian rule where developed countries with high historical emissions are allocated a negative carbon budget, a consequence of the equity principle underlying the effort-sharing approach.

Approaches requiring extreme sudden changes may not be politically or practically feasible and countries will likely choose an effort-sharing methodology which suits their own ambitions. This highlights the need and challenge of a globally harmonised approach. Extensive discussions in forums such as the UNFCCC are likely to be needed to share the decarbonisation effort transparently and equitably. It is likely that broad framework of the Sustainable Development Goals (SDGs) will play a role in these discussions.

3 Climate Policy Carbon Budgets

In contrast to the approach described in the previous section where a global carbon budget is used to calculate a carbon budget for an individual country along with an effort-sharing methodology, *Climate Policy Carbon Budgets* are developed by countries where the long term carbon budget is derived from national decarbonisation trajectories. For example, under the Climate Change Act 2008, the United Kingdom legislated for an 80% reduction in GHG emissions by 2050 relative to 1990 levels, which was subsequently used to establish five-year carbon budgets to provide short term goals aligned with a long term target. More recently, the UK has increased their long-term ambition and legislated for a net-zero target for 2050, which has decreased the UK's five-year carbon budget quantities. However, the UK's long-term cumulative carbon budget to 2050 is not defined and no effort-sharing methodology is applied a national total carbon budget, so its share of the '*carbon-quota pie'* is not explicitly derived. Section 4.4 reviews in more detail the UK process of developing and governing carbon budgets.

The EU has also taken a *Climate Policy Carbon Budget* approach. As part of the climate and energy policy framework for 2020, member states agreed on a 20% reduction target in GHG emissions outside the emissions trading scheme (ETS) relative to 2005 levels. These non-ETS GHG emissions broadly cover emissions from transport, buildings, agriculture, and low energy intensive industry. Member states agreed on binding annual emission allocations (AEAs) in an effort-sharing agreement (Decision 406/2009/EC) for the period 2013-2020. The total amount of AEAs effectively provided each member state with a non-ETS GHG budget for this period, which aggregated non-ETS CO_2 emissions and non-CO_2 GHG emissions using the GWP_{100} metric. The EU adopted the same approach for the 2030 target for non-ETS GHG emissions (Regulation 2018/842), by setting AEAs for each year in the period 2021-2030 for all member states. The effort-sharing of each member state is based upon GDP/capita, which is then adjusted to reflect cost-effectiveness. The EU has recently agreed an increased 2030 ambition of a 55% reduction in GHG emissions in the context of legislating for a 2050 net-zero GHG target.

In both these examples from the UK and EU, C*limate Policy Carbon Budgets* have been effectively used to flexibly deliver different decarbonisation rates within a multi-annual time window. They can also be reviewed on an ongoing basis to consider greater ambition and/or mitigation potential from technological progress. However, in the context of the Paris Agreement, if national long-term ambition is aligned only with Article 4 (net-zero target), alignment with Article 2 (long-term temperature stabilisation) is not guaranteed. For a detailed explanation of why see the following Section 3.1. To date, most national long-term decarbonisation targets have not been derived from a given temperature target or global carbon budget, nor do they explicitly consider effort-sharing approaches to equitably sharing the GCB. Because *Climate Policy Carbon Budgets* are not formed in a way which states a share of the '*carbon-quota pie'*, they tend to be non-compliant with Article 2 of the Paris Agreement [12].

An example of the implications of using a *Climate Policy Carbon Budget* approach can be seen in analysis of the first round of Nationally Determined Contributions (NDCs), which were a key part of the Paris Agreement. If all first round NDCs were fully implemented, there is a 67% probability that the global average temperature would increase by 2.9°C–3.4°C by 2100 [13]. The NDC registry shows that none of 196 member states explicitly defined a cumulative national carbon budget in their NDC target, although both Armenia and Costa Rica have defined emission budgets up to 2050. Furthermore, many NDC target typologies are used [14], some of which are non-quantitative and unmeasurable.

An important difference between *Climate Policy Carbon Budgets* and *Climate Science Carbon Budgets* is that the former are often defined in terms of carbon dioxide equivalent (CO_2eq), which makes an equivalence between CO_2 and non-CO_2 GHG emissions (see Box 2), something *Climate Science Carbon Budgets* don't do.

3.1 Relationship between net-zero GHG targets and carbon budgets

Article 4 of the Paris Agreement includes an objective to achieve a balance between anthropogenic GHG emissions by sources and removals by sinks in the second half of this century. This is increasingly referred to as a net-zero GHG target. Over 100 countries are currently considering a 2050 net-zero GHG targets as a long-term mitigation target [15]. The EU is proposing a net-zero GHG target by 2050 under the EU Green Deal, which is yet to be enshrined in law [16]. Currently only UK, France, Sweden, New Zealand, Hungary and Denmark have set legally-binding net-zero targets [16].

A key insight from climate modelling is that limiting the global mean temperature rise to 1.5°C above pre-industrial levels requires that global GHG emissions must reach net-zero by between 2045 and 2060 [17], while also requiring high levels of short-term ambition and an "overshoot". In a climate modelling context, an overshoot is defined as *"the dependence of the magnitude and duration of possible temporary exceedance of temperature targets"* [18].

However, achieving net-zero is a necessary but not sufficient requirement for meeting Paris Agreement ambitions, specifically the temperature stabilisation target (Article 2). This is because different possible emissions trajectories between now and the net-zero date, and the level of negative emissions, thereafter, lead to very different cumulative CO_2 emissions and therefore climate forcing. Figure 1 illustrates this point, showing three different decarbonisation trajectories which achieve net-zero by 2050. However, the temperature rise associated with the "late action" trajectory is double that of the "early action" trajectory. Hence, for Article 2 and the temperature stabilisation target, the *path* to net zero is at least as important as the *date* we get there.

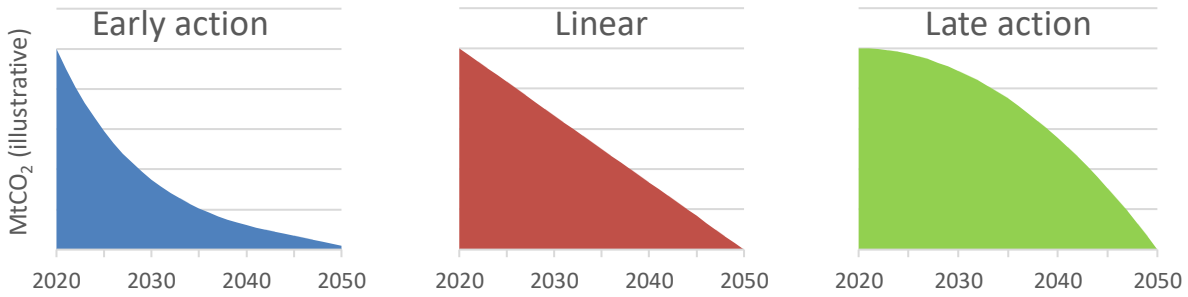


Figure 1: Illustrative decarbonisation trajectories to 2050: each pathway above reaches the same 2050 goal of net-zero CO2 emissions, but in the Late Action pathway, cumulative emissions are double that of the Early Action pathway, leading to double the warming impact.

4 How do different countries use carbon budgets?

This section reviews a number of countries which use or are planning to use carbon budgets.

4.1 France

France's long term decarbonisation plan establishes a linear trajectory toward a net zero GHG target in 2050 [19]. The governance of achieving this target makes use of short term (4-5 year) carbon budgets, which are economy wide and sectorally disaggregated. The French government legislated for carbon budgets via the Energy Transition for Green Growth Act in 2015. The Act contains a net zero emissions target by 2050 across all GHGs. The short-term sectoral carbon budgets are legally binding for the public sector only [20].

Inspired by the UK's independent Committee on Climate Change (CCC), France set up its equivalent *Haut Conseil pour le Climat* in May 2019, with a purpose to provide an independent perspective on the government's climate policy, issue advice on five-year carbon budgets, and assist in the implementation of France's national low-carbon strategy (SNBC) which sets out an economic decarbonisation roadmap.

The first SNBC, published in 2015, defined the first three sectoral and national carbon budgets for France for the periods 2015-2018, 2019-2023 and 2024-2028. The first carbon budget was only for a 4-year period, but following that, all carbon budgets are over five-years. The 2015-2018 carbon budget was exceeded by 62 $MtCO_2eq$ or 14% [21]. In a review of the first carbon budget, chair of the *Haut Conseil pour le Climat,* Prof. Corinne Le Quéré remarked that "the initial efforts are worthy, but they are clearly insufficient and have not produced the expected results" [21]. In setting carbon budgets, France has adopted a *Climate Policy Carbon Budgets* approach*,* it has not used a global carbon budget or effort-sharing approach.

4.2 New Zealand

In November 2019, the New Zealand government introduced the Climate Change Response (Zero Carbon) Amendment Act [22] to legislate for carbon budgets and introducing a legally binding 2050 net-zero GHG target.

The Climate Change Commission of New Zealand was established in December 2019 to provide independent, evidence-based policy advice to help New Zealand transition to a zero emissions economy. At the time of writing, New Zealand has not yet agreed national carbon budget quantities. The first carbon budget period will be 2022-2025 and every five years thereafter.

