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Carbon Budgets to Inform Climate Action: A society-wide, integrated GHG quota and accounting perspective

Author: Paul R. Price

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EPA Support for
Climate Change Advisory Council Research Fellowships

Carbon Budgets to Inform Climate Action: A society-wide, integrated GHG quota and accounting perspective

Research Summary Report for the Climate Change Advisory Council

End of Project Report available for download on

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Prepared for the Climate Change Advisory Council

by Paul R Price (CCAC fellow)

and Barry McMullin and Aideen O'Dochartaigh (co-principal investigators)

Dublin City University

Author:

Paul R. Price

Climate Change Advisory Council

An Chomhairle Chohairleach Um Athrú Aeráide

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

Email: info@climatecouncil.ie

Phone: 01 2680180 Website: www.climatecouncil.ie

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This report is based on research carried out including data analysis from January 2021 to March 2023. More recent data may have become available since the research was completed.

Climate Change Advisory Council Research

Under Section 11 of the Climate Action and Low Carbon Development Act 2015, the General functions of the Advisory Council include:

(2) For the purposes of the performance of its functions, the Advisory Council may—

(a) gather such information as it considers necessary or appropriate, and

(b) meet and consult with such persons (including members of the public) as it considers appropriate.

To enable this the EPA supports the Climate Change Advisory Council in the commission and administration of research.

Details of Project Partners

Paul R. Price (*CCAC Carbon Budgeting Fellow)* ORCID: 0000-0002-7995-6712

School of Electronic Engineering

Dublin City University

Glasnevin

Dublin 9

Ireland

Tel.: +353 1 280 9887

E-mail: paul.price@dcu.ie

Fellowship research advisors (DCU co-principal investigators)

Professor Barry McMullin ORCID: 0000-0002-5789-2068

School of Electronic Engineering

Dublin City University

Glasnevin

Dublin 9

Ireland

Tel.: +353 1 700 5432

Email: barry.mcmullin@dcu.ie

Dr. Aideen O'Dochartaigh ORCID: 0000-0003-1209-2371

Assistant Professor in Accounting

Business School

Dublin City University

Glasnevin

Dublin 9

Ireland

Email: aideen.odochartaigh@dcu.ie

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Executive Summary

> *The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (IPCC, 2022)*

A principal recommendation from this fellowship research for Ireland's next carbon budgeting cycle (spanning 2025-2040) is that, from the beginning and throughout, the assessment should include a strong focus on clarifying what is necessary for climate action to be 'consistent with' equitably meeting the Paris Agreement temperature goal, as per the Climate Act (Government of Ireland, 2021). A clearer early understanding of the long term carbon budget objective would focus feasibility assessment on the starting assumption of *cost effectiveness analysis* – actions should meet the set target without fail – rather than assessing feasibility on a cost benefit, notional least cost basis without an explicit warming limit objective. This research offers a framework to identify the key normative and quantitative choices required for any national such national Paris Test (PT) and applies it to enable a reassessment of Ireland's initial PT to identify necessary clarifications and potential quantitative adjustments. Adopting such a transparent framework will support national advisory clarity, societal debate, and public accountability for climate mitigation action.

This research covered a wide range of topics and the full set of outputs from this fellowship can be found in the **public DCU project repository** and from the links specified on this **DCU project page**. The project proceeded under four main topic headings that are the titles of the main Sections 2 to 5 of this report. For each of these topics, key findings of the research are briefly summarised below.

Section 2, *Integrated carbon budget assessment of existing policy* (associated supplementary materials):

- **1.5ºC national "fair share" mitigation overshoot is imminent.** By 2024, Ireland will likely overshoot its global equal per capita quota of a global [CO_2&N_2O&CH_4] CO_2we budget, from 2015, for 1.5ºC (50% likelihood) global temperature increase.
- **A Paris Test (PT) assessment framework** developed in this research, based on key literature sources and illustrated using the 2021 CCAC carbon budget technical report,

can guide reasoned and systematic consideration of fair share mitigation assessment for any nation.

- **Reassessing the 2021 CCAC Paris Test (PT).** Using the PT framework for detailed reassessment finds that *at most* only one of the 2021 core scenarios passes an adjusted 2050 temperature impact PT quantification. Further, the (partial) sectoral emissions ceilings subsequently adopted by Government are not consistent with *any* scenarios that pass this adjusted PT.
- **Assessing historical responsibility**, global warming would already have reached 3.1ºC above pre-industrial if all nations had the same past emissions profile as Ireland's for 1870–2018. On the same basis, the least developed countries' (LDCs) relative historical contribution is only 0.4ºC. Ireland is unusual among wealthy nations in having a relatively even balance of historical warming contribution from energy and agriculture, each about 1.5ºC up to 2018 – future CO_2 emissions will add to the energy ºC total, but the agriculture total could decrease from 1.5ºC if annual methane emissions are reduced substantially.
- **Early carbon budgeting assessment.** As of 2022, Ireland's GHG projections indicate the adopted statutory carbon budgets to 2030 will not be met. In particular, land use emissions are higher than assumed in the 2021 CCAC analysis informing the initial budget proposals. This is in part due to an upward scientific revision of 2 $MtCO_2\ yr^{-1}$ in the timeseries of forest soil carbon emissions, but also the already-anticipated rise in timber harvest milling rate after 2020.

Section 3, *Assessing alternative integrated emissions scenarios including methane and carbon dioxide removal (CDR)* (associated supplementary materials):

- **Defining "climate neutrality"** for Ireland and other high emitting nations already in overshoot of equitable global budget quotas relative to a 1.5ºC warming limit (50% likelihood by 2100 or earlier), now implies first reaching a "no-further-warming point", at an *overshoot net zero* (ONZ) point – corresponding to maximum quota overshoot or "carbon debt" (McMullin et al., 2019). Therefore, returning to a *quota net zero* (QNZ) level requires sufficient net negative emissions (net temperature reduction through some combination of CH_4 mitigation and carbon dioxide removal (CDR).
- **Methane mitigation is now crucial to any chance of limiting to 1.5ºC.** In addition to necessary radical reductions to zero annual net [CO_2+N_2O] on a CO_2e basis, a substantial early, deep, and sustained cut in $CH_4\ yr^{-1}$ rate is now also very likely required for alignment with a 50% chance of 1.5ºC, globally, and in Ireland on a fair share basis. Early $CH_4\ yr^{-1}$

reduction limits temperature overshoot and can greatly limit the CDR required for temperature stabilisation on a global or national fair-share basis.

- **Methane warming and GWP* analysis.** Further improvement of the DCU GHG-WE spreadsheet tool (Price and McMullin, 2022) enables mitigation analysis of methane and aggregate GHG warming in national and sectoral scenarios, and for assessment of historical responsibility. Studies of GWP* parameter change and livestock warming add to understanding of GWP* application by acting as a 'micro climate model' (Meinshausen and Nicholls, 2022) in the context of meeting the Paris goal.

Section 4, *Agriculture, forestry, and land use (AFOLU) scenarios within Paris-consistent pathways* (associated supplementary materials):

- A preliminary, AFOLU scenario model enables coarse grained national land use planning based on land areas, nitrogen flows, and emissions. This model illustrates that provided radical energy CO_2 mitigation is being achieved, strong AFOLU policies to cut agricultural non-CO_2 and land use GHG emissions, could still enable Ireland to meet a Paris-consistent target.
- A reanalysis of the AgriBenchmark report's 2008-2015 mean, farm-type nitrogen flux data (Murphy et al., 2019) enabled the mean nitrogen flux and related *effective platform* (EP) areas to be determined for the key production-types of Irish agricultural land use (Milk, Cash crops, and Livestock) over the benchmark period.
- A number of small studies elucidated several AFOLU points that are not commonly recognised and require greater attention: due to ongoing focus on intensifying grass-based ruminant production, Ireland's agri-food system is the least nitrogen efficient in Europe and this has worsened over the past decade; the projected rise in livestock methane increase to a "stable herd" would likely ensure that a Paris-consistent carbon budgeting pathway to 2050 cannot be met; anaerobic digestion (AD) production of biogas is unlikely to have any climate benefit and its digestate is unlikely in itself to displace chemical N; in the context of climate action, limiting the forest sink "carbon cliff" (CCAC, 2021, p. 86) by prioritising *preservation* of standing forest carbon stocks by limiting harvest may be a least cost mitigation option for society to 2030; and the increased methane from rewetting organic soils can substantially cancel out the climate benefit to 2050 found in the modelling for the CCAC (2021) report.

Section 5, *Integrating national and business-sector carbon accounting and management (NCAM and BCAM)* (associated supplementary materials):

- **Critical literature review** finds that BCAM and NCAM are currently not, and likely cannot ever be, quantitatively aligned. This supports a view that the edifice of BCAM – including only voluntary carbon accounting and disclosure and adoption of "science based targets" that neglect equity principles aligned with accepted environmental law – is currently functioning largely as a non-transformative "discourse of delay" (Lamb et al., 2020). Typically, it serves to deflect national and international pressure away from robust measures, such as regulation and taxation, that could adequately constrain business use of carbon energy and agricultural fertilisers within remaining carbon budgets.
- **Concept mapping of global and national use of emission drivers to warming,** demonstrates the parallel concepts, yet quantitative incommensurability of BCAM and NCAM. Under IPCC and UNFCCC frameworks, carbon accounting by Party does provide highly open and relatively complete emissions accounting for all Parties on a common sectoral and by-individual-gas GHG basis. By contrast, corporate disclosure is non-transparent and incomplete. The Paris Agreement requires common-but-differentiated action implemented on the basis of equity among the Parties, whereas business's science-based targets are not consistent with this objective.

As of this report (March 2023), EPA emission projections based on existing and additional (proposed) measures indicate Ireland's climate action is already falling far short of what is required to meet the initial programme of three five-year carbon budgets. Therefore, policy corrections by Government are urgently needed to greatly increase actual achievement of early and deep GHG mitigation.

The primary finding of this two-year research project is that achieving "fair share" climate action by Ireland 'consistent with' the Paris Agreement (PA) Article 2 temperature goal, as required by the Climate Act, is likely to require much more demanding policies and far more urgent climate action measures than was indicated in the first cycle of carbon budgeting assessment in 2021. As reassessed, our research finds that the five-year carbon budgets to 2030 and to 2050 required to meet the same Paris Test as set out in the first carbon budgeting assessment cycle (CCAC, 2021) are much smaller, and consequently a Paris-consistent carbon budgeting pathway is considerably more difficult to meet than was assessed.

Therefore, we recommend that the second carbon budgeting assessment cycle in 2023–2024 by the CCAC, and also by the Oireachtas, considers the downward revision of the existing and provisional carbon budgets to ensure "Paris-consistent" climate action as required by the Act.

1. Introduction: report content and research context

1.1 Presentation format and layout of this summary report

This short summary report is only intended to provide a brief synopsis of the range of research undertaken during this fellowship, the primary outputs from this fellowship will be available on or through the CCAC website. The full set of outputs related to Paul Price's fellowship work – including open-access peer-reviewed and working papers, workbook analyses, slide and video presentations, and other contributions (including Joint Oireachtas Committee appearances, advisory submissions, and media articles) – can be found in the **public DCU project folder** and from the links specified on this **DCU project page**. Both the project folder and project page will be updated with any revisions or additions as they become available, including open-access pre-publication or published journal papers related to the fellowship work.

This report summarises findings and recommendations from the four work package topics explored during this two-year, desk-based, CCAC carbon budgeting fellowship. These package topics are set out as Sections 2 to 5 and each section heading links to the relevant section outputs on the project page. For these main topic sections, each study undertaken is given a sub-section heading, each with brief descriptions of the *Research question*, *Methods*, *Findings*, and *Recommendations*. Some key figures or tables are provided to illustrate the key findings. The detailed reporting for all of the main topics and research approaches, including all figures, tables, and supplementary material (such as Excel workbooks and presentations), can be found through the specified links found in the DCU project folder and project page.

1.2 Context: Global

Due to wholly insufficient international climate action to date, it is now almost certain that overshoot of 1.5ºC globally will occur soon after 2030, meaning that, in addition to achieving net zero emissions CO_2 globally by mid-century, earlier temperature reduction measures and a period of net negative emissions will be required to limit and return from overshoot. Therefore, carbon budgeting aligned with meeting the LTTG, globally, or on some fair share basis by nation, needs to assess the aggregate warming outcome of alternative mitigation scenarios including all of the main GHGs – CO_2, N_2O, and CH_4 – as well as any projected future dependence to 2100 on carbon dioxide removal (CDR) to land or, more reliably and permanently to geological storage. Under the PA, it is the Parties, the signatory nation-states and blocs of nations, that are responsible for limiting their society-wide GHG emissions within an equitable share of meeting the LTTG, rather than individual emission sectors (such as transport or agriculture) or corporate sectors and entities. Additionally, the PA requirement for climate action on the basis of equity means that national carbon budgeting needs to assess the warming due to proposed multi-gas scenarios relative to a defined fair share allocation of a remaining warming budget related to the meeting the LTTG.

1.3 Context: Ireland's Climate Act and the Paris Agreement objective

Ireland's Climate Act (Government of Ireland, 2021) as amended in 2021 outlines the basis for expert assessment and democratic consideration and approval of a programme of legally binding five-year society-wide carbon budgets. A principal requirement under the Act is that Government, its ministers, and the Climate Change Advisory Council (CCAC) are required by the Act perform their functions 'in so far as practicable' 'in a manner consistent with' Paris Agreement Article 2 and 4(1)', which specifies the global long-term temperature goal (LTTG) and equitable implementation by its Parties, the nations of the world, of actions to meet this goal. Research cannot decide what is practicable politically, but it can aim to assess interpretation of *what is necessary* for the PA Parties to meet the PA LTTG equitably, through mitigation 'in accordance with best available science' (PA4(1)) and 'implemented to reflect equity and the principle of common but differentiated responsibilities and respective capabilities [CBDR-RC], in the light of different national circumstances' (PA2.2).

2. Integrated carbon budget assessment of existing policy

During the first months of this fellowship research in 2021 the CCAC was engaged in the first cycle of carbon budgeting assessment (Apr–Oct 2021), and also in 2021 the Oireachtas passed the amended Climate Act and an associated Regulation defining the scope of carbon budgeting. These events redefined and strengthened the research framework for carbon budget assessment of existing policy, so this work package first focused on producing a literature review and scenarios for the CCAC in the context of Paris-consistent fair share GHG mitigation. Following publication of the Carbon Budget Technical Report and its *Paris Test* (PT) of national scenarios, this research focused on clarifying PT assessment and quantification of PT thresholds and scenario outcomes. Being part of fair share assessment, quantitative historical responsibility for warming by nation is also explored.