New Zealand have declared their net-zero GHG target will exclude biogenic methane; however, they have a separate target to reduce biogenic methane emissions by 24–47% below 2017 levels by 2050 [23]. New Zealand has a large agricultural sector which emits more methane as a share of total GHG (38%) than the OECD average (9%).

Despite aiming to achieve Article 4 of the Paris Agreement (Net-Zero by 2050), because New Zealand's cumulative carbon budget, GCB, or effort sharing methodology is not defined, the country can be said to be using a *Climate Policy Carbon Budget.*

4.3 Denmark

Danish climate law does not establish a national carbon budget. Instead, it sets legally-binding targets to reduce GHG emissions by 70% in 2030 compared to 1990 levels and to becoming a climate neutral society by no later than 2050 [24]. The targets are part of the 2020 Climate Act which also strengthens Denmark's existing independent Danish Council on Climate Change, sets annual climate reporting obligations by government to the parliament, commits Denmark to international climate engagement, and requires periodic national climate target setting accompanied by a climate action plan.

As part of their input to the Climate Act, The Danish Council on Climate Change recommended that the climate targets set by the Climate Act should translate to a long-term national carbon emission budget of 325-425 Mt CO_2[25]; the range is due to range in the GCB, which is 420-570 $GtCO_2$. While both GCBs aim to limit global warming to 1.5°C with a 67% probability, the range in GCB is due to uncertainty in additional warming which has already occurred. This national carbon budget is calculated based on the effort-sharing equality principle, with a population of around 0.075% of the world's population, Denmark can emit 0.075% of the GCB. Denmark's long-term carbon budget of 325-425 Mt CO_2[25] is then converted by the Danish council on climate change to include all GHGs, this value is 325-525 Mt CO_2eq[25]. The assessment uses a hybrid of *Climate Science Carbon Budgets*, as the national carbon budget is based upon a GCB and an effort-sharing methodology and *Climate Policy Carbon Budgets,* as all GHGs are considered (see Box 2).

According to the Climate Act, the government must set a national climate target every five years with a ten-year perspective [24]. The first climate plan should be prepared in 2020. This climate plan should focus on the 2030 target and also set an indicative target for 2025. Following this, a new climate plan should be prepared every five years. This means that the next climate plan should be prepared in 2025 with the aim of reaching the 2030 and 2035 targets. The overview of this process is outlined below [25]. The Danish Council on Climate Change recommends a framework with single year targets set every five years.

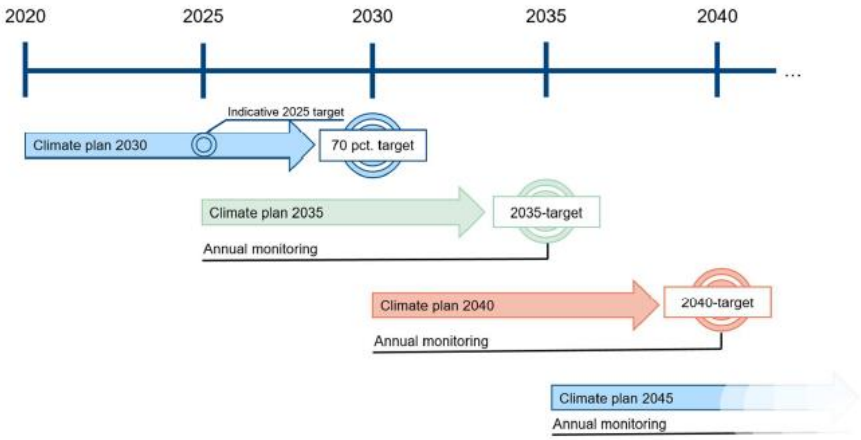


Figure 2 Denmark's Climate Council framework of the climate policy [25] This schematic outlines the 10-year Climate Plans

Ireland's recently approved Programme for Government stated about setting carbon budgets "In setting the second carbon budget for 2026-2030, we will not yet be in a position to identify all the emerging technologies, changing scientific consensus or policies to meet our full ambition. This will require a further allocation within the overall carbon budget, subject to intense evaluation. This approach, which mirrors the Danish model, will be reflected in the Climate Action (Amendment) Bill and in future iterations of the Climate Action Plan."

In Denmark however, the approach is not based on carbon budgets. In their input to the Climate Act, the Danish Council on Climate Change recommends a framework with single year targets set every five years (I.e. setting a 2035 target in 2025, a 2040 target in 2030, etc.). Although, using carbon budgets is an option, the Danish Council on Climate Change considers that the increased complexity of these budgets and the mixed experience from other countries outweigh the benefits.

4.4 United Kingdom

The UK was the first country to introduce legally binding carbon budgets in 2008. The UK government are advised by the Committee on Climate Change (CCC), who recommend sectoral and total quantities for five-year carbon budgets, 12 years in advance. The carbon budgets account for both CO_2 and non-CO_2 GHG emissions. In calculating the UK's targets, the CCC stated they do not start from an assumption that the world will meet the Paris Agreement's temperature goal. Instead, they have identified a UK target that they say is within reach and best supports an increase in global effort, consistent with bringing the expected temperature rise down from the current trajectory [26]. Using the term we introduced in Section 3, the UK has a *Climate Policy Carbon Budge*t.

The UK's carbon budget trajectory follows a simple near linear pathway towards a net-zero GHG emissions target by 2050. However, as already stated this linear myopic approach is not informed by an optimal long-term scenario based on a GCB effort-sharing approach. Such an approach was investigated by Pye et.al, who showed that for more ambitious targets, a convex curve rather than a linear trajectory was more optimal [27].

The CCC monitors progress with annual reports, conducts and commissions analysis on climate policy topics (such as infrastructure needs, economic impacts, forestry, sectoral impacts, etc) and collaborates with a wide range of organisations.

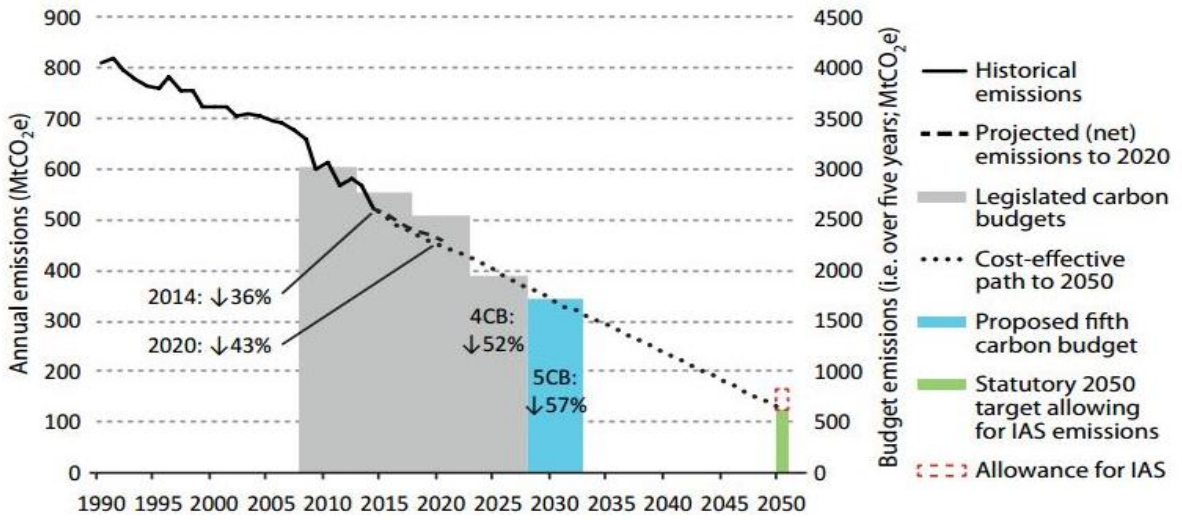


Figure 3: UK'S Five-Year Carbon Budget Trajectory [11]

Due to the longer history of UK's carbon budgets, there is a greater capacity to learn from their approach, therefore this section will cover in detail the setting and managing of UK's national carbon budgets. The UK is currently in their third carbon budget (2018-2022). The first and second carbon budgets were successful as their net actual emissions were less than the emission budget by 1% and 14% respectively [28]. International Aviation and Shipping (IAS) emissions are not currently included in the UK's carbon budgets (current carbon budgets have a 120 $MtCO_2eq$/year allowance for IAS, see Figure 3). If IAS emissions are excluded in future carbon budgets then the UK will need negative emissions in 2050 to offset IAS emissions, so the UK can achieve net-zero GHG 2050 target. Peatlands, which occupy 12% of UK land area [29] will be included into annual accounts from 2020, which will convert land use, land-use change & forestry (LULUCF) from a carbon sink to a carbon source [30].