2.1 Assessing Ireland's fair contribution to global climate action

2.1.1 Research Question (as requested by the CCAC-Secretariat)

Based on literature review what is Ireland's fair contribution to the global effort to limit global warming to 1.5ºC or well below 2ºC?

2.1.2 Methods

Literature review assesses scientific and fair-share interpretation of the Climate Act and Paris Agreement, with an addendum to the review after IPCC AR6 WGI publication. A GHG-WE Excel workbook tool (McMullin and Price, 2020) is used to assess a multigas GHG budget for Ireland.

2.1.3 Results

- For full details, see the Literature Review and its Addendum (following AR6 WGI) published on the CCAC website, and a One-Pager summary as requested by the CCAC Secretariat.
- Identical global cumulative budgets and net zero targets in GWP_{100} CO_2e can have ambiguous temperature impact if methane pathways vary, whereas step-pulse metrics, such as GWP* for cumulative CO_2we from a specified CBDR-RC reference year to a specified threshold or end-year, enable unambiguous assessment of scenario temperature impact.
- On a global equal per capita [CO_2+N_2O+CH_4] warming equivalent basis from 2015, Ireland's remaining NCQ*, the national cumulative GHG quota from 2015 for a 50% likelihood of limiting to 1.5ºC is estimated as 400–440 $MtCO_2we$, but 310 $MtCO_2we$ had already been emitted for 2015–2020 inclusive, leaving 90–130 $MtCO_2we$ from 2021.
- Other than relatively minor accounting differences, AR6-WGI does not evidence any substantive 'distinct characteristics of biogenic CH_4' (quoting the Climate Act) relative to fossil CH_4 – the near-term CH_4 warming from each is identical. All GHG emissions from agriculture are classed as anthropogenic, and thus subject to applicable mitigation policy and technology choices.

2.1.4 Recommendations

- **A national carbon budget programme cannot be assessed for costs or consistency with PA A.2 goals unless some specific estimate of the remaining global carbon budget is explicitly adopted** – to reflect a concrete judgement of prudence (application of the precautionary principle) combined with an articulated global basis for equitable "fair sharing".
- Only scenarios with net CO_2 becoming net negative by 2050 with at least a 50% mass flow reduction in CH_4 and N_2O plausibly satisfy the NCQ* requirement while limiting net CDR requirement close to, or under the prudential upper policy limit on Ireland's suggested practical policy limit of 200 $MtCO_2$ proposed by McMullin et al. (2020).

- **Based on assessment of the IPCC climate model database and a minimally equitable, equal per capita sharing from 2015, it is likely that overshoot of Ireland's fair contribution NCQ* has already occurred or is imminent.**

2.2 Defining and using a Paris Test assessment framework

As the 2021 Climate Act as amended required carbon budgeting to be 'consistent with' PA Article 2, the *Paris Test* (PT) set out in the Carbon Budget Technical Report (CCAC, 2021) provides an internationally valuable example of a serious attempt to set out a test of Paris-consistent equitable action, a quantified PT pass/fail threshold defined on a global CBDR-RC basis, and a methodology to quantify the temperature impact of proposed scenarios.

2.2.1 Research question

Informed by the CCAC 2021 PT example, what are the key considerations and questions that any national climate change advisory or decision-making body needs to address to provide society with an open and transparent PT of national fair share climate action consistent with meeting Article 2 of the Paris Agreement?

2.2.2 Methods

- Examining the CCAC (2021) report's initial PT and key peer-reviewed research literature, this research sets out a five-element tabulated framework of key considerations and questions (Figure 1) that can be used by expert advisory bodies in any nation for Paris Test assessment.

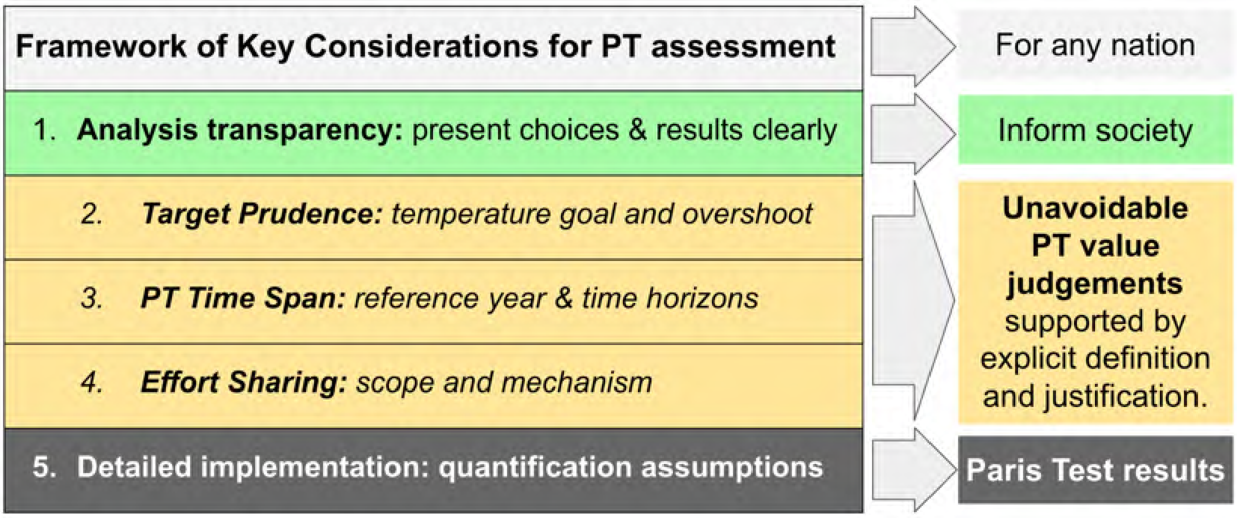

Figure 1. Framework of key considerations offered for Paris Test assessment in any nation.

- To illustrate use of the framework it is then applied to the 2021 report's PT text and findings, the results tabulated, and recommendations for Ireland's second carbon budgeting assessment (over 2023 and 2024) are made.

- Adopting such a transparent and explicit PT assessment framework supports national advisory clarity, societal debate, and public accountability for climate mitigation action, particularly in the context of temperature target overshoot-and-return requirements (Geden and Löschel, 2017).
- As shown in Figure 2, in any PT framework to assess CBDR-RC mitigation effort among nations, the choice of reference year should be assumed as common to all nations and the commonly-allocated "remaining budget" from that year is then depleted from then on differentially by nations' differing annual emissions. Note that the reference year used in any most-recent IPCC WGI assessment report for a "remaining global carbon budget" *cannot* be applied as a justified CBDR-RC basis because the IPCC does not make such a normative claim. McMullin et al. (2019) argue that 2015 the year of the PA is a "minimally equitable", latest-defensible reference year.

- **Therefore, choosing the reference year is a crucial value judgement affecting emissions grandfathering that requires explicit justification.**

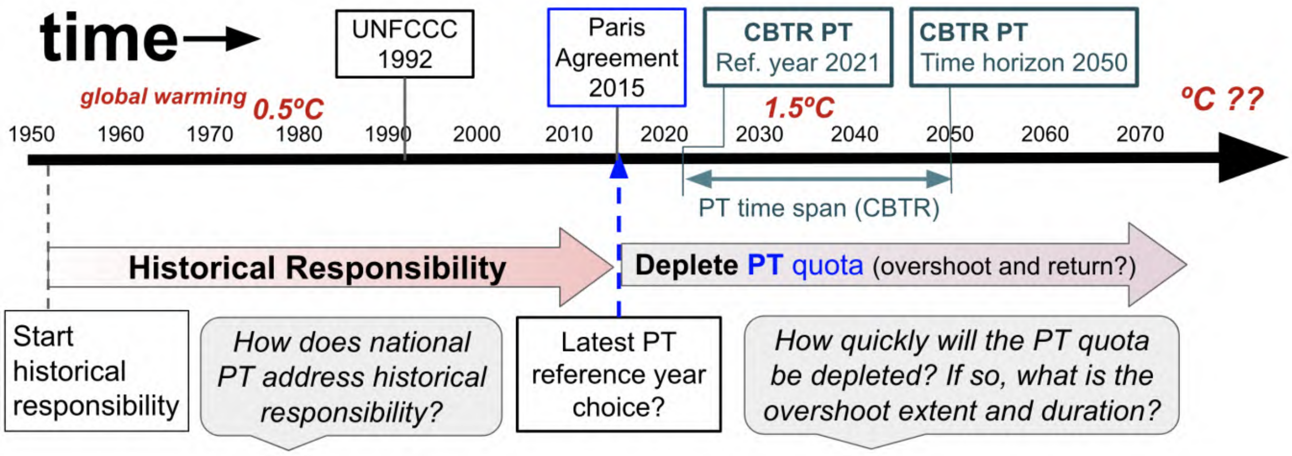

Figure 2. Reference year demarcates historical responsibility from remaining responsibility.

2.2.3 Results of applying the PT assessment framework to the CCAC (2021) report

- **Analysis transparency** is lacking as several value judgements (reference year basis, CBDR-RC) embodied in the CCAC PT are not clearly stated or justified. National core scenarios have similar cumulative CO_2e values for 2020–2050 but significantly different temperature (cumulative CO_2we) outcomes due to differing annual methane reduction to 2030.
- **Prudence (temperature goal likelihood and overshoot):** 1.5ºC global goal is identified but the associated likelihood of limiting to this goal is unclear – though implicitly it is 50% given the CO_2-only budget. Likely imminent overshoot of given upscaled PT is not noted or discussed.

- **PT Time Span (reference year and time horizons):** The global reference year (start of 2020) for the PT threshold does not match the scenarios reference year (start of 2021). Normative CBDR-RC and grandfathering implications of reference year choice are not discussed, nor is literature to justify the choice given. Historical responsibility for emissions is not discussed.
- **Effort Sharing Scope and Basis:** Global PT threshold basis is CO_2-only which does not match the national core scenario [CO_2&N_2O&CH_4] basis. International Aviation and Shipping is excluded from PT threshold and national core scenarios without justification. Alternatives to territorial GHG accounting such as consumption emissions or income based assessment are not discussed.
- **Detailed implementation:** Feasibility was assessed first on a CO_2e basis, yet the scenarios were tested for necessary Paris-compliant action on a temperature (CO_2we basis). All bioenergy use is assumed to be unproblematically carbon neutral at the point of use, despite the existence of a wide literature that is highly critical of this approach. See sub-section 2.3, below, for detailed quantification refinements.

2.2.4 Recommendations for Ireland's next carbon budgeting assessment cycle

- **Analysis transparency:** Increase transparency by making all normative and prudential assumptions explicit, such as global equal per capita allocation. Avoid "value neutrality" claims such as an unjustified reference year. Clarify climate justice impacts in terms of historical responsibility vs. remaining responsibility.
- **Prudence (temperature goal likelihood and overshoot):** Explicitly state temperature goal and likelihood of limiting to it. Clarify that national pathways now require minimising overshoot and enabling a return to a fair share temperature budget through a period of net negative emissions.
- **PT Time Span (reference year and time horizons):** In no circumstances should the sharing reference year be shifted further *forward* (i.e., beyond the 2021 value adopted in the first carbon budget cycle). Critically review the choice of reference year, including the strong CBDR-RC case for shifting it back to at least 2015 (if not earlier).
- **Effort Sharing Scope and Basis:** Clarify and discuss the PT effect of using alternative effort sharing methods for PT assessment, e.g., equal per capita, consumption, GDP and income, or historical emissions and loss and damage.
- **Detailed implementation:** In the next carbon budgeting cycle, *first* quantify reasoned global PT threshold options on an equitable basis (as 'consistent with' PA 2 is given higher precedence in the Climate Act than feasibility), and *then* explore scenarios that meet or come close to meeting these options by 2050. In that way, analysis focuses on assessing 'what is necessary' and

attempting to make the necessary feasible, rather than examining feasibility based on current near-term or lock-in preferences and only examining Paris-compliance as a secondary issue.

2.3 Detailed implementation: refinements to quantification of the CCAC 2021 "Paris Test"

The 2021 Carbon Budgeting Technical Report (CBTR) (CCAC, 2021) set out a benchmark *Paris Test* to assess whether alternative 2021–2050 mitigation *core scenarios* (NS_{2050}) for Ireland resulted in an aggregate warming temperature impact lower than a "Paris-consistent" 2050 value, defined on a global equal-per-capita basis from 2020. Only one of the core scenarios was found to marginally fail the defined PT.

2.3.1 Research Question

In detailed implementation of the <u>*same*</u> *PT methodology as in CCAC (2021), can any quantitative refinements be recommended to the CCAC carbon budgeting working group toward the second carbon budgeting assessment cycle in 2023–2024?*

2.3.2 Methods

Given the alignment and quantification issues identified by use of the PT assessment framework discussed in the previous sub-section a detailed quantitative analysis is provided in the supporting Supplementary Material for a submitted journal paper.

2.3.3 Results

(A) Recalculation of aggregate GHG warming based on cumulative CO_2we using the most recently published improved GWP* parameters (Smith et al., 2021) changes the trajectory to 2050 and increases the upscaled global ΔT values in 2050 for all NS_{2050} by about +0.06ºC;

(B) Aligning the GCB* reference year to 2021 reduces global PT ΔT threshold to 0.21ºC;

(C) Correcting the global budget methodology from CO_2-only to [CO_2&N_2O&CH_4] yields GCB^*_{2021} global ΔT of 0.15ºC;

(D) Allowing for an illustrative IE IAS scenario, upscaled to global level, effectively reduces the GCB^*_{2021} for strictly territorial emissions by a further 0.08ºC, effectively resulting in a GCB^*_{2021} global ΔT of 0.07ºC;

(E) Adjusting to a 2015 sharing reference year and still allowing for the illustrative IE IAS scenario reduces the GCB^*_{2015} of 0.29ºC by 0.33ºC, resulting in a GCB^*_{2015} global ΔT of -0.04ºC, which is to say that Ireland would be classified as having gone into overshoot of its Paris aligned GCB* share already as early as 2015 (unless it enacts policies to achieve earlier, deeper, IAS mitigation).

See these adjustments to the 2050 aggregate GHG temperature impact (adjustment A) and the PT threshold (adjustments B to E) are charted in Figure 3 and set out in Table 1: (a) globally upscaled ºC temperature format, as in CCAC (2021), and (b) national downscaled as $MtCO_2we$. (Note that these CO_2we values cannot be compared with CO_2e values on a like-with-like basis.)

This reassessment of the <u>same</u> five core scenarios, on the <u>same</u> Paris Test basis as the CCAC (2021) CBTR, finds that <u>only one or none</u> of the core scenarios pass the CBTR's test.

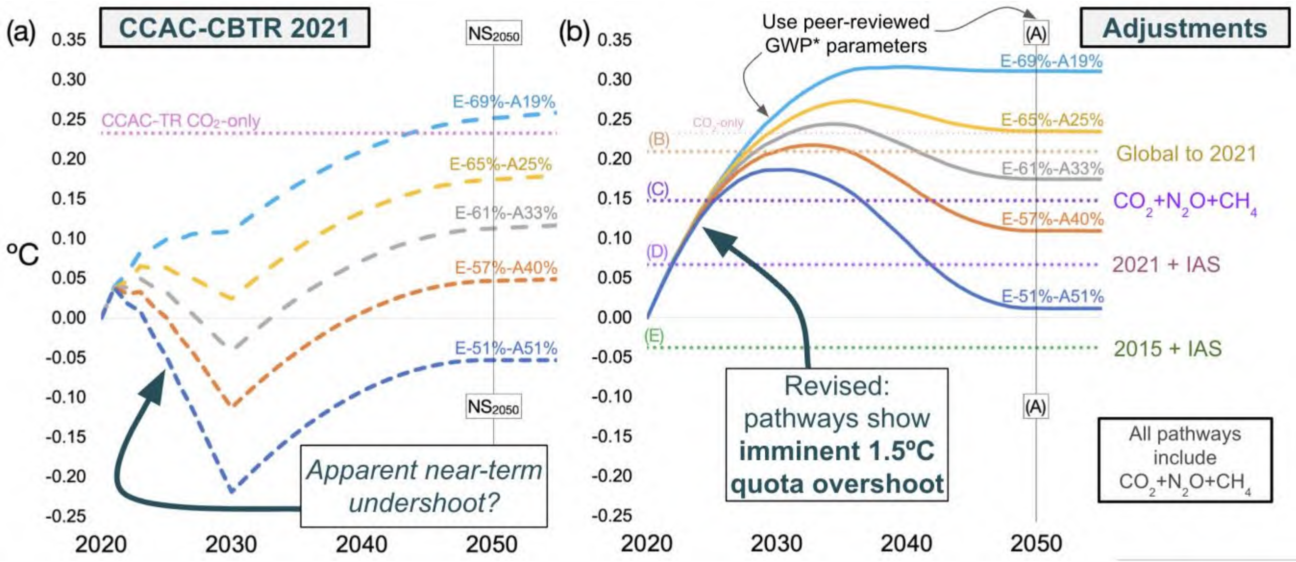

Figure 3. CCAC (2021) and Adjusted GWP* core scenario GHG temperature impacts.
All plots aggregate [CO_2&N_2O&CH_4]. (a) replicating CBTR pathways (b) with quantitative adjustments A–E. In (b), the vertical A line at 2050 indicates the NS_{2050} values for the scenarios as adjusted for literature GWP parameters, and B–E indicate adjustments to the PT threshold level defined respectively as per the text.*

Table 1. Suggested refinements to the CCAC (2021) PT quantification.

(a) shows upscaled PT threshold values in ºC for PT (NCQ) as of 2050, with PT pass/fail differences for each NS showing the in the CBTR PT threshold and NS PT outcomes for adjustments (A) to (E) – pass (green) or fail (orange).*

(b) presents the directly equivalent findings (via national population and TCRE) but shows downscaled values in $MtCO_2we$.

		National Scenarios (NS)				
(a) Global ΔT (°C): Upscaled PT for NS		**E51-A51**	**E57-A40**	**E61-A33**	**E65-A25**	**E69-A19**
CBTR NS warming contribution (in 2050) =		*-0.05*	*0.05*	*0.11*	*0.17*	*0.25*
GWP* adjusted NS warming contribution (in 2050) =		0.01	0.11	0.17	0.24	0.31
Paris Test threshold basis (NCQ*)	**PT Threshold**	**Scenario 2050 minus PT threshold**				
CCAC 2021 [CO2 only]	*0.23*	*-0.29*	*-0.19*	*-0.12*	*-0.06*	*0.02*
(A) GWP* parameter change	*0.23*	-0.22	-0.12	-0.06	0.01	0.08
(B) Align global and national ref. year	0.21	-0.20	-0.10	-0.04	0.03	0.10
(C) Adjust PT basis to [CO_2&N_2O&CH_4]	0.15	-0.14	-0.04	0.03	0.09	0.16
(D) Adjust for IE IAS scenario to 2050	0.07	-0.06	0.04	0.11	0.17	0.24
(E) Change to 2015 ref. yr from 2021	-0.04	0.05	0.15	0.21	0.27	0.35

(b) National $MtCO_2we$: Downscaled PT for NS		**E51-A51**	**E57-A40**	**E61-A33**	**E65-A25**	**E69-A19**
CBTR warming contribution (in 2050) =		*-80*	*70*	*160*	*250*	*360*
GWP* adjusted NS warming contribution (in 2050) =		20	160	250	330	440
Paris Test threshold basis (NCQ*)	**PT Threshold**	**Scenario 2050 minus PT threshold**				
CCAC 2021 [CO2 only]	330	-410	-260	-170	-80	30
(A) GWP* parameter change.	330	-310	-170	-80	10	120
(B) Align global and national ref. year.	300	-290	-150	-50	30	140
(C) Adjust PT basis to [CO_2&N_2O&CH_4]	210	-190	-50	40	120	230
(D) Adjust for IE IAS scenario to 2050.	90	-80	60	150	240	350
(E) Change to 2015 ref. yr from 2021.	-50	70	210	300	390	500

2.3.4 Recommendations

- **Adjustments A to C – GWP* parameter change, reference year alignment, and common [CO_2&N_2O&CH_4] assessment basis – are recommended to the CCAC as necessary quantitative corrections for the CCAC (2021) PT. Some form of IAS scenario is such as adjustment D is required to properly include international aviation and shipping in the PT.**
- For comparison it is recommended that a "minimally equitable" PT threshold for depletion of a national quota share of the 2015 remaining global GHG budget is also shown.
- **As noted in the previous section any future PT reassessment using a later date than the start of 2021, as used in CCAC (2021), would be inherently inequitable by grandfathering additional global temperature budget to wealthy nations.**

2.4 Historical responsibility for global warming by nation or region

2.4.1 Research Question

"What level of warming would the world have reached if the world had followed the per capita historical emissions path of a given region, country, or bloc?"

2.4.2 Methods

- The PRIMAP data set (Gütschow et al., 2019) is used to source 1850–2018 by-mass emission pathways (for CO_2, N_2O, and CH_4) on an aggregate and sectoral basis. GWP* analysis is then applied to evaluate historical responsibility for aggregate and by-sector warming to 2018. Upscaling by the fractional population share enables the question to be answered.

2.4.3 Results

- An Excel workbook was developed that enables comparison of any four regions, nations, or blocs input by the user. As per the example in Figure 4, charts then show aggregate warming and also by-sector warming for energy, industry, agriculture (livestock, mostly methane, is also shown as a sub-sector), and waste.

2.4.4 Recommendations

- **This assessment can inform the CCAC consideration of Ireland's relative historical responsibility in having regard to climate justice under the Climate Act and PA equitable implementation.**

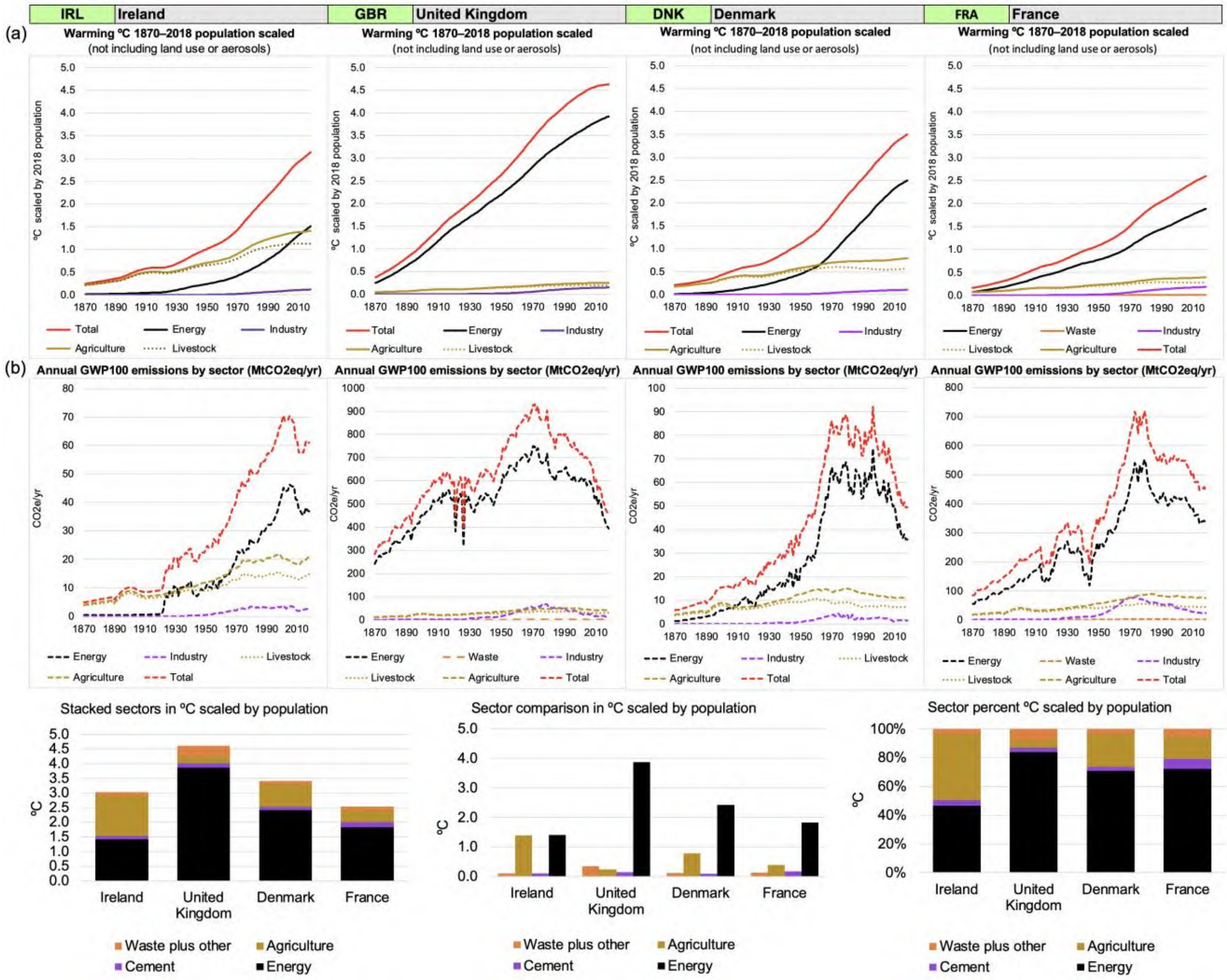

Figure 4. Historical responsibility: output from Excel comparison workbook

Comparing European nations (Ireland, UK, Denmark, France): (a) warming for 1870–2018 scaled by 2018 population, vertical scale 0–5ºC, using GWP analysis of PRIMAP data; (b) Annual GWP_{100} mass emissions in total and by sector for 1870–2018; (c) bar charts using data scaled by population – from left to right, stacked sectors, sector comparison, and sector percent share.*

2.5 Are the two five-year carbon budgets to 2030 likely to be met?

2.5.1 Research Question

Given the 2022 EPA emissions projections, are the first two five-year carbon budgets to 2025 and 2030 likely to be met?

2.5.2 Methods

Chart the aggregate CO_2e emission pathways for WEM and WAM shown by the most recent EPA Projections and compare with CB1 and CB2.

2.5.3 Results

- Analysis of the national emissions projections strongly indicates that neither of the first two carbon budgets will be met. Preliminary data indicates 2022 emissions are likely to be the same or higher than 2018 so emissions are not following the declining trajectory required.
- The line chart on the left in Figure 5 shows annual CO_2 equivalent emissions from 2018 to 2030. The green line is a two-part linear pathway that meets Carbon Budget 1 for 2021–2025 and Carbon Budget 2 for 2026–2030. Note this line hits a 2030 level that is -57% below the 2018 level. Even if the "Additional Measures" line is actually achieved up to 2025 then to meet the 10 year budget the 2030 target would be -84% below the 2018 level.
- Therefore, continued policy or analysis references to "51% by 2030" can be highly misleading.

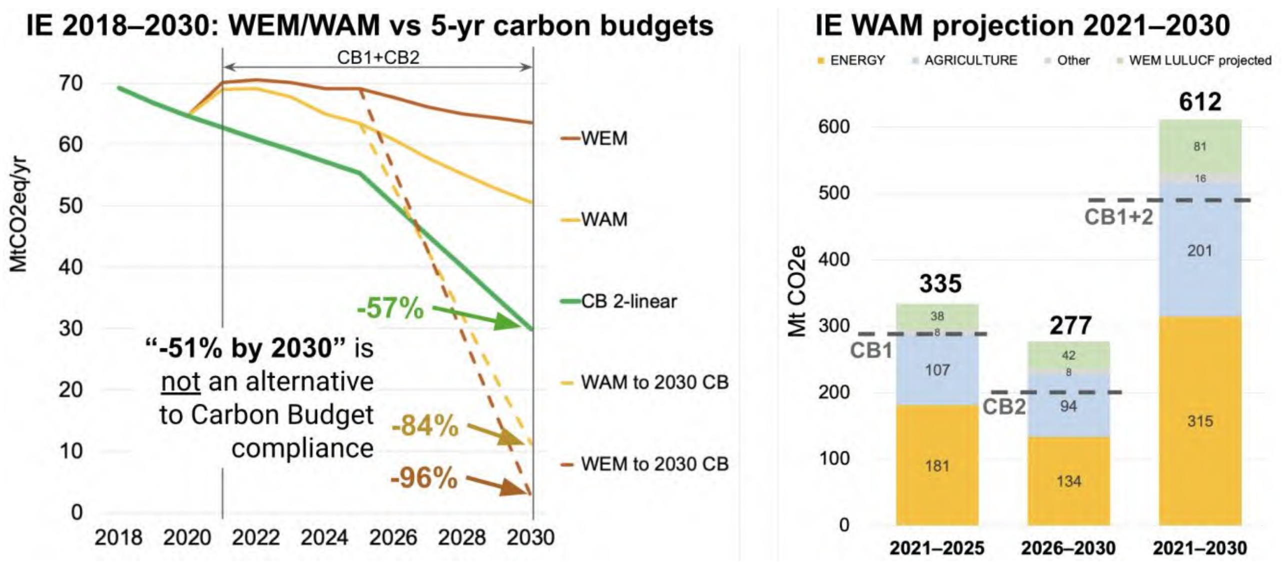

Figure 5. Comparing trajectories and totals for EPA projections and the carbon budgets. *Left, scenario pathways of annual CO_2 equivalent emissions from 2018 to 2030. Right, bar charts showing projections for Energy, Agriculture, Other, and LULUCF relative to CB1, CB2 and CB1+2.*

- The right hand bar charts in Figure 5 show the projections for Energy, Agriculture, and Land Use which sum to exceed the 5-year carbon budgets and exceed the 10 years combined budget by a substantial margin.
- In particular, land use emissions are higher than assumed in the 2021 CCAC indicative 51% cut by 2020 used in the core scenarios, in part due to an upward scientific revision of 2 $MtCO_2\ yr^{-1}$ in the timeseries of forest soil carbon emissions, but also the already-anticipated rise in timber harvest milling rate after 2020.