4.4.1 Modelling & governance – setting a budget

The CCC provide detailed advice to the government regarding the future energy system and decarbonisation. This analysis includes an assessment of the investment and financing needs, technical innovation, evolution of societal or individual behaviours, timing of deliveries, co-benefits, infrastructure and leadership by key actors [30]. To provide robust advice, the CCC obtains decarbonisation modelling results from a range of tools and organisations; a key modelling tool is UK TIMES [31]. The CCC are 95% confident that modelling uncertainty in projections 20 years ahead is limited to 34% [33], this uncertainty is reduced with shorter projections. The 8% over-estimation in 2009 of UK's second carbon budget (2013-2017) was mainly due to changing economic activity which was based on an eight-year projection. The amount of GHGs emitted is measured each year by the UK's National Atmospheric Emissions Inventory (NAEI). The NAEI measure emissions data implied an uncertainty range of 154 $MtCO_2eq$ in the second carbon budget from 2013 - 2017 [33], which is a margin of error of 6%.

4.4.2 Ex-post analysis

The CCC provide feedback and ex-post analysis on decarbonisation polices. Three external factors that are isolated are economic activity, energy prices, and air temperature. This in turn helps the CCC to isolate the effectives of the combined policies and determine the policy gap. The policy gap looks at the difference between the outturn conditions (what happened) and the counterfactual conditions (forecast when carbon budget was set). The UK achieved their second carbon budget (2013- 2017) by 14% or 384 $MtCO_2eq$. This achievement was largely due to an accounting change in the UK's share of the Emissions Trading Scheme (ETS); the UK's carbon budget accounts for both ETS and non-ETS emissions. The UK's ETS allowances for the 2013-2017 period was set in 2009 at 1,078 $MtCO_2eq$. However, this was set before the EU ETS changes had been finalised and following legislation changes, this was revised downwards to 782 $MtCO_2eq$ [33]. The reduction of emissions in the ETS sector created 296 $MtCO_2eq$ of "headroom" in the non-ETS sector of the UK's second carbon budget, which combined with the economic downturn, meant the UK easily achieved their second carbon budget. This highlights that carbon budgets are impacted by many factors, not just policy implementation. In this example, factors outside the UK's control (the ETS) compensated for domestic policy underachievement, which was only brought to light by ex-post. Ex-post analysis is an essential component of effective carbon budget governance.

4.4.3 Flexibilities

The CCC analysis and target of net-zero by 2050 recommend against reliance on flexibilities. After over performing of UK's second carbon budget the CCC stated *"Carrying over any surplus risks further papering over the cracks of not implementing satisfactory measures to put the UK on course to achieve its long-term and ambitious target of net zero by 2050."* However, the UK government uses three flexibilities to help manage carbon budgets, these are:

Flexibility	Description
Carry forward over-achievement from earlier budgets	The Act allows for Government to carry forward overachievement from one carbon budget to the next.
Carry back from later carbon budgets	The Act allows for the Government to increase the carbon budget in one period with a corresponding tightening of the next carbon budget. This 'borrowing' is limited to one per cent of the later carbon budget.
Use international carbon credits (EU ETS)	The Act allows for the purchase of international carbon credits to contribute to meeting carbon budgets but with a limit on the use of these credits set 18 months in advance of the relevant carbon budget

Table 2: UK Carbon Budget Flexibilities [28]

5 A national decarbonisation strategy consistent with the Paris Agreement

In this section, an approach for developing a carbon budget in an Irish context is outlined. The two broad approaches that have been described so far - *Climate Science Carbon Budgets* and *Climate Policy Carbon* Budgets - are compared (i.e.– See Figure 4). While both approaches have merits and have contributed in different ways to climate mitigation, a key difference is that a *Climate Science Carbon Budget* is informed by global climate modelling which informs global climate targets; by contrast, a *Climate Policy Carbon Budget* is not directly linked to global climate modelling. By consistent with the Paris Agreement, we mean compliance with both Articles 2 (1.5°C and 2°C temperature limit) and Articles 4 (a balance between GHG sources and sinks by 2050).

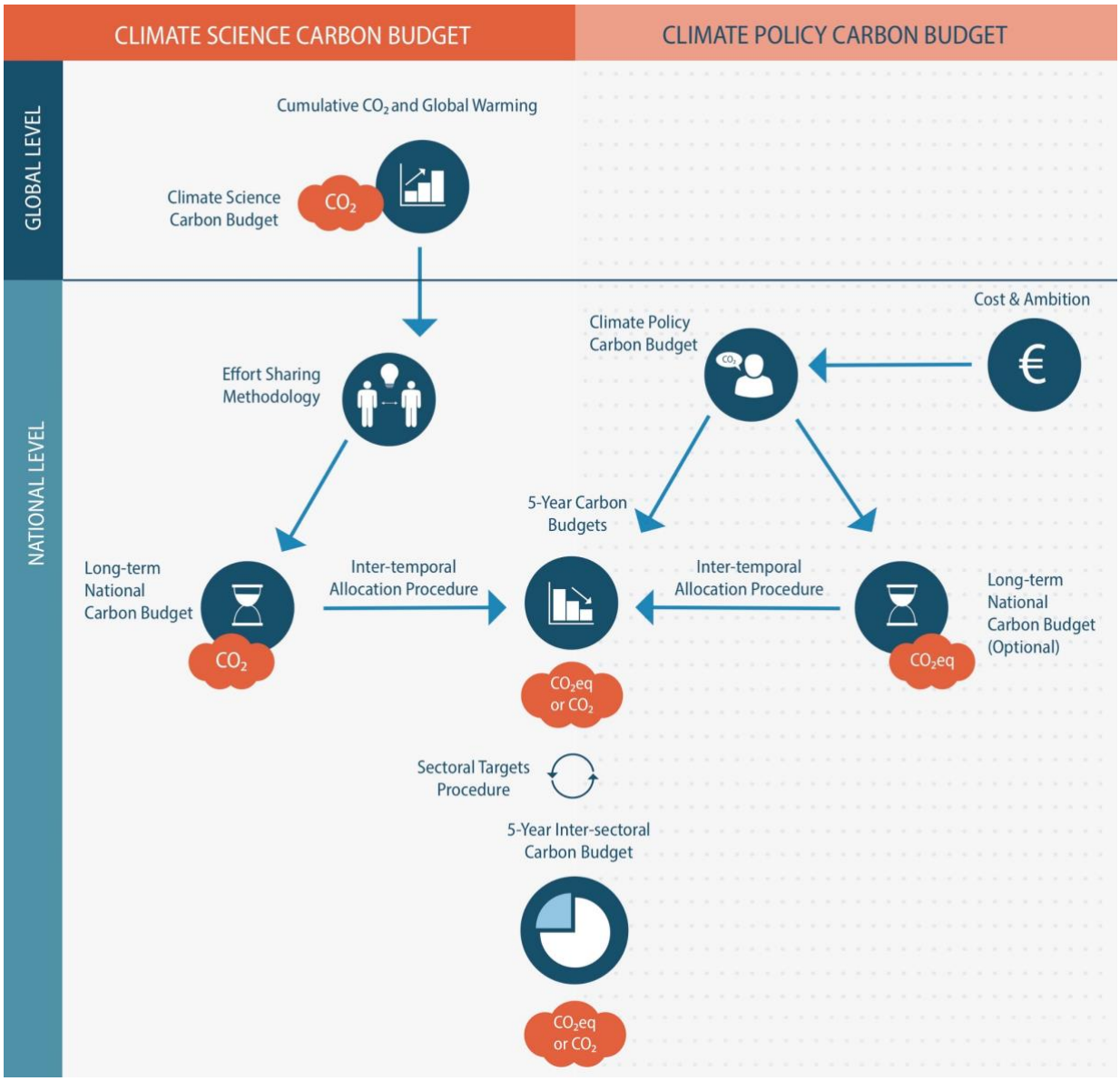


Figure 4 Flowchart to derive five-year carbon budgets The flowchart outlines the steps in the two approaches to obtain five-year carbon budgets. The left side represents the climate science approach and the right side represents the climate policy approach

Box 3: What are the benefits of using a carbon budget?

From a global perspective, the use of carbon budgets can provide essential transparency and clarity on whether or not compliance with the Paris Agreement will be achieved. One of the innovations of the Paris Agreement was the instrument of NDCs, whereby individual countries conducted and published their own analysis on decarbonisation pathways. In the first round of NDCs, seventy-eight member states defined a mitigation target compared to a *base year* and eighty-seven member states used a reduction target compared to *business as usual (BaU*) scenario. A weakness with both of these methods is the lack of clarity of absolute emission limits that both pathways achieve. As outlined in Section 3.1, different emission pathways with different cumulative emissions will have very different implications for global warming. Without the specification of a carbon budget in a country's NDC it is difficult to analytically aggregate the impact of the NDCs and to determine if their impact is consistent with the temperature target of the Paris Agreement. Carbon budgets provide some additional benefits to the common NDC emission target types. Despite the absolute emissions being transparent within carbon budgets, the effort-sharing methodology is not transparent unless explicitly stated.

5.1 Global carbon budget and effort sharing methodology

The first step in using a carbon budget approach to align a decarbonisation strategy with the Paris Agreement is to choose a Global Carbon Budget and an effort sharing methodology to allocate a national long-term carbon budget. Section 2 provided an overview of the Global Carbon Budget (Box 1) and a summary of the main effort sharing methodologies.