- Any chance of meeting Ireland's legally binding carbon budgets to 2030 now requires achievement of urgent course corrections through revised policies that can actively and urgently and directly limit emission driving inputs to Ireland's economy.

2.5.4 Recommendations

- Technical measures alone appear unlikely to limit emissions within CB1 and CB2, therefore policy measures to limit highly GHG intensive activities directly are likely necessary.
- **Therefore, an organised process to enable rapid-response national climate reporting, governance, research, and modelling, is needed to continually update, publicise, and revise the necessary trajectory to meet the set carbon budgets.**

3. Assessing alternative integrated emissions scenarios including methane and CDR

To assess alternative society-wide emissions scenarios relative to the Climate Act's national climate objective of achieving a "climate neutral economy" that is also 'consistent with' PA Article 2.

3.1 "Climate neutrality" in Paris-consistent scenarios for the world and for Ireland

3.1.1 Research Question

Including non-CO_2 and CDR, define the meaning of "climate neutrality" relative to the PA temperature goal and fair share climate action by Ireland?

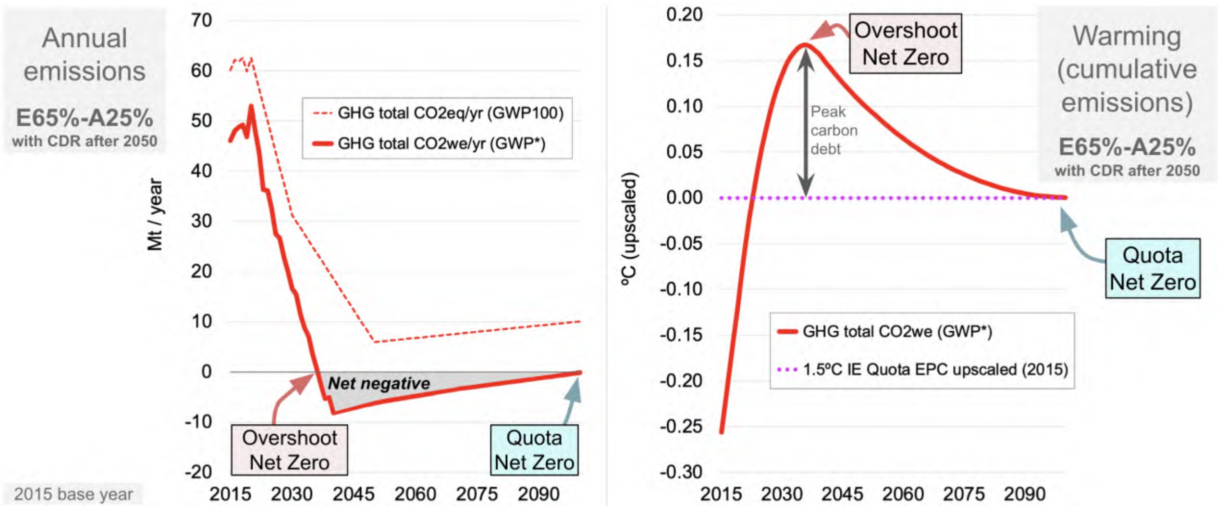

Figure 6. Climate neutrality aligned with the PA goal is only achieved at Quota Net Zero.
Peak scenario warming is reached at Overshoot Net Zero (at annual net zero CO_2we).

3.1.2 Methods

Outputs from the GHG-WE tool for a single scenario – the CCAC (2021) core scenario E65% –A25% is used to illustrate the meaning of climate neutrality relative to stabilisation at a global-equal-per-capita "fair share" quota level.

3.1.3 Results

- Figure 6 (left) shows annual GHG emissions in millions of tonnes, and (right) shows the resultant warming impact over time relative to the dotted magenta line indicating a global equal per capita share for Ireland of limiting warming to 1.5ºC.
- In the left-hand annual chart of aggregate GHG impact, the dashed red line plots CO_2 equivalent (using the GWP_{100} metric) and the solid red line plots CO_2 warming equivalent (using the GWP* metric).

3.1.4 Recommendations

- Note that GWP* use shows that the "net zero" ("no further warming") point is reached in about 2036 but this occurs in substantial overshoot of the 1.5ºC quota and at the peak carbon debt, so a period of net negative CO_2we emissions is then required to return to stabilise Ireland's temperature contribution at the 1.5ºC level.
- **A "net zero" target for Ireland is insufficient as it is not consistent with the Paris temperature goal.** (Net zero targets for a single sector or non-state-actors are not meaningful because the Paris Agreement only refers to implementation by Parties through their NDCs.)
- **Scientifically, on a temperature impact basis (CO_2we not CO_2e), it is best that expert advisory outputs are unambiguously clear that, globally and in Ireland, a fair share 1.5ºC target now requires targeting a net negative economy before 2050.**

3.2 Assessing trade-offs between CH_4 mitigation and CDR in 1.5ºC fair share overshoot-and-return scenarios

3.2.1 Research Question

In 1.5ºC fair share pathways, assess mitigation trade-offs for Ireland between gross [CO_2+N_2O] mitigation, and, for negative emissions, between methane mitigation and CDR, given previously assessed limited national CDR potential?

3.2.2 Methods

Using Ireland as a case study, we leverage the GWP* method to estimate temperature impact based on cumulative CO_2 warming equivalent (CO_2we) of [CO_2+N_2O+CH_4] from 2015 to assess: a "fair share" 1.5ºC national GHG quota to be met by illustrative policy-relevant multi-gas scenarios. This enables assessment of mitigation trade-offs between gross [CO_2+N_2O] mitigation; and, separately, the temperature impact reduction trade-offs between methane mitigation and limited national CDR potential.

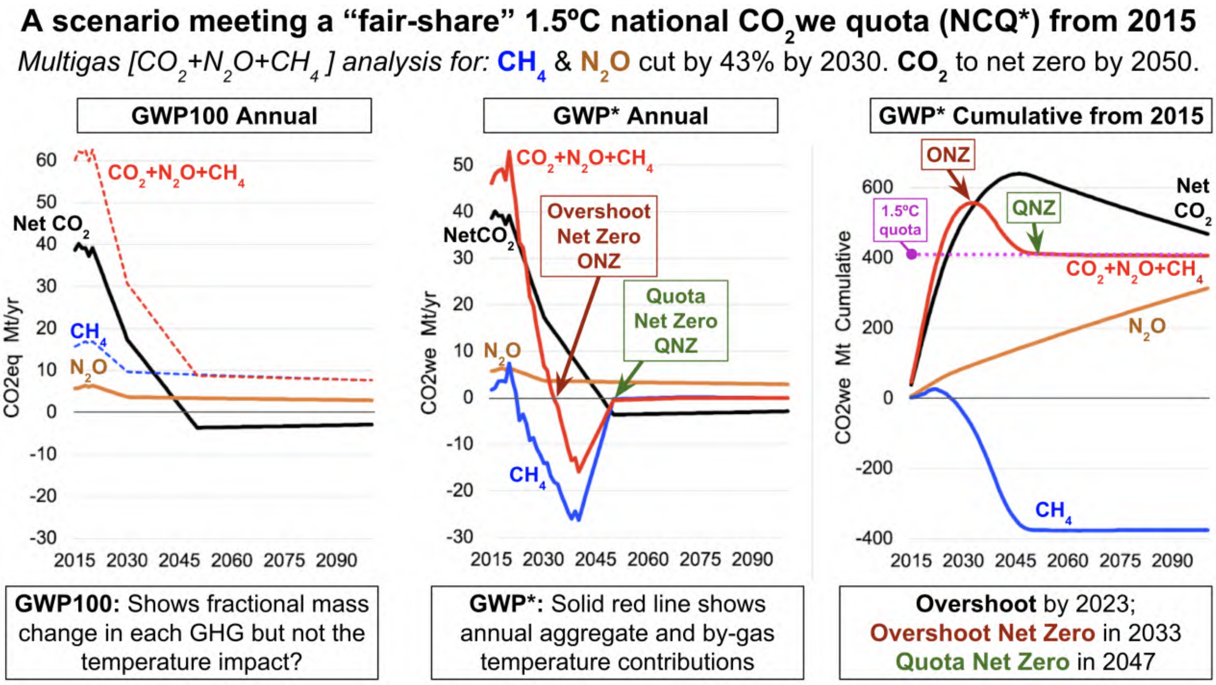

Figure 7. Output from the GHG-WE tool for one scenario:

Left, GWP_{100} annual; Centre: GWP annual; Right: GWP* cumulative, relative to a global equal-per-capita quota of a remaining $1.5ºC_{50\%}$ global budget as of the beginning of 2015.*

3.2.3 Results

- The Figure 7 charts for the core scenarios from the Council's first cycle of carbon budgeting assessment illustrate the warming impacts by gas and in aggregate using GWP* analysis.
- For non-CO_2 to 2030, the scenarios range from a -19% cut to a -51% cut in non-CO_2 (for CH_4 and for N_2O), CH_4 temperature impact zeroed from 2030, and net CO_2 and N_2O to zero by 2050. These radical reductions are seen in all scenarios but are not yet being achieved.
- As seen in the previous slide, all of the scenarios overshoot the given 1.5ºC equitable quota before 2025 and peak warming between 2030 and 2040 but with different levels of overshoot.

- Deeper methane mitigation limits overshoot carbon debt and, as the bar charts show, also limits the amount of CDR required in future, which may be important as in previous research we suggested a policy maximum for reliance on CDR storage.
- This analysis in Figure 8Figure 9 shows that in addition to very deep and sustained Energy and Land Use CO_2 mitigation, achieving deep, early, and sustained agricultural methane mitigation is now also important to Paris-consistent mitigation.

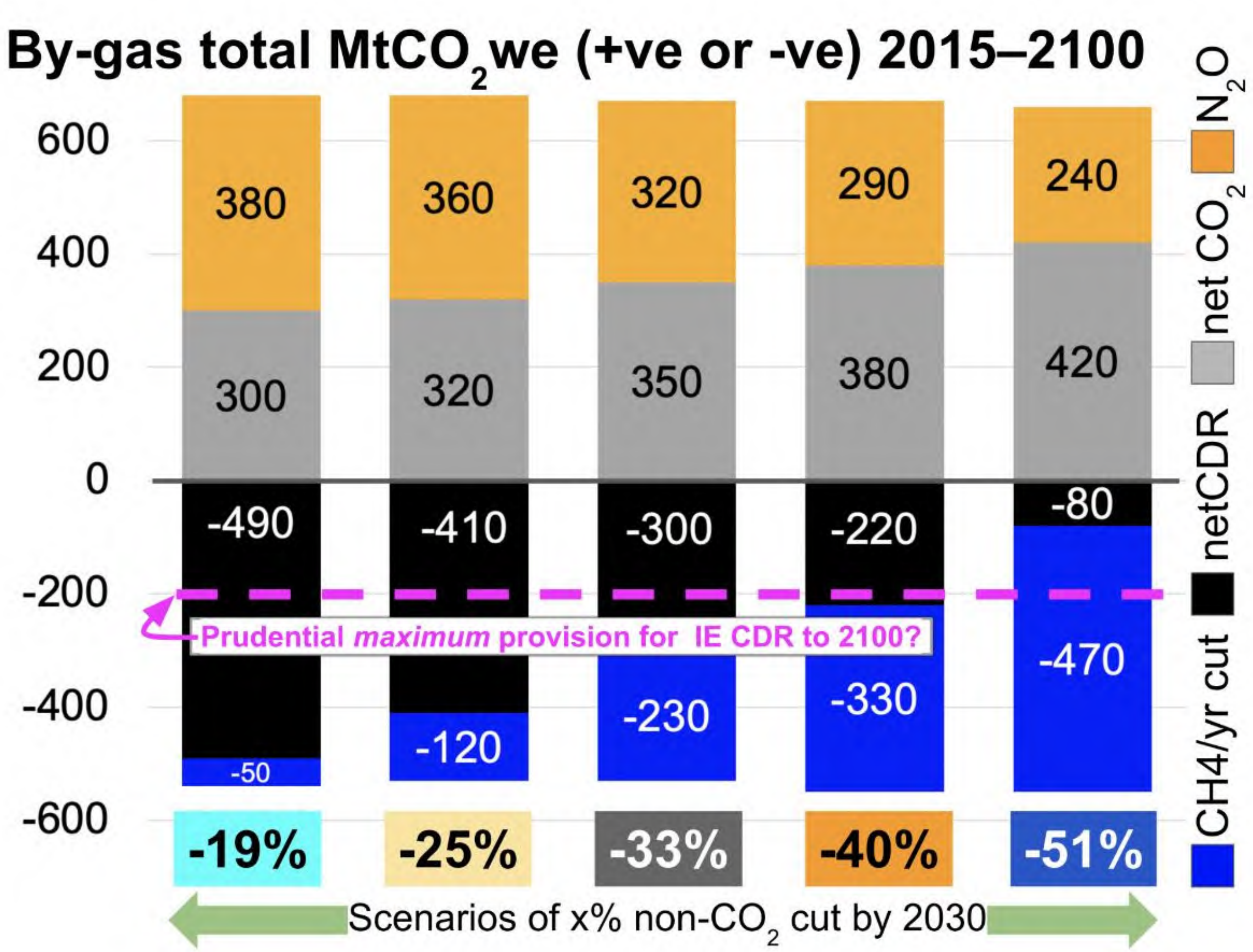

Figure 8. By-gas 2015–2100 cumulative MtCO₂we for the five CCAC2021 core scenarios.
The dashed magenta line shows the maximum Irish territorial CDR dependence as suggested as a prudential policy limit by McMullin et al. (2020).

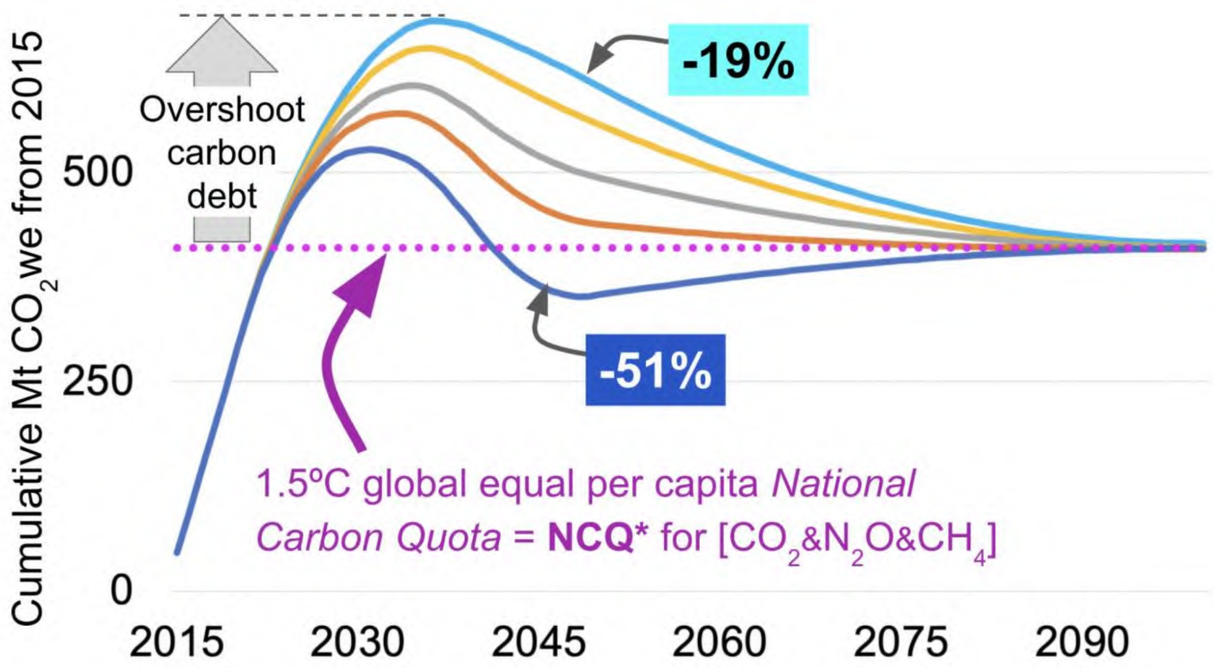

Figure 9. Temperature impact trajectories for the five CCAC2021 core scenarios 2015–2100

Trajectories assume fair-share quota depletion from the beginning of 2015 and sufficient CDR after 2050 to return to Quota Net Zero at the "fair share" NCQ level by 2100 at latest. From 2100 onward CDR is assumed to balance [netCO_2+N_2O] on a CO_2e basis.*

- The case of Ireland's depletion of an Equal Per Capita quota from 2015 illustrates the imminent quota overshoot faced by many wealthy, so-called developed nations. The immediate policy aim must be to limit the peak carbon debt level reached by the Overshoot Net Zero point (sometimes described as "no further warming contribution"), and to achieve an early return to Quota Net Zero, which is the Paris-consistent objective.
- Ireland has high methane emissions therefore it has a large methane mitigation opportunity toward meeting a Paris-consistent 2050 target that can be effective provided serious substantial annual methane reduction begins immediately. Other nations and globally may have a proportionately lesser methane mitigation lever, but, globally, methane mitigation is likewise important in limiting the CDR requirement.

3.2.4 Recommendations

- **National 1.5ºC overshoot-and-return scenarios should be assessed, as shown here, on a temperature target and trajectory basis to evaluate mitigation of national emissions and the resulting requirement for negative emissions (temperature reduction) requirement to limit overshoot and return to a Paris-consistent "fair share" quota level for Ireland.**

- The use of *cumulative* CO_2*we* (via GWP*) analysis allows rapid and informative, Paris-aligned temperature analysis of alternative national scenarios. (Note, it is essential that any GWP* analysis clearly states its reference year, normative and quantitative parameter assumptions.)
- For a Paris-aligned temperature goal, GWP* can be used to assess a multigas remaining cumulative carbon budget from a given base year, and, within clearly specified normative parameters, GWP* can assess the multigas aggregate temperature impact of proposed policy pathways. GWP_{100} will continue to be used in global and national GHG assessment but GWP* assessment can usefully compare the temperature impact of all proposed multigas pathways.
- As well as GWP* analysis, the use of simple climate models is recommended to enable rapid assessment of comparative scenario temperature outcomes meeting the *quota net zero* target.
- In addition to the primary society-wide mitigation focus on CO_2 mitigation, the certainty of substantial negative CO_2we from early, deep methane mitigation has crucial mitigation value to enable meeting a 1.5ºC quota while also limiting national reliance on uncertain future CDR.
- **Advisory and government bodies need to recognise the rapidly escalating difficulty of achieving equitable Paris-consistent climate action. This means that the reference in many research articles to some sectors as "hard to abate" is becoming ever less scientifically defensible.** Sectors such as aviation or intensive meat and dairy production that have a substantial contribution to increasing or sustaining climate forcing likely have to be abated, otherwise good-faith commitment to Paris-consistent action becomes impossible.

4. Agriculture, forestry, and land use (AFOLU) scenarios within Paris-consistent pathways

This research looked at different aspects of how agriculture, forestry, and land use (AFOLU) pathways affect carbon budgeting, land use and nitrogen fluxes. Supplementary research furthers some of these aspects, including agricultural production-types and their emissions; Ireland's national and land nitrogen budgets; the warming outcomes of anaerobic digestion plant fugitive methane losses; and rewetting of organic soils.

4.1 Alternative AFOLU emissions pathways and national carbon budgeting

The imminence of PA LTTG overshoot, globally and on a national fair share basis for Ireland, means that AFOLU planning is increasingly important to Paris-consistent carbon budgeting. Mengis and Matthews (2020) find that to meet the 1.5ºC goal there is already an impossibly small remaining global fossil fuel carbon budget *unless* non-CO_2 emissions from agriculture, especially methane, and CO_2 emissions from land use, are *also* successfully and urgently mitigated.

4.1.1 Research Question

How could a coarse-grained, long-term national land use planning model for AFOLU enable the sector's inclusion in society-wide Paris-consistent pathways that maintain or increase food, feed and fibre production?

4.1.2 Methods

A spreadsheet-based linear model of land use in Ireland was developed to explore the utility of a simple pilot for assessing land use planning at a benchmark period (2008–2015) and changes in land use suitable for agriculture or forestry from that benchmark through chosen percentage change trajectories over time. The measures of change chosen are land area, nitrogen use, and GHG emissions and removals, and include taking land areas such as peat extraction out of production. Land use and farm-gate nitrogen mean data is based on the AgriBenchmark EPA report (Murphy et al., 2019), which uses the 2008–2015 range. Nitrogen input and output (in proteins) is used as a proxy for food production, given that Ireland has focused on (animal) protein exports. EPA inventory data is used for GHG emissions. As outlined in this sub-section, the draft model was developed first to assess its possible design and relevance to including AFOLU in carbon budgeting; the method and results for a land-nitrogen-emissions (LNE) benchmark assessment of agricultural production-types is set out in the next sub-section 4.2.

4.1.3 Results

- The model takes user inputs to identify a 2050 target scenario and a mitigation trajectory of percentage change toward the scenario from the benchmark period. The preliminary outputs shown in Figure 10 illustrate the kind of outputs that a fully developed national LNE AFOLU model could produce to assist the CCAC and decision-makers in meeting Paris-consistent carbon budgeting.

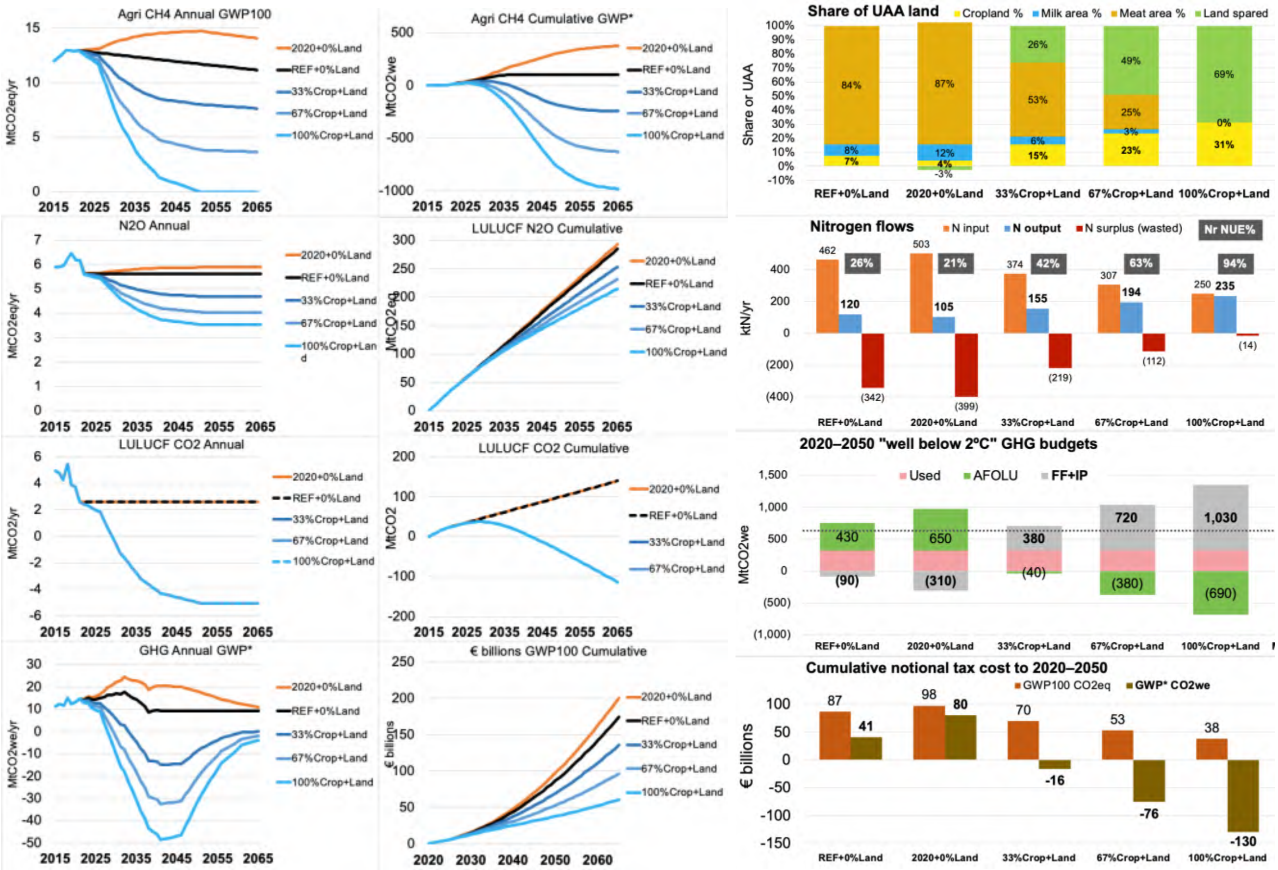

Figure 10. Illustrative outputs from a preliminary AFOLU LNE model.

The figure's 2050 scenarios are based on percentage of maximum available tillage land used for cash crop production. Scenarios follow a user-defined trajectory over time to the target 2050 scenario. Outputs shown include: (left) trajectories for annual emissions and resultant warming (cumulative CO_2we using GWP) and comparative GHG cost based on projected carbon tax rates; (right) bar charts indicate the share of national agricultural land used by activity, nitrogen flows and system NUE, scenario cumulative CO_2we vs. "fair share" Paris goal, and notional carbon tax costs.*

- This indicative modelling shows Ireland's AFOLU policy is now critical to meeting stringent carbon budgets aligned with the Paris goal. Therefore, as in the illustrative comparison in Figure 11, strong land use policy in this decade can substantially ease a Paris-consistent society-wide low carbon transition. If AFOLU policy in this decade continues to be weak then methane emissions will not be cut deeply and the forest sink will continue to decrease, adding to future warming (positive net cumulative CO_2we) as shown by a positive value for land use in the upper bar in Figure 11. However, if AFOLU policy in this decade is strengthened to meet climate action then methane emissions will be cut deeply (which can be done while enabling greater crop food production) and timber and peat extraction will be limited to preserve and increase the land carbon reservoir. Such strong AFOLU policy results in a substantial warming reduction, shown in Figure 11 as a net negative AFOLU Land value.

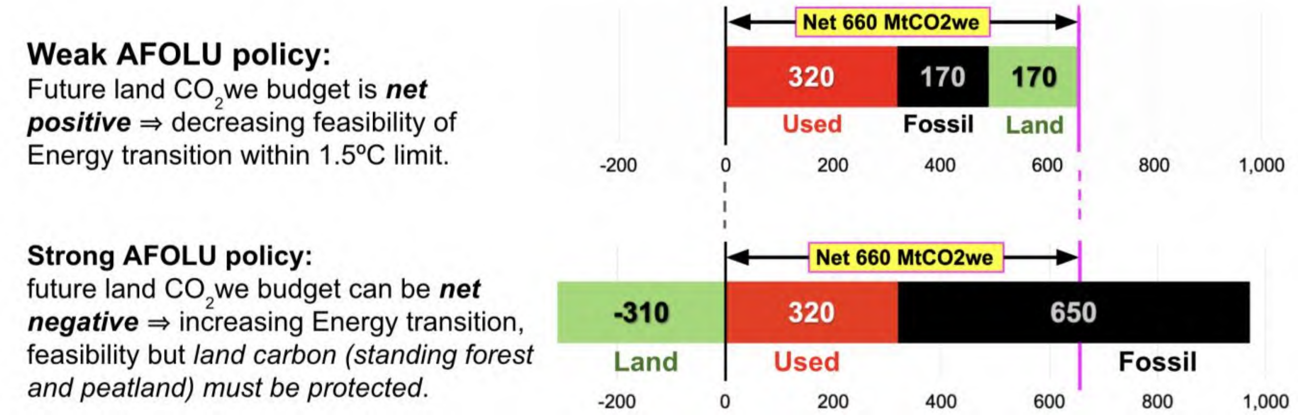

Figure 11. Comparing weak and strong AFOLU policy within the same carbon budget limit. *Used (2015–2020 inclusive) and scenario Land and Fossil values in MtCO2we. The examples are outputs from two different land uses scenarios LNE AFOLU model developed for this study. The major difference is that in the strong policy case tillage and forestry land areas are increased (within limits of soil quality) and dairy and livestock pasture area is reduced.*

4.1.4 Recommendations

- The results of this study confirm proof-of-principle meaning that further development of such a coarse-grained, LNE-based AFOLU model would complement existing modelling by enabling exploration of land use change options that could increase system NUE and protein output, while enabling sufficient negative CO_2we emissions to limit national PA LTTG quota overshoot and enable an early return to *quota net zero* (see sub-section 3.1).
- **Further development of LNE AFOLU modelling is recommended to assist the CCAC and governance in land use planning and decision-making aligned with Paris-consistent carbon budgeting.**

4.2 Land, Nitrogen and Emissions (LNE) analysis of agricultural production-types

National assessments of alternative pathways equitably meeting the Paris Agreement (PA) and Sustainable Development goals (SDGs) require advisory research that clearly identifies the critical relationships between land use, agricultural production, and pollution outcomes. Existing analysis and modelling typically focuses on the economic productivity and emissions intensity of existing farm-types, which can each include a mix of dairy, crops, and livestock production-types. However, it is the land area, reactive nitrogen (N_r) input, and pollution losses, of these *production-types* that are more directly relevant than the *farm-types* to assess agricultural protein output, emissions, and environmental impacts for national land use planning. NUE is a key measure, but care must be taken in comparing values from different NUE methodologies (due to differing fluxes included and/or different system boundaries); nonetheless changes in an NUE results for a system over time are indicative of changes in system productivity and environmental pollution (Hutchings et al., 2020).