Since the choice of effort sharing methodology will influence what quantity of the Global Carbon Budget will be allocated nationally, many considerations are likely to influence this decision. These considerations could include climate justice, intergenerational equity, and how the Global Carbon Budget is likely to change over time as different countries achieve different levels of decarbonisation. How a national allocation of the Global Carbon Budget is defined, whether as a quantity of carbon or a % share of the total, could be consequential. If a national target is to be defined in terms of a global carbon budget, something to that be considered and agreed in advance is how (or whether) the national target is updated in response to changes in global decarbonisation progress.

5.2 Inter-temporal and inter-sectoral national carbon budgets

Once a national long-term carbon budget is established, the challenge is to allocate how to "spend" the budget, over time (giving a decarbonisation trajectory) and over different sectors. The national carbon budget can thus be allocated to short-term or "inter-temporal" carbon budgets (typically in five-year periods) and further subdivided by sector into "inter-sectoral" carbon budgets. A five-year national carbon budget timeline more closely aligns with elected government timelines than long term targets, a feature which will possibly add political accountability for each inter-temporal and inter-sectoral carbon budget.

5.3 Ireland

Previously, Ireland's long-term national climate strategy was based on the 2015 National Climate Policy Position of an at least 80% reduction in energy related CO_2 emissions by 2050 (compared to 1990) and "an approach to carbon neutrality in the agriculture and land-use sector, including forestry, which does not compromise capacity for sustainable food production". The Climate Action Plan (2019) included a range of decarbonisation policy measures, a commitment to increase Ireland's decarbonisation ambition to net-zero greenhouse gas emissions by 2050, an outline of a new governance regime of five-year carbon budgets, and a strengthening of the Climate Change Advisory Council (CCAC).

The recently approved Programme for Government cited Denmark's climate action model, which it recommended that Ireland mirrors (Section 4.3). If Ireland was to derive a national carbon budget based upon population similar to Denmark, then Ireland's long-term carbon budget would be in the range 275 – 360 $MtCO_2$, which complies with a 67% probability of limiting global temperature to 1.5°C above pre-industrial temperatures (uncertainty due to additional warming which has already occurred).

5.3.1 National long-term carbon budget

This section describes in more detail some of the *stages* in setting a *Climate Science Carbon Budget* for Ireland. Developing carbon budgets for Ireland is an iterative process which will require extensive discussions on choices, exclusions, effort-sharing approach, issues and assumptions from all stakeholders to provide a transparent long-term carbon budget which can be easily absorbed by all stakeholders (Section 6 outlines some discussions for Ireland).

As previously mentioned, the first step in determining a national carbon budget is to choose a GCB. Figure 5 shows two GCB associated from the IPCC for 1.5°C and 2°C. It is worth noting the very large difference that 0.5°C makes to these GCBs. Some preliminary results of assigning Ireland's long-term carbon budget from these GCBs are shown in Table 4. We present a range of different numbers in this section to highlight the importance of the *process* of developing a carbon budget decarbonisation pathway.

5.3.1.1 Effort sharing methodologies

Two different national carbon budgets for Ireland are shown here based on two different effort sharing methodologies: the Regensburg Model and the Extended Smooth Pathway Model (ESPM). The Regensburg Model [27] is primarily based upon the Contraction and Convergence (C&C) approach, which is outlined in Section 2. While the EPSM [2] is based on a weighted distribution of population, which is the equity approach outlined in Section 2, and emissions which is the grandfathering approach outlined in Section 2. Both models are available to download at [34].

The preliminary results indicate that if Ireland is to equitable comply with a 67% probability of limiting global warming to 1.5°C, then the maximum CO_2 budget is *263 $MtCO_2$* using the Regensburg Model and *225 $MtCO_2$* using the ESPM. These preliminary calculations do not include land use, international aviation and shipping (IAS) emissions, non-CO_2 emissions or negative emissions i.e. net carbon emissions only.

Ireland emits about 40 $MtCO_2$/year [35] this means we can continue to emit at similar levels for 5 – 9 years until we exceed our fair-share of the remaining 1.5°C GCB (not including historical budget, in which Ireland is in 'carbon debt'). The 67% probability of limiting global warming to 2°C results are also shown below. To comply with the 2°C warming limit, Ireland can continue to emit at similar levels for 18 – 22 years until we exceed our fair-share of the remaining 2°C GCB.

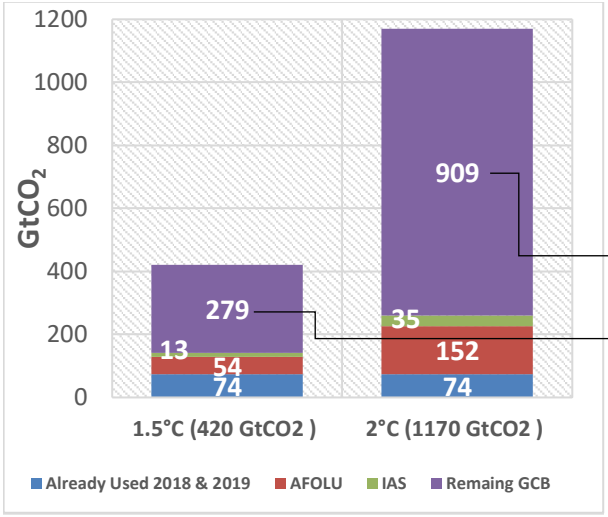


Figure 5 Two GCB [3] which provide a 67% probability of limiting global warming to their respective warming targets.

Effort-sharing methodology (and GCB)	National Carbon Budget 2020-2100 ($MtCO_2$)
Regensburg Model (279 $GtCO_2$)	251-263
Regensburg Model (909 $GtCO_2$)	834 - 857
ESPM (279 $GtCO_2$)	225
ESPM (909 $GtCO_2$)	734

Table 4: Ireland's Long-Term Carbon Budget using two GCB and two effort-sharing models [34] calculations applied to Ireland from 2020

Ireland's first 2050 climate target (an 80% reduction in CO_2 emissions and carbon neutrality in forestry and agriculture) and Ireland's latest 2050 climate target (net-zero GHG emissions) equate to two very different carbon budgets. Similarly, different carbon budgets arise from two 2030 targets: a 30% reduction in non-ETS GHG emissions (an EU derived target) and a 7% p.a. average GHG reduction from 2021-2030 (Programme for Government). Figure 6 outlines the four different potential carbon budgets arising from combining these different 2030 and 2050 targets. A key insight here is that greater levels of GHG reductions before 2030 (e.g. 7% p.a. reduction) leads to a significant overall reduction in Ireland's longer term (i.e. 2021-2050) carbon budget.

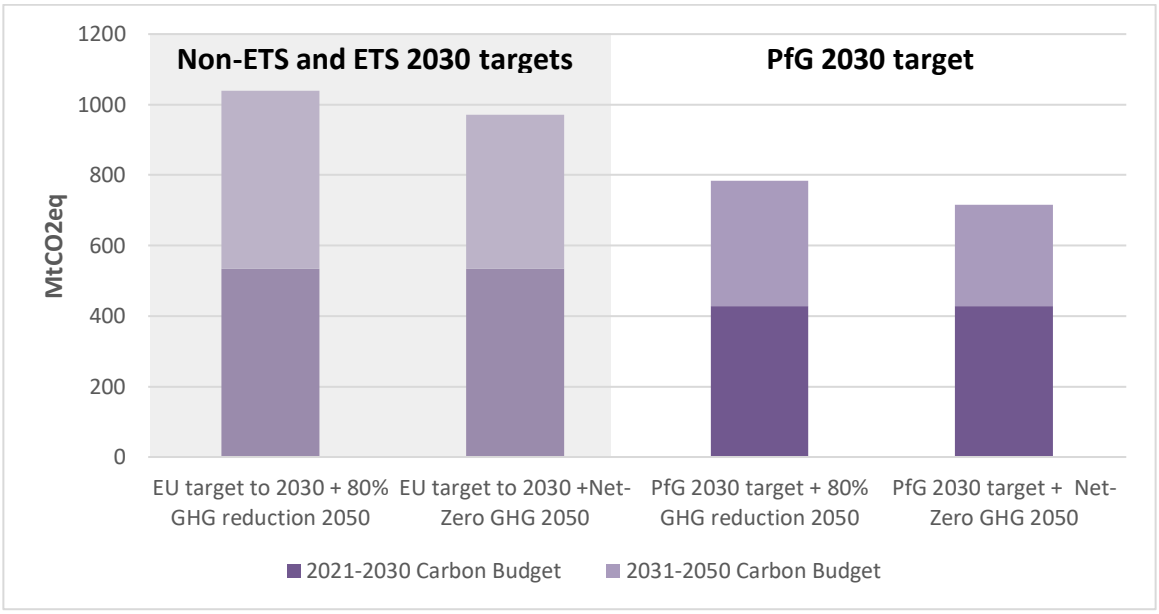


Figure 6 Ireland's Carbon Budget (2021-2050) using two different 2030 targets and two 2050 targets

5.3.2 National climate mitigation pathway to 2030

Ireland's 2021-2030 climate mitigation pathway is fundamental to Ireland's long-term carbon budget. Ireland's current legally binding non-ETS GHG emission targets from 2021-2030 and Europe's 2.2% annual reduction of ETS GHG emissions from 2021-2030 can provide the foundation to forming Ireland's carbon budgets up to 2030, in that complying with EU targets will be the minimum effort goal or maximum carbon budget. Ireland's recent programme for government have agreed to a commitment of 7%/year on average reduction in overall GHG emissions from 2021 to 2030 (a 51% reduction over the decade) and to achieving net-zero emissions by 2050. Figure 7 below shows three carbon budgets, one carbon budget is from Non-ETS and ETS 2030 targets, which are EU derived targets and two carbon budgets are from the PfG 2030 targets, one low carbon budget with annual consistent reductions and one high carbon budget which allows for increased emissions (late action scenario) but still complies with the PfG 2030 target by having an average 7%/year GHG reduction and 51% GHG reduction over the decade.

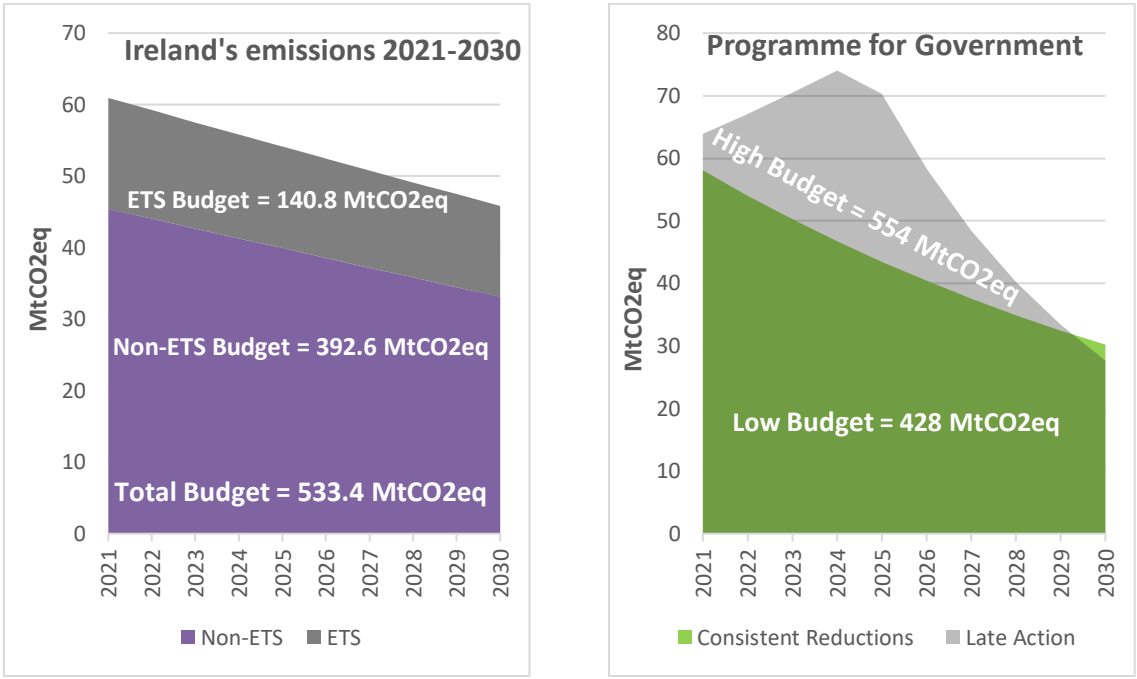


Figure 7 Ireland's 2030 targets and respective Carbon Budgets

For Ireland to comply with the current 2030 EU targets (i.e. a 30% reduction), this would equate to a budget of 533.4 MtCO2eq from 2021-2030. The new programme for government does not define a carbon or GHG budget, so with annually consistent reductions of 7%, the GHG budget would be approximately 428 MtCO2eq; however, in an extreme scenario it could be higher than EU 2030 targets; this would happen if Ireland increased GHG emissions, then reduced GHG emissions at a maximum rate of 17%/year (see Figure 7 – Late Action). Although this High Budget scenario is very improbable, it is included here to show that a climate pathway based on an average annual reduction could still have a larger than allowable carbon budget, which would make a difference to levels of global warming.

Based upon a 428 MtCO2eq budget (i.e. a 7% linear per annum reduction), the first 5-year carbon budget (2021-2025) would be expected to be about 252 $MtCO_2eq$ and the second carbon budget (2026-2030) about 176

$MtCO_2eq$. According to the EPA if Ireland is to continue on a With Existing Measures (WEM) pathway to 2030, Ireland is likely to emit 644.76 MtCO2eq [36]. To comply with current EU 2030 targets (i.e. a 30% reduction) Ireland will need to emit 17% less GHG emissions compared to WEM. For Ireland to comply with an average 7%/year GHG reduction to 2030 target, between 14–34% less emission would be required compared to WEM.

The Climate Action Plan 2019 provides higher detail in the Non-ETS sector emissions savings and the EU flexibilities up to 2030. Figure 8 below shows some sectoral division of the cumulative savings required in the 2021-2030 period. Ireland also has a large LULUCF allowance, which can be used to offset emissions if forestry (carbon sinks) is planted. This information should be used in calculating five-year carbon budgets.

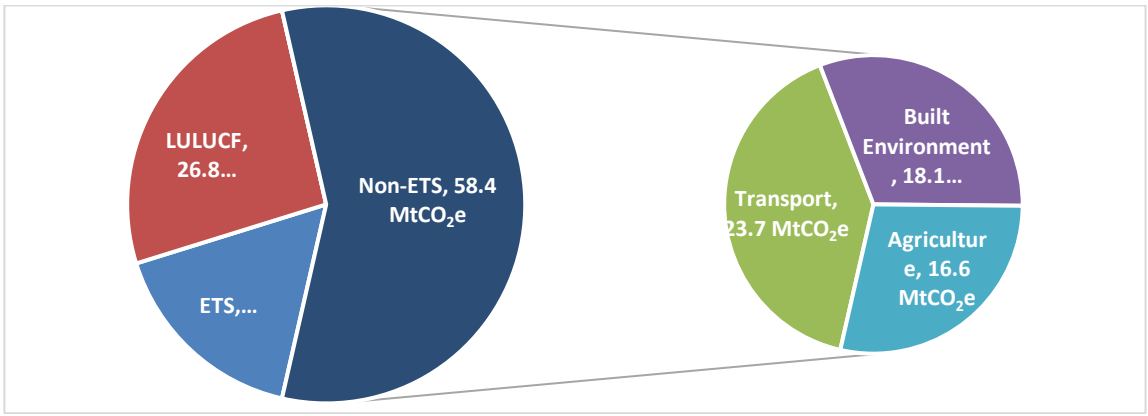


Figure: 8 Climate Action Plan 2019, cumulative emission savings 2021-2030 [37]

Further work on Ireland's GCB effort-sharing and climate mitigation pathways up to 2070 was done by Glynn et al. 2019 [38]. Thirty-eight scenarios were considered, and the GCB effort-sharing was based on equitable per capita shares (equality approach) of the remaining GCB. A range of national carbon budgets and scenario variants were used to account for uncertainty in climate mitigation policy choices. The results produced show a range of variation in optimal pathways with given budget constraints, with the 376 $MtCO_2$ budget also showing a difference between early action and delayed action (i.e. starting in 2025) in Figure 9.

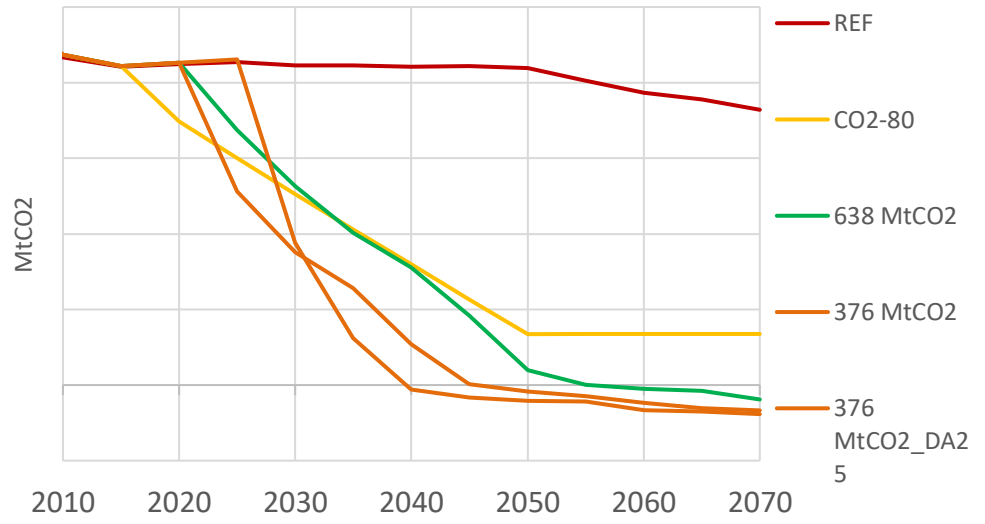


Figure 9: Energy system CO_2 emissions pathways for Ireland [38]. The reference emissions pathway up to 2070 can be compared to a 638 $MtCO_2$ national carbon budget and a 376 MtCO2 national carbon budget (Early & Delayed Action).