4.2.1 Research question

Given farm-type data what are the annual per hectare nitrogen intensities (import, export, and surplus) and related production areas, described here as the effective platform (EP) for each of the three main production-types – Milk, Cash crops, and Livestock – for agricultural land in Ireland?

4.2.2 Methods

The AgriBenchmark EPA report (Murphy et al., 2019) uses a farm-gate boundary to evaluate mean annual nitrogen per hectare flux values and national representative areas for Ireland's farm-type data on basis for a benchmark period of 2008–2015. Reanalysis of this data through simultaneous equation solution enables the *same* benchmark period data to show the mean annual nitrogen per hectare flux values and related national areas – termed Effective Platform (EP) areas in this study – for Ireland's principal land use production-types, *Milk, Cash crops,* and *Livestock*. (Cash crops include only crop production that is exported from farms, so farm-grown crops consumed as feeds on-farm are excluded.) These production-type values, and changes in them over time, can then be used in a simple or more developed land use model of the kind described in the previous subsection 4.1.

4.2.3 Results

- As the bar charts in Figure 12Figure 13 show, *Milk* and *Livestock* production have very high emissions relative to their farm-gate output, whereas *Cash Crop* production has far lower emissions and is far more nitrogen efficient. National system outcomes have worsened over the past decade, since the benchmark period, due to decreased tillage area and increased imports of fertilisers and feed, for increased milk and maintained meat production.

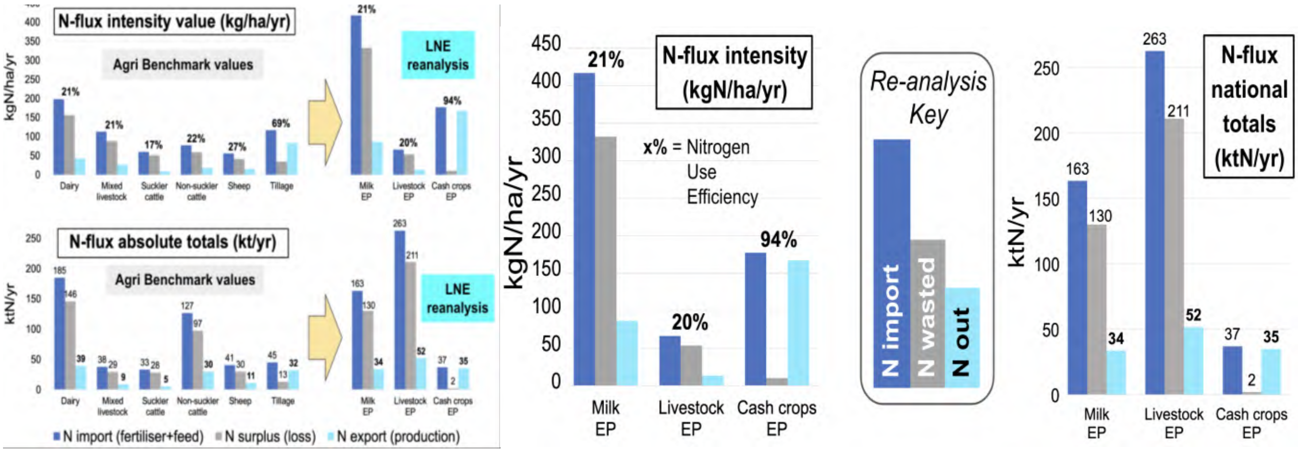

Figure 12. AgriBenchmark and LNE reanalysis for N ha^{-1} intensity and N-flux kt yr^{-1} totals. *Left, indicating that LNE reanalysis is directly derived from the AgriBenchmark report farm-type data for mean 2008–2015 N intensities and areas. Right, LNE reanalysis benchmark period production-type (Land, Cash-crops, and Livestock) values for N-flux N ha^{-1} intensity (with NUE percent values) and national totals in ktN yr^{-1}.*

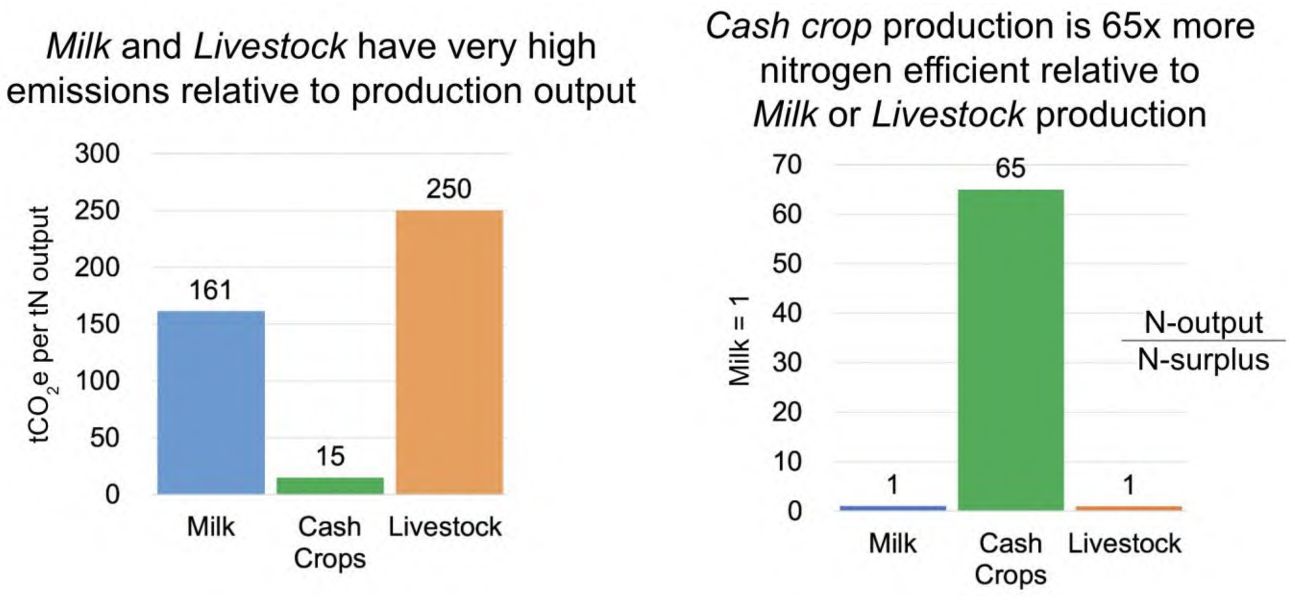

Figure 13. Relative GHG efficiency and N efficiency of different production-types 2008-2015.

4.2.4 Recommendations

- **As seen in this LNE benchmark reanalysis, sustainable land use planning would do well to start from a recognition that Ireland's agri-food system is highly dependent on grass-based ruminant agriculture, which is an inherently inefficient food production system in terms of land, nitrogen, and emissions.**

- Sustainable land use policy would reduce this dependence by directing land use away from pasture, on good soils toward tillage production, and on less suitable soil to permanent forestry, to substantially increase the land carbon reservoir. However, this recognition would first require an acknowledgment that agricultural strategies and policies over the past decade have adopted the opposite approach.
- Global food system analysis in the context of the meeting the PA LTTG indicates that an increased adoption of plant-based diets is likely required globally, so sustainable agri-food system development implies far greater emphasis on crop production for food rather than feed, increased local nitrogen cycling, and greatly reduced chemical fertiliser inputs (Rockström et al., 2020; Billen et al., 2021a). Therefore, planning for sustainable agriculture for Paris-consistent food production and consumption might best plan accordingly.

4.3 Knowledge Gaps report for Ireland's AFOLU in Ireland and carbon budgeting

In research for this AFOLU Work Package, it became apparent that there are analyses of Ireland's agri-food system analyses relevant to AFOLU and carbon budgeting that are not commonly presented. This subsection summarises these findings, which are more fully detailed in a Knowledge Gaps report.

4.3.1 Concept mapping Ireland's agri-food system analyses relevant to AFOLU and carbon budgeting

4.3.1.1 Research Question

In Ireland's agricultural production system, what are the nodes and relations for nitrogen flux (inputs, internal flows, outputs, and losses) and GHG emissions?

4.3.1.2 Methods

A simplified concept map of nodes and flows is developed to identify the external and internal system drivers of production and pollution.

4.3.1.3 Results

- Figure 14 provides an indicative schematic of reactive nitrogen (Nr) flows into, within, and from Ireland agricultural production system. The current system is focused on dairy and livestock production, primarily based on grass pasture and silage, which is heavily reliant on chemical N fertiliser inputs to sustain high levels of rye-grass production to maintain animal protein and manure output. The LNE analysis in subsection 4.2 indicates that benchmark period system nitrogen losses (NH_3, N_2O, nitrates etc.) are equivalent to about 74% of national system nitrogen input. As the schematic suggests, Ireland's increasing output of animal sourced food (milk and meat products) has the result of increasing chemical and feed N input requirement and resultant climate, air, and water pollution, including CH_4.

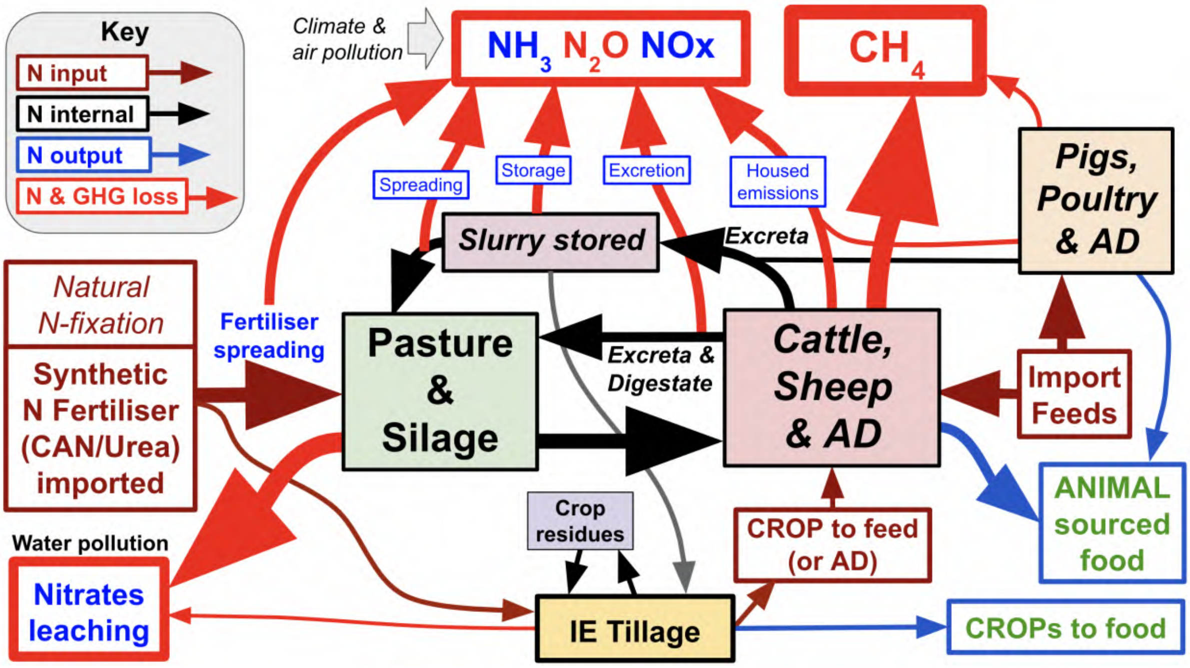

Figure 14. Schematic Ireland's agri-food system showing nitrogen flows and GHGs.
Arrows show internal N flows and pollution losses and give an indication of their relative size.

4.3.1.4 Recommendations

- **Advisory recommendations should acknowledge a key point illustrated by Figure 14 in that AD does <u>not</u> add new Nr to the system so, contrary to what is implied in many policy advisory documents, *ceteris paribus,* AD digestate production is unlikely to displace synthetic N fertiliser to any substantive degree. Any AD production should be planned within a national system achieving substantial reduction in total national chemical N input.**

4.3.2 Comparison of Ireland's national and land surface nitrogen balances

4.3.2.1 Research Question

How do different system boundary assessments of Ireland's nitrogen balance compare?

4.3.2.2 Methods

Using the available data, charts are made for two alternative views of nitrogen balance for Ireland. Nation level nitrogen balance, showing production+imports vs. consumption+exports, is produced from collated 1961–2013 FAO data (Billen et al., 2021b). The land surface nitrogen balance is produced from EPA Ireland data (personal communication).

4.3.2.3 Results

- Compared to other nations Ireland's agri-food system is highly dependent on inherently nitrogen and GHG inefficient grass-based ruminant agriculture. As Figure 15 illustrates, large amounts of chemical fertiliser are required annually to maintain the grass production (and manure production) required to produce pasture and silage for fodder as ruminant consumption. Total N losses are equivalent to a substantial fraction of new chemical N fertiliser inputs.
- Total ruminant N consumption in Ireland is of the order of 20 times greater than human N consumption (vegetal and animal combined). Exported (mostly dairy and meat protein) food N is substantially less than imported (mostly vegetal protein) N.

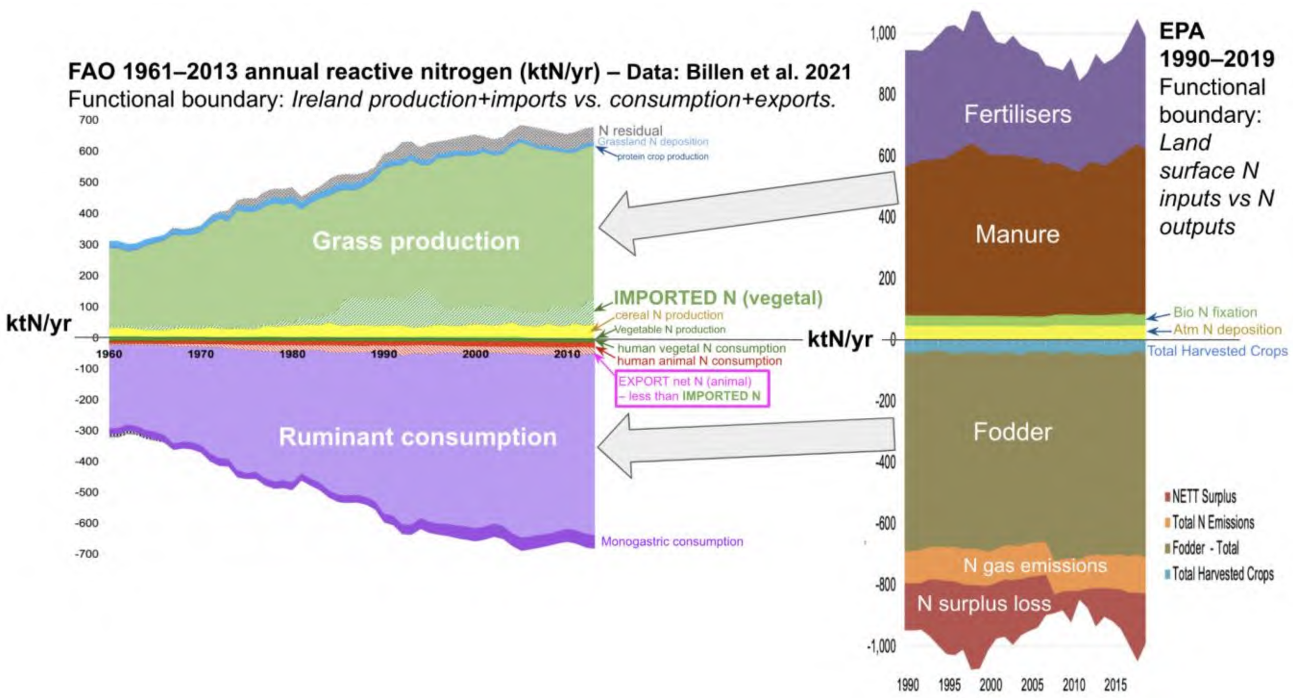

Figure 15. Comparing Ireland's national (left) and soil surface (right) nitrogen balances.
FAO Nr inputs/consumption data and EPA inputs/production. Own charts from: FAO 1961–2013 data (as collated in "XLSfile" in Billen et al. 2021) and EPA 1990–2019 data. For ease of comparison, vertical and horizontal scales have been matched.

4.3.2.4 Recommendations

- **As the nitrogen balance comparison illustrates, to increase system NUE in Ireland, toward increasing net N and land use agricultural efficiency, primarily requires a reduction in grass-based ruminant-derived food production and a reversal of the decline in tillage land area.**

4.3.3 Ireland's agri-food system N efficiency relative to other European nations

4.3.3.1 Research Question

How does Ireland's agri-food system N efficiency compare to other European nations given available data?

4.3.3.2 Methods

Based on collated 1961–2013 FAO data (Billen et al., 2021b), total N import and total N export data are calculated, and agri-food system NUE is given by imports divided by exports.

4.3.3.3 Results

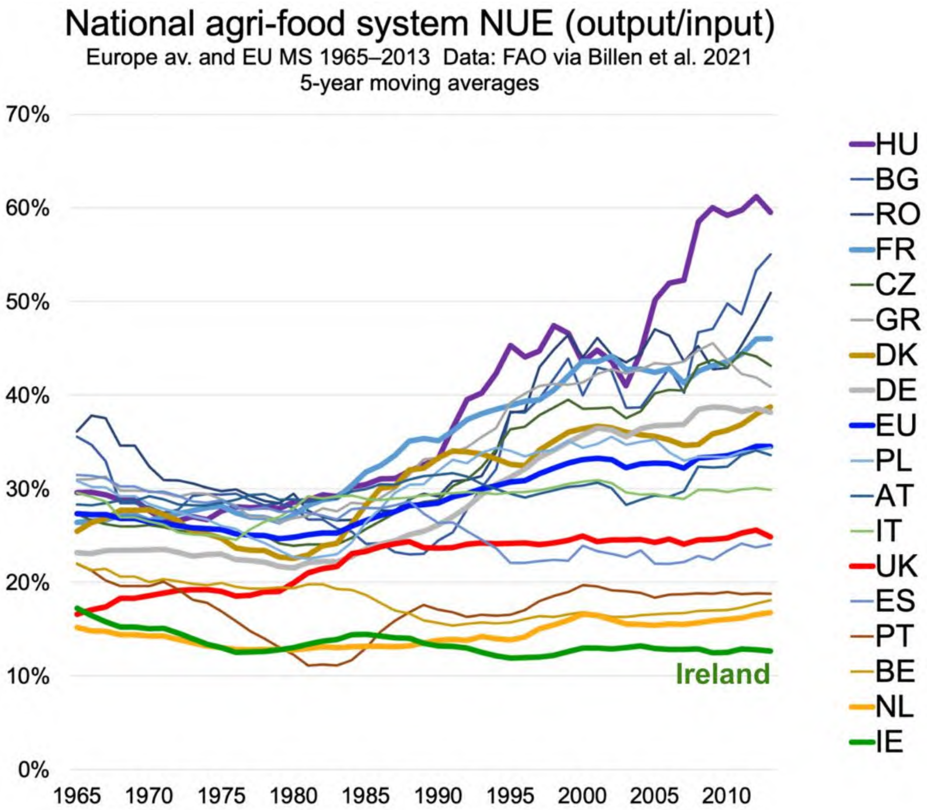

Figure 16. NUE analysis using UN FAO data for 1961–2013 (collated by Billen et al., 2021b).

- Figure 16 shows an analysis of total agri-food system net nitrogen use efficiency (NUE) in European countries – defined as N-exported divided by N-imported– indicates that Ireland's agri-food system is the least nitrogen efficient in Europe. Most other European countries have increased their nitrogen efficiency over time, but Ireland has not.
- Ireland's poor NUE relative to other nations is due to a relative imbalance in the production-types and nitrogen cycling of its agri-food system that has prioritised animal production and reduced tillage/horticulture production. The FAO data shown only extends to 2013 but the LNE analysis in subsection 4.2, which is echoed by river catchments data (EPA, 2021) indicates that the system NUE has fallen further still since 2013.

4.3.3.4 Recommendations

- **Ireland's poor NUE relative to other nations is due to an agri-food production system that is (increasingly) imbalanced between animal production and tillage/horticulture, and, in parallel, increasing reduction of local nitrogen cycling. Therefore NUE analysis of future system scenarios would provide an improved basis of agri-food system assessment and national land use planning**.

4.3.4 Comparing agriculture GHG emissions and warming in Ireland and Denmark.

4.3.4.1 Research Question

Given their similar level of current national animal protein export but differing agri-food systems, how do the agriculture GHG emissions and warming profiles of Ireland and Denmark compare?

4.3.4.2 Methods

Using the PRIMAP data set for 1850–2018 (Gütschow et al., 2019), cumulative emissions are plotted from 1850 onward, using both GWP_{100} (for CO_2e) and GWP* (for CO_2we).

4.3.4.3 Results

- Cumulatively, as shown in Figure 17, Denmark has only slightly greater total N_2O CO_2e emissions to date than Ireland. However, Ireland has greater CH_4 CO_2e and, most notably, much greater CH_4 CO_2we, with a particular difference from 1970 onward.
- Examination of agricultural N-flux and production data in collated 1961–2013 FAO data (Billen et al., 2021b) indicates that Denmark moved away from grass-based pasture and silage ruminant production to increase tillage cereal production to feed housed animal systems, with an

increasing fraction of animal protein from monogastric (pig and poultry) production. Denmark's CH_4 CO_2we plot shows a substantial reduction in agricultural temperature impact from 1970 to 2005. By contrast, Ireland has continued to focus on less N efficient grass-based ruminant production.

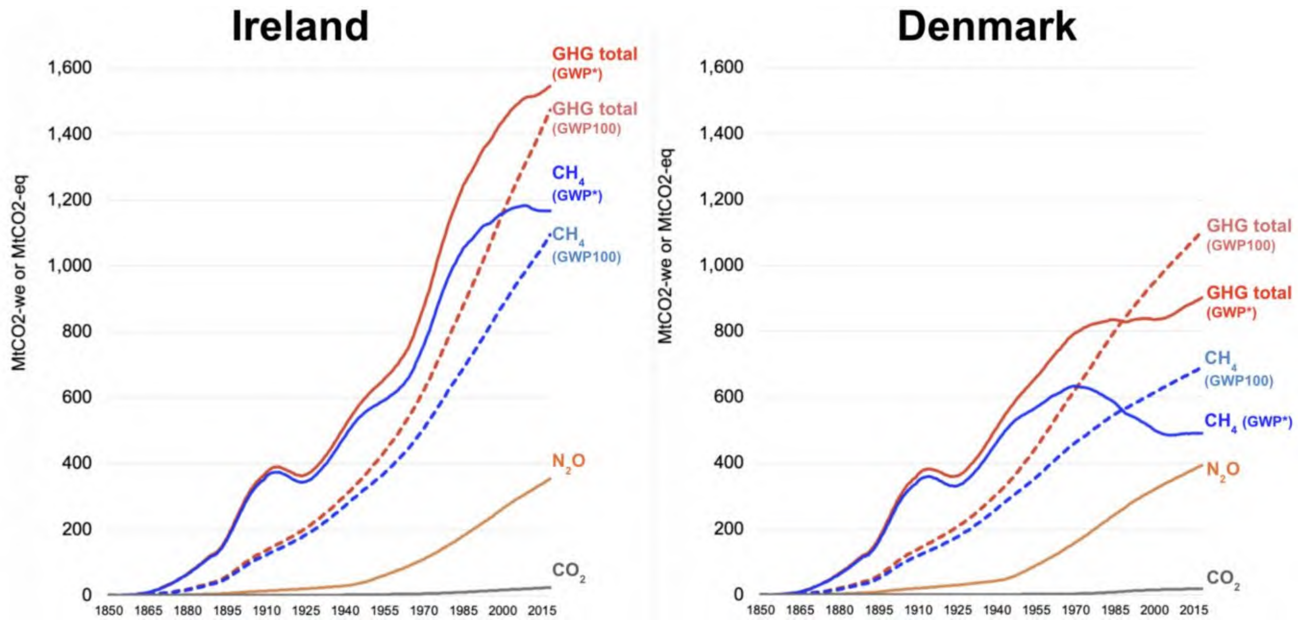

Figure 17. Cumulative GHG emissions for agriculture in Ireland and Denmark 1850–2018

PRIMAP data. Ireland and Denmark currently have similar annual animal protein outputs.

4.3.4.4 Recommendations

Recognition of Ireland inherently N and GHG inefficient focus on intensifying grass-based ruminant production would better inform agri-food system change toward sustainability. Housed animal systems with home-produced grain and protein (replacing grass feeding) would reduce animal farming emissions and nitrogen losses to water, but other pollution and welfare concerns arise.

4.3.5 Change in total beef and dairy production relative to N-excreted and CH_4.

4.3.5.1 Research Question

Given substantial changes production output and methods, what does EPA N-excreted and CH_4 data indicate for beef and dairy totals and intensities?

4.3.5.2 Methods

EPA data are used in emissions calculation and carbon budgeting, therefore the EPA data for agriculture are the most relevant source for agricultural data. Using the beef and dairy data in the supporting workbooks for Agriculture produced for the EPA inventory (EPA, 2022a, 2022b), totals for production, N-excreted and CH_4, and derived efficiency measures were collated. Tables of change relative to 2010 (index = 1.0) were calculated and the result plotted as in Figure 18.

4.3.5.3 Results

- Contrary to industry and advisory claims, the EPA data does not indicate any substantial change in national-level beef or dairy efficiency since 2005. The beef data has a noisier sawtooth pattern but the CH_4 $head^{-1}$ yr^{-1} data and the average of other data indicates a stabilisation in CH_4 and N-excreted annual per head and related national total data from 2005 through 2021.
- Dairy data shows a constant total national milk production under the milk quota until 2011. Previously, total N excreted and CH_4 emissions substantially reduced up to 2005, then levelled out until 2011, but have risen quickly since 2011, strongly coupled with total milk output.
- In the EPA data, beef and dairy efficiency measured by totals of N-excreted or CH_4 relative to production appear to be largely unchanged since 2005, therefore, as has been seen in increased milk production, any change in production within the current system will have a corresponding change in the largely coupled N-excreted production.

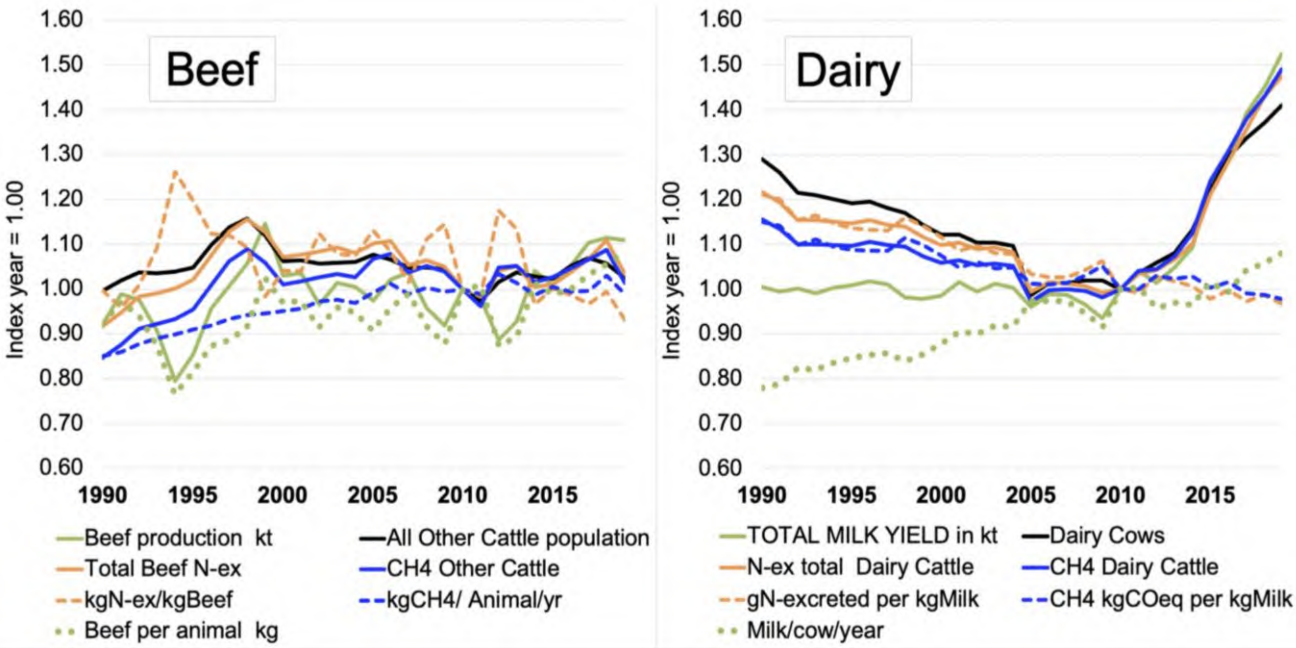

Figure 18. Ireland 1990–2019: beef and dairy production, N-excreted, CH_4, relative to 2010.