The modelling results suggest that an optimum decarbonisation pathway for a cumulative carbon budget follows a convex trajectory shape rather than a linear trajectory [38]. Significant additional detail about the modelling behind Figure 9 is available in the linked publication.

5.3.3 Ireland's carbon budget governance

Ireland's carbon budget governance structure has not yet been fully implemented, nor has the inter-temporal and inter-sectoral ambition being quantified yet. Based on the Climate Action Plan 2019 and the anticipated new Climate Action Bill, a hypothetical governance structure is outlined in Figure 10. This outline is intended to stimulate discussion. Given the reach of carbon-based energy into all parts of Irish life and society, it is important that all stakeholders can have an input, so that Ireland's carbon budget governance is transparent for all. The figure has colour coded organisations/activities depending on whether it is part of the setup and/or managing of carbon budgets.

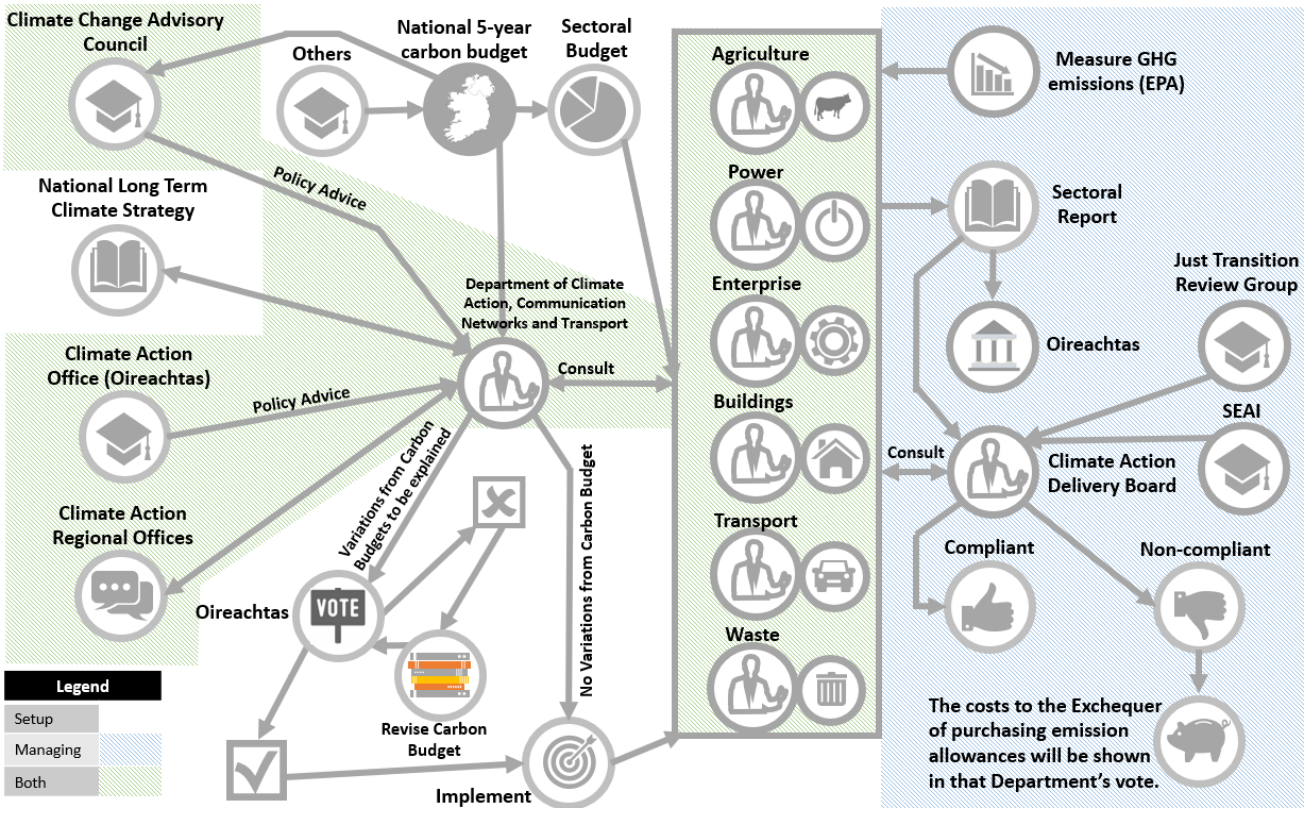


Figure 10: Hypothetical Carbon Budget Governance Structure For Ireland

6 Discussion

In this final section, we first briefly discussion the relationship between analytical energy modelling and the policy-making process, highlighting some of the principles and practices that can make this process more effective (section 6.1). Then we give a brief survey of a range of open issues related to the process of developing a carbon budget for Ireland (section 6.2). This section summarises a number of open questions and important considerations (accounting, technical, procedural) that we believe must be addressed if the process of forming a carbon budget is to be equitable and robust.

6. 1 The energy policy-modelling interface

Robust quantitative analysis and information is an important ingredient in the energy and climate policy making process. But energy modelling should *support* the policy making process rather than *determine* its contents; the policy-making process is best served by being evidence-informed rather than evidence-based [39]. This means the interface between energy modelling and the policy making process should be an iterative one that incorporates regular review and feedback as new issues and questions emerge.

According to the climate policy architecture put in place by the Paris Agreement, each nation takes responsibility for developing their own climate targets and climate mitigation pathway. Each country will take into account their own unique circumstances and will have their own combination of different energy system modelling tools and processes for developing policies, i.e. processes that include discussions between researchers, consultants and government to assess optimal and feasible national climate mitigation pathways.

Mindful of this diversity, Strachan et. al, 2016 provide an idealised energy modelling-policy interface (Figure 11) that would capture insights from an expert user group based on a modelling platform (B), incorporate interdisciplinary external review by wider stakeholders (C), and comprehensive quality assurance, version control and documentation (D). These insights would be fed into future model improvements and applications by coupling model-development to funding and policy cycles (A). There are a broad set of viewpoints on the overall role of modelling in the policy process, studies that actually examine the energy modelling–policy interface acknowledge the weak links between provision of insights and policy-maker needs [40].

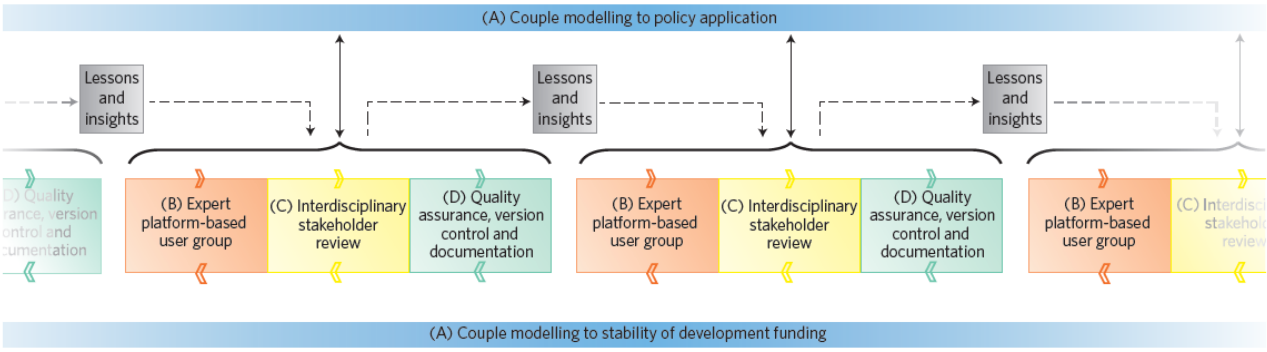


Figure 11: Idealised energy modelling–policy interface with full iterative feedbacks ([19])

6.2 Open Issues

6.2.1 Global carbon budget

In this discussion paper we have created a distinction between *Climate Policy Carbon Budgets* and *Climate Science Carbon Budgets.* This distinction was made to explain different types of carbon budgets that have been devised and adopted by different countries. For countries to adhere to Article 2 of the Paris Agreement, i.e. "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" some use of a global carbon budget that is consistent with these targets will be required.

However, this is not a simple process. As shown in Box 1, there are a number of global carbon budgets for different temperature targets (2℃ or 1.5°C) and each of these targets has a range of carbon budgets associated with different probabilities (50%, 67%) of being achieved. *Which of the global carbon budgets should Ireland choose?*

Once a carbon budget is chosen, the question arises of how an individual country (e.g. Ireland) apportions a share of that budget, i.e. what effort sharing methodology is used? Section 2 outlines the main effort sharing methodologies that have been used. Each effort sharing methodology and associated global carbon budget will provide different results. *Which effort sharing methodology should Ireland choose?*

Furthermore, these carbon budgets are true for a point in time but will inevitably change over time as different countries perform differently. It should be made clear when adopting a global carbon budget, what will happen in the future as circumstances change [1],[2].

Climate science carbon budgets are CO_2 only, which is scientifically robust, while using an effort sharing methodology to equitably divide the GCB. Climate science carbon budgets do not include all GHGs, and therefore may require either separate non-CO_2 GHG targets and/or the use of the GWP* metric. The particular share of non-CO_2 emissions in a country's inventory of emissions will also affect the level of uncertainty for the overall carbon budget.

Finally, like all science, climate science is constantly evolving, so provision should be made for changes that may arise because of this.

6.2.2 National emission categories - what to include or exclude?

In theory, a carbon budget will account for all activities in a country that produce or sequester carbon-based emissions. In practice, decisions will be made about what to include or exclude in a national carbon budget. The ramifications of these decisions could have big impacts on a national carbon budget. For example, activities with an international dimension such as aviation and shipping could represent a very large share of a national carbon budget. We outline some of the considerations and questions below.

Should biogenic methane be included or excluded from the carbon budgets? This is a consequential question for Ireland. As shown in Figure 12, Ireland has a 21% share of GHG emissions from methane, which is one of the highest shares of non-$C0_2$ GHGs in the world. The OECD average is 9%. If biogenic methane is included in a carbon budget, that will be proportionally less is available for other sectors. New Zealand has a 38% of GHG emissions methane, the highest in the world. New Zealand has taken the approach of not including biogenic methane in their national carbon budget.

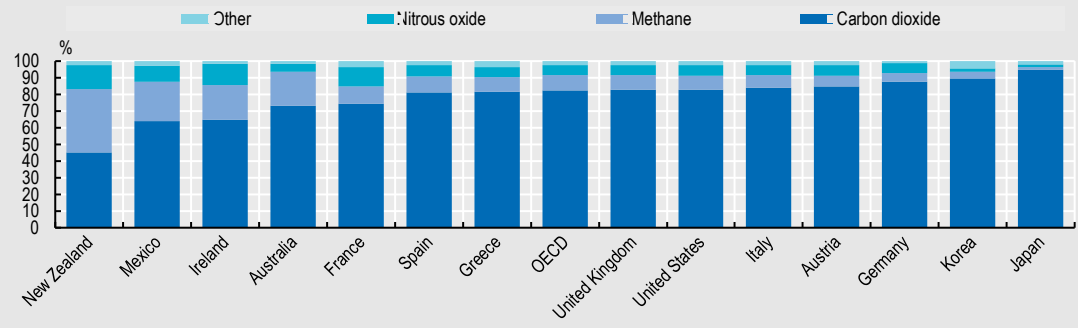


Figure 12: type of GHG emissions by OECD nation (source: OECD)

How should emissions associated with land-use be accounted for? Because Greenhouse Gas emissions associated with LULUCF can contribute to global warming, they are included in the Paris Agreement, which (in Article 4) cites the target of "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". EU legislation also addresses LULUCF emissions with a number of key policy changes coming into effect during 2021-2030.
While compliance will be required with EU legislation, the timing of these regulations might occur later than 2021. For example, the scope of LULUCF will extend to include all wetlands from 2026 [41]. Therefore the question arises, *when should LULUCF be included in a carbon budget for Ireland?*

Should international aviation and shipping (IAS) sector be included? Currently, international aviation and shipping are not included in Ireland's national emissions accounting by the EPA. This is consistent with many other countries. To date, efforts at decarbonising international aviation and shipping have been through international agreements led by industrial representation of these industries. UK and Denmark, two countries that have legislated for long-term net zero climate targets, do not currently include IAS in their targets; however, both countries plan to include IAS in later budgets. For Ireland, international shipping emissions are very small whereas international aviation emissions are very large.

How should the ETS and non-ETS sectors be incorporated a long-term carbon budget? Until the year 2030, Ireland's emissions are subject to separate ETS and non-ETS targets, though there is some flexibility permitted in using allocations from the ETS for the non-ETS. For the period after 2030, there is at present no mandatory targets for either ETS and non-ETS sectors. Therefore, how or whether the ETS/non-ETS distinction will be dealt with post 2030 remains open.

What flexibilities will be designed into the system? The UK has allowed for 3 carbon budget flexibilities which are outlined in section 4.4.4. What flexibilities should be used in achieving Ireland's carbon budgets? Ireland currently has Non-ETS GHG budget flexibilities within the EU. Ireland's Climate Action Plan accounts for the non-ETS GHG budget flexibilities. Current non-ETS flexibilities include banking, borrowing, and buying and selling between Member States, other flexibilities include access to EU ETS allowances and credits from the land use sector.

6.2.3 Governance

Many questions remain about the process of forming, agreeing, monitoring, managing compliance, and updating carbon budgets. A transparent plan on the steps and stakeholders involved in setting overall and sectoral carbon budgets will be necessary. Some of the issues highlighted in Section 6.1 will be pertinent here, e.g. *how and when will formal analytical modelling be used and how will it be balanced with discussions and negotiations between departments?* Additional questions that arise include: *should sectoral carbon budget be set at the beginning of a carbon budget along with the carbon budget or should allowances be set every year to provide more flexibility? Who is accountable for reducing emissions? Who is accountable to monitor progress and how shall slow progressing sectors proceed?*

6.2.4 Consistency with EU climate goals

While the topic of consideration here is a national carbon budget for Ireland, it will be important for any Irish decarbonisation policy goals to be consistent with current, planned or anticipated EU climate goals. Ireland's track record on compliance with EU climate and energy goals is poor. To achieve compliance with 2020 climate and energy targets, Ireland will likely be required to purchase of credits which will divert resources from investment that would achieve decarbonisation. Further future non-compliance would be similarly costly.

Recently, the EU goals for 2030 of a 40% reduction in overall GHG emissions (compared to 1990) was increased to a 55% reduction. For Ireland, the old target (a 40% reduction) was converted to a national target of a 30% reduction, with a number of flexibility measures permitted. Under The Green New Deal proposal, this 2030 target was to be increased to either 50% or 55%. Recent discussion in the European Parliament have called for increasing the 2030 target to a 60% or 65% reduction, although there is not consensus on this change. Given these dynamics, it will be important for any Irish national carbon budget to have consideration for a pathway that is consistent with these more ambitious medium-term goals or have a mechanism to adjust national/temporal/sectoral carbon budgets when circumstances change.

The EU's 2050 long-term strategy is "to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions". Analysis underpinning this long-term goal uses global carbon budgets (from AR5) that are consistent with global temperature targets of "below 2°C or 1.5°C"; however, the long-term target is still framed in terms of a single year (i.e. 2050) rather than a cumulative amount of emissions (i.e. a carbon budget). This could change when revised global carbon budget estimates from AR6 are released.

6.2.5 National energy system circumstances

The headline goals of The Paris Agreement are the 1.5 degree and 2-degree global temperature targets, but achievement of these goals is also acknowledged to rely on "different national circumstances", i.e. what is feasible. For the energy system, assumptions about resources, costs, and capabilities will influence what is feasible and at what cost. Some of these factors are inherently uncertain (e.g. the future price of oil), however other factors are well within the domain of national decision-making and will be influenced and policy-making and policy supports. Some factors include: the range of carbon tax up to 2030, the projected amount of data centres, the domestic bioenergy resource, the potential for district heating, the potential for carbon capture & storage (CCS), offshore wind capacity, etc.

6.2.6 Social discount rate

Economic evaluations of future investments use a % discount rate as standard practice. The social discount rate is a way of comparing the future value of an investment with the same investment today. The higher the discount rate, the lower the perceived value of future investments. Discount rates are used as an evaluation metric. They are composed of consideration of risk and the changing value of money. The outcomes of most evaluations are extremely sensitive to discount rate values. Therefore, transparency about what the discount rate is and how it was calculated are very important.

Ireland's social discount rate is recommended at 3.7% or rounded up to 4%, which is based upon the Social Time Preference Rate (STPR) equation using methodology from [42] *based on calculations from* [43]. The equation has two components. The *time preference* component comprising pure social time preference (δ) and catastrophic risk (L). The *wealth effect* component, where μ is the elasticity of the marginal utility of consumption and g is the rate of per-capita consumption growth.

Energy systems modelling analysis on Ireland's carbon budget, which varied social discount rates, showed that

Ireland's first two carbon budgets varied by up to 20%, when a social discount rate between 3% - 7% was applied [44]. This is a significant change and therefore the social discount rate is a highly sensitive variable and it should be openly discussed.

The UK Greenbook states "*Policies or projects which involve long term effects may require a different approach. This can be particularly important for policies expected to have significant environmental effects"* [42]. The UK Greenbook has set a default social discount rate of 3.5% in the UK. The UK recommended discount rate for risk to health and life is 1.5%. The health social discount rate is applied to projects which will affect a person's quality of life known as Quality Adjusted Life Years (QALYs), which combines both longevity and level of health in a single measure. It is worth discussing – does climate change effect our longevity or quality of life? Applying the same to Ireland, by excluding the 'wealth effect' the social discount rate of 3.7% would fall to **1.4%.**

Human rights and ethical debates around intergenerational considerations have revolved around discounting future generation in climate mitigation projects. Ireland's ***time preference*** value is focused on values around 1% [43], this means if Ireland is to consider future generations to have equal value to the current generation, then the social discount rate applied should be about **2.7%.**

Combining both health and intergenerational considerations, would mean Ireland's social discount rate should fall to about **0.4%**. *What value or range of values should be set for Ireland's social discount rate?*

This question is partly being addressed by Action 9 of the Climate Action Plan "*Reform the Public Spending Code to increase the shadow price of carbon and introduce more robust consideration of climate impacts in project appraisal*". As part of this, the Irish government recently published updated guidance on using discount rates.

6.2.7 Consumption based emissions

The UN method for measuring national GHG emissions is based on territory emissions only, for example an iPhone's materials are sourced from different parts of the globe and manufactured in China. The GHG emissions from the production of an iPhone used in Ireland, are not associated with Ireland's GHG emissions as the emissions were not produced in Ireland's territory. But consumption-based emissions would account for this. Denmark plan to include policy initiatives which can contribute to reducing the total climate footprint of imported goods, thereby reducing global emissions. However, the consumption footprint is not included in meeting the target [25]. *Should and if so, how should Ireland incorporate consideration of with consumption-based emissions*

Contact Details

Jason Mc Guire jason.mcguire@ucc.ie

Hannah Daly h.daly@ucc.ie

Fionn Rogan f.rogan@ucc.ie

Brian Ó Gallachóir b.ogallachoir@ucc.ie

www.marei.ie/project/capacity

Acknowledgements

This discussion paper is an output of the CAPACITY (Climate Action Pathways and Absorptive Capacity) project, which is supported by the Department of Environment, Climate and Communications under Grant Number RFT2016/01213/12806. Additional support was provided by Science Foundation Ireland (SFI) and the National Natural Science Foundation of China (NSFC) under the SFI-NSFC Partnership Programme Grant Number 17/NSFC/5181.

7 References

[1] D. Frame, “Report on New Zealand’s Recent Climate Policy Developments,” 2019.

[2] M. R. Raupach *et al.*, “Sharing a quota on cumulative carbon emissions,” *Nat. Clim. Chang.*, vol. 4, no. 10, pp. 873–879, Oct. 2014.

[3] J. Rogelj *et al.*, “Mitigation pathways compatible with 1.5°C in the context of sustainable development - Global warming of 1.5°C - An IPCC Special Report,” 2018.

[4] A. H. Macdougall, “The Transient Response to Cumulative CO 2 Emissions: a Review,” *Curr Clim Chang. Rep*, vol. 2, pp. 39–47, 2016.

[5] IPCC, *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. 2013.

[6] United Nations Framework Convention on Climate Change, *Adoption of the Paris Agreement*. 2015.

[7] P. M. Forster, A. C. Maycock, C. M. McKenna, and C. J. Smith, “Latest climate models confirm need for urgent mitigation,” *Nat. Clim. Chang.*, vol. 10, no. 1, pp. 7–10, Jan. 2020.

[8] M. R. Raupach *et al.*, “Sharing a quota on cumulative carbon emissions,” *Nat. Clim. Chang.*, vol. 4, no. 10, pp. 873–879, Oct. 2014.

[9] H. Tian *et al.*, “The terrestrial biosphere as a net source of greenhouse gases to the atmosphere,” *Nature*, vol. 531, no. 7593, pp. 225–228, 2016.

[10] M. R. Allen *et al.*, “A solution to the misrepresentations of CO 2-equivalent emissions of short-lived climate pollutants under ambitious mitigation,” *npj Clim. Atmos. Sci.*, vol. 1, p. 16, 2018.

[11] N. J. Berg *et al.*, “Implications of various effort-sharing approaches for national carbon budgets and emission pathways.”

[12] “Paris Equity Check | Pledged Warming Map.” [Online]. Available: http://paris-equity-check.org/warming-check.html. [Accessed: 28-Aug-2020].

[13] J. Rogelj *et al.*, “Paris Agreement climate proposals need a boost to keep warming well below 2 °C,” 2016.

[14] A. Herold, A. Siemons, and L. M. Herrmann, “Is it possible to track progress of the submitted nationally determined contributions under the Paris Agreement?,” 2018.

[15] “Net Zero Tracker | Energy & Climate Intelligence Unit.” [Online]. Available: https://eciu.net/netzerotracker. [Accessed: 28-Aug-2020].

[16] European Commission, *Establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law)*. Brussels, 2020.

[17] J. Rogelj *et al.*, “Energy system transformations for limiting end-of-century warming to below 1.5 °C,” *Nature Climate Change*, vol. 5, no. 6. Nature Publishing Group, pp. 519–527, 26-Jun-2015.

[18] K. L. Ricke, R. J. Millar, and D. G. Macmartin, “Constraints on global temperature target overshoot,” 2017.

[19] Ministère de la Transition Ecologique et Solidaire, “National Low Carbon Strategy Project: The ecological and inclusive transition towards carbon neutrality,” 2018.

[20] “France National Low-Carbon Strategy,” 2015. [Online]. Available: https://www.ecologique-solidaire.gouv.fr/sites/default/files/SNBC_France_low_carbon_strategy_2015.pdf. [Accessed: 11-Mar-2020].

[21] High Council on Climate, “Annual Carbon Neutrality report,” 2019.

[22] “Climate Change Response (Zero Carbon) Amendment Act 2019 No 61, Public Act – New Zealand Legislation.” [Online]. Available: http://www.legislation.govt.nz/act/public/2019/0061/latest/whole.html#LMS183848. [Accessed: 31-Aug-2020].

[23] “Climate Change Response (Zero Carbon) Amendment Act | Ministry for the Environment.” [Online]. Available: https://www.mfe.govt.nz/climate-change/zero-carbon-amendment-act. [Accessed: 21-Apr-2020].

[24] Ministry of Climate Energy and Supply, *Lov om klima (Climate Law)*, vol. 2019–2855. 2020.

[25] The Danish Council on Climate Change, “A framework for Danish climate policy,” 2019. [Online]. Available: https://klimaraadet.dk/da/system/files_force/downloads/english_translation_-_a_framework_for_danish_climate_policy.pdf?download=1.

[26] Committee on Climate Change, “Net Zero: The UK’s contribution to stopping global warming,” 2019.

[27] S. Pye, F. G. N. Li, J. Price, and B. Fais, “Achieving net-zero emissions through the reframing of UK national targets in the post-Paris Agreement era,” *Nat. Energy*, vol. 2, no. 3, p. 17024, 2017.

[28] S. Priestley, “A House of Commons Library Briefing Paper on the UK Carbon Budgets,” 2019.

[29] “UK natural capital - Office for National Statistics.” [Online]. Available: https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalforpeatlands/naturalcapitalaccounts. [Accessed: 14-Dec-2019].

[30] “Net Zero Technical report Committee on Climate Change,” 2019.

[31] “WholeSEM.” [Online]. Available: http://www.wholesem.ac.uk/research-models/models. [Accessed: 31-Aug-2020].

[32] “Reducing UK emissions 2019 Progress Report to Parliament Committee on Climate Change,” 2019.

[33] Cambridge Econometrics, “Final Report A report for the Committee on Climate Change How the UK met its carbon budgets Covering carbon budgets 1 and 2,” 2019.

[34] “Download tools - NDCs calculators: Regensburg Model and Extended Smooth Pathway Model - national emission budgets and reference values.” [Online]. Available: https://www.klima-retten.info/downloads.html. [Accessed: 31-Aug-2020].

[35] “GHG Final 2018 :: Environmental Protection Agency, Ireland.” [Online]. Available: https://www.epa.ie/pubs/reports/air/airemissions/ghg2018/. [Accessed: 31-Aug-2020].

[36] Environmental Protection Agency, “GHG Emissions Projections Report,” 2018.

[37] Department of Communications Climate Action and Environment, “Climate Action Plan 2019,” 2019.

[38] J. Glynn, M. Gargiulo, A. Chiodi, P. Deane, F. Rogan, and B. Ó Gallachóir, “Zero carbon energy system pathways for Ireland consistent with the Paris Agreement,” *Clim. Policy*, vol. 19, no. 1, pp. 30–42, Jan. 2019.

[39] Science Advice for Policy by European Academies (SAPEA), “Making sense of science for policy under conditions of complexity and uncertainty,” 2019.

[40] N. Strachan, B. Fais, and H. Daly, “Reinventing the energy modelling–policy interface,” *Nat. Energy*, vol. 1, no. 3, pp. 1–3, 2016.

[41] “Land use and forestry regulation for 2021-2030 | Climate Action.” [Online]. Available: https://ec.europa.eu/clima/policies/forests/lulucf_en. [Accessed: 25-Sep-2020].

[42] HM Treasury, *The Green Book*. 2018.

[43] D. O’callaghan and S. Prior, “Staff Paper 2018 Central Technical Appraisal Parameters Discount Rate, Time Horizon, Shadow Price of Public Funds and Shadow Price of Labour,” 2018.

[44] J. Mc Guire, F. Rogan, B. O Gallachóir, and H. E. Daly, “Sensitivity of Ireland’s potential carbon budget pathways with varyin…,” 2020. [Online]. Available: https://www.slideshare.net/IEA-ETSAP/sensitivity-of-irelands-potential-carbon-budget-pathways-with-varying-social-discount-rates-in-an-energy-system-optimization-model. [Accessed: 31-Aug-2020].



FUNDED BY:

Ireland's European Structural and Investment Funds Programmes 2014-2020
Co-funded by the Irish Government and the European Union

European Union
European Regional Development Fund

Science Foundation Ireland
SFI For what's next