Changes in annual production, N-excreted and CH_4 national beef (left) and dairy (right) parameters relative to 2010 (index = 1.0) showing solid lines for animal population (black), production (green), CH_4 (blue) and N-excreted (orange), based on EPA inventory data relative to 2010, for which the index value is 1.00. Own intensity calculations are shown for changes in yield per animal (green dotted), CH_4 kg^{-1} (blue dashes) and N-excreted kg^{-1} (orange dashes).

4.3.5.4 Recommendations

- **Agriculture projections that bear on carbon budgeting and agricultural pollution outcomes should acknowledge that N-excreted and CH_4 emissions are largely coupled to milk and meat production. Therefore, unless substantial system change occurs away from grass-based ruminant production, the currently projected, policy-supported increases in dairy production to 2027 will result in increased CH_4 emissions.**
- **Assessments should also recognise that the projected beef and dairy animal numbers to 2027 are not in line with the agriculture scenarios submitted for CCAC consideration (Figure 3-1 in CCAC, 2021).**

4.3.6 Assessing Ireland's historic and scenario methane warming due to livestock

Over 93% of Ireland's methane emissions are from livestock. Total livestock methane in 2020 was 557 $ktCH_4\ yr^{-1}$, 493 $ktCH_4\ yr^{-1}$ from enteric fermentation in ruminant digestion and 64 $ktCH_4\ yr^{-1}$ from animal manure management. Dairy cows emitted 202 $ktCH_4\ yr^{-1}$ (increasing at an average of +7 $ktCH_4\ yr^{-1}$ since 2010) ; 302 $ktCH_4\ yr^{-1}$; other cattle (mostly beef); and sheep 30 $ktCH_4\ yr^{-1}$.

4.3.6.1 Research Question

What amount of warming is due to livestock methane emissions in Ireland over time and how do alternative mitigation scenarios to 2050 compare in warming outcome?

4.3.6.2 Methods

GWP* analysis is used to produce cumulative CO_2we as a proxy for warming for PRIMAP data (Gütschow et al., 2021) for historic livestock methane and scenarios of percentage reduction from 2021, and, for comparison, a scenario as if methane mitigation had continued after 2010.

4.3.6.3 Results

- In both Figure 19 and Figure 20, historic and scenario annual livestock methane emissions by mass for Ireland are presented in the upper chart and the lower chart shows the resultant forcing equivalent warming represented by cumulative CO_2we using GWP*.

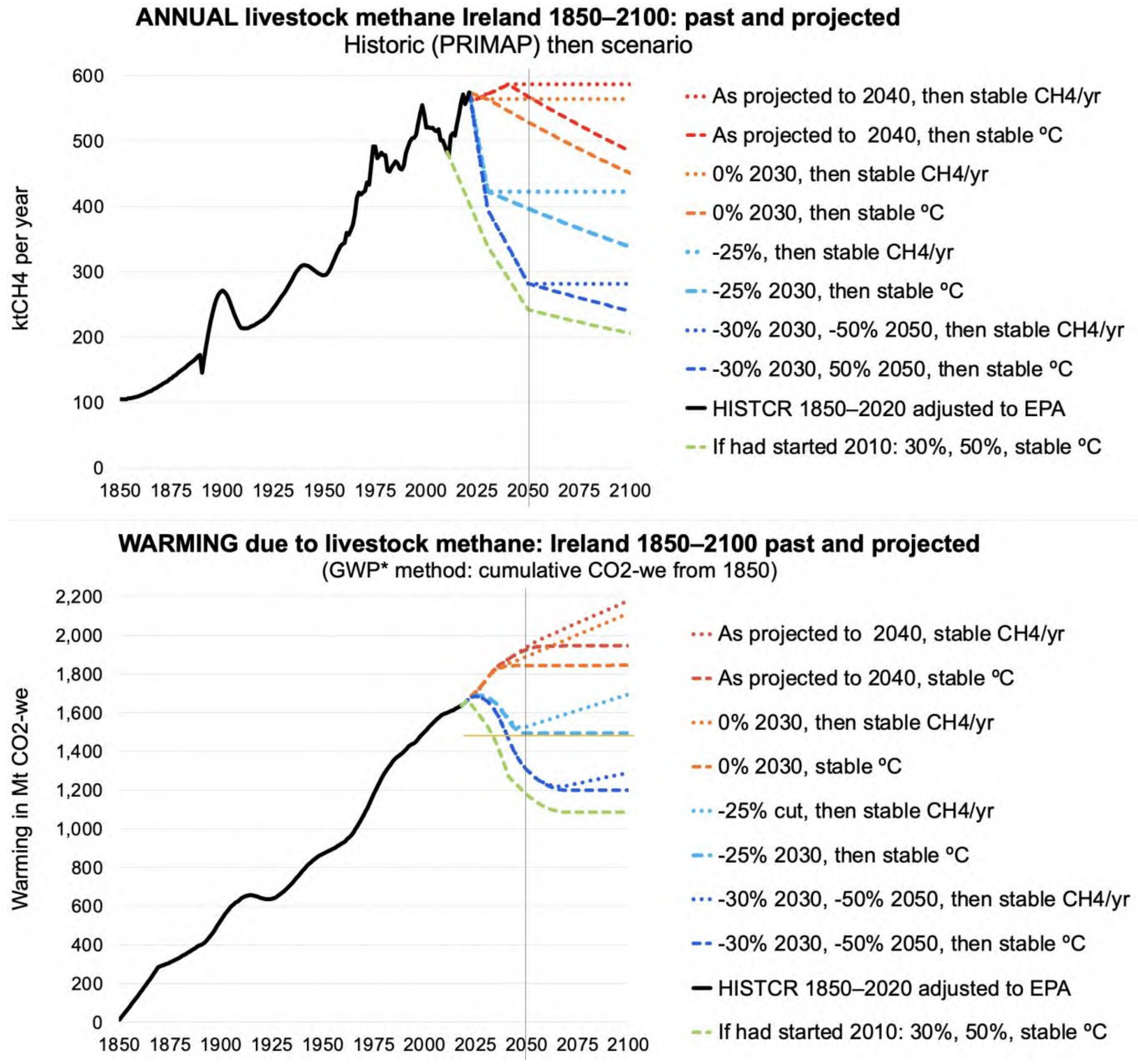

Figure 19. Historic & scenario annual livestock methane and resultant warming 1850–2100.

- Figure 19 presents: the full historic livestock methane emissions data for Ireland 1850–2018 from the PRIMAP data set, extended to 2020 using EPA recorded emissions; and then alternative scenarios from 2021 onward, and in addition a "time machine" scenario, presented *as if* livestock methane mitigation had continued the trend of reducing annual emissions seen from 1998–2010. Only after World War I does the warming trend decrease, otherwise the methane warming sustained by Ireland's livestock increases continuously to a 2010 level that is maintain warming equivalent to a one-off release of 1,600 $MtCO_2we$.

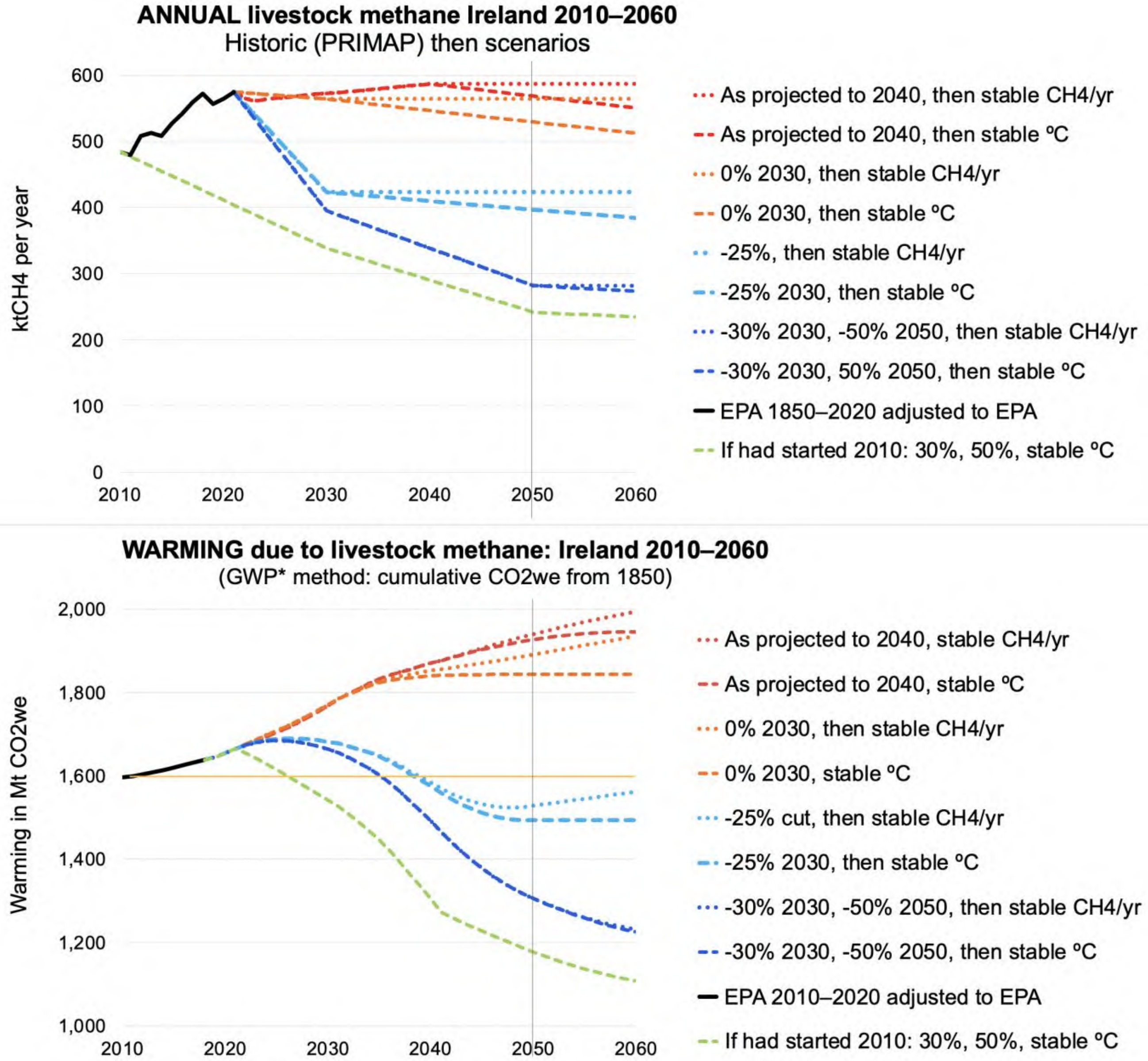

Figure 20. Historic & scenario annual livestock methane and resultant warming 2010–2060

- Figure 20, presents the same scenarios as in Figure 19 but shows the resultant warming in terms of cumulative CO2we. Most of the scenarios indicate the percent cut in annual methane emissions relative to 2020 by 2030, and by 2050 if mitigation continues, and after this initial cut they show two alternative options, stable emissions, or temperature stabilisation. The temperature stabilisation cases require ongoing an ongoing cut in total annual livestock methane emission by 3% per decade. These 2030 scenarios are compared with the current policy-based modelled projection of livestock methane continuing to rise until 2040 (EPA, 2022a).
- The worst case shown is the projected existing policy increase to 2040 (in EPA workbook data) and then a “stable herd”, maintaining annual ruminant methane mass emissions at the projected

2040 level onward. This results in a net increase in maintained livestock warming to a level equivalent to a one-off emission of 1930 $MtCO_2$, with further warming thereafter. By contrast, cutting methane from 2020 by 30% to 2030, and then by 50% to 2050, maintained methane warming is cut to 1300 $MtCO_2$we by 2050 with further reduction thereafter. This is a substantial scenario range in the context of a Paris-aligned goal, illustrating the importance of CH_4 mitigation.

4.3.6.4 Recommendations

- Combined CO_2 and N_2O emissions will incur a substantial carbon debt even if combined they reach net zero on by 2050 Figure 6), and, as per Section 3 findings, cutting the rate of annual methane emission would enable a substantial temperature reduction to limit and reduce carbon debt and tacit CDR dependence. Therefore, as this analysis shows, whether the rate of livestock methane emissions increases or decreases to 2030 will have a major effect on whether or not Ireland meets a carbon budgeting programme to 2050 that is consistent with meeting a fair share PA goal.
- **As shown in Figure 20, a scenario with the projected continued increase in livestock methane up to 2040 and a "stable herd" thereafter – as is recently commonly stated as an objective by stakeholders (Phelan, 2021) – is liable to ensure that a Paris-consistent carbon budgeting goal <u>cannot</u> be met, even with the most radical energy CO_2 reduction achievement. Clear advisory messaging to stakeholders on this point is advised.**

4.3.7 Anaerobic Digestion: assessing the warming impact of fugitive CH_4 emissions

4.3.7.1 Research Question

Given GWP_{100} data for emissions from AD resulting from different slurry:silage feedstock ratios and different plausible rates of fugitive CH_4 emissions, what are the warming impacts shown by GWP analysis?*

4.3.7.2 Methods

GWP_{100} and by-gas mass data for AD GHG emissions for differing slurry:silage feedstock ratio are sourced Beausang et al. (2021), which assumed a CH_4 loss rate of 2.4%, the average rate of emissions for 13 agricultural biogas plants in Denmark. Here, 0.2%, 3.7% and 8.1% – the low, mean, and high field measurements of fugitive CH_4 measured for UK biogas plants (Bakkaloglu et al., 2022) – are used to extend this analysis to possible higher real world methane loss rates. To assess relative warming across the scenarios, GWP* analysis was then applied to determine net cumulative CO_2we from the start of AD operation based on the by-gas mass values and the different leakage rates.

4.3.7.3 Results

- Even in the Beausang et al. (2021) GWP_{100}-based analysis, only high slurry to low silage feedstock mixes result in AD emissions lower than the alternative avoided emissions. However, GWP* analysis worsens all cases so that even 100% slurry mono-digestion AD case does not enable a saving relative to the non-AD alternative for the first 20 years.
- The higher UK-recorded loss rates worsen these outcomes.
- The SEAI Heat Study assumes a slurry:silage mix equivalent to the highest silage mix shown in Beausang (2021) which fails to deliver a saving even at a 0.2% CH_4 leakage rate. The level of failure of the SEAI study's feedstock mix increases quickly with leakage rate.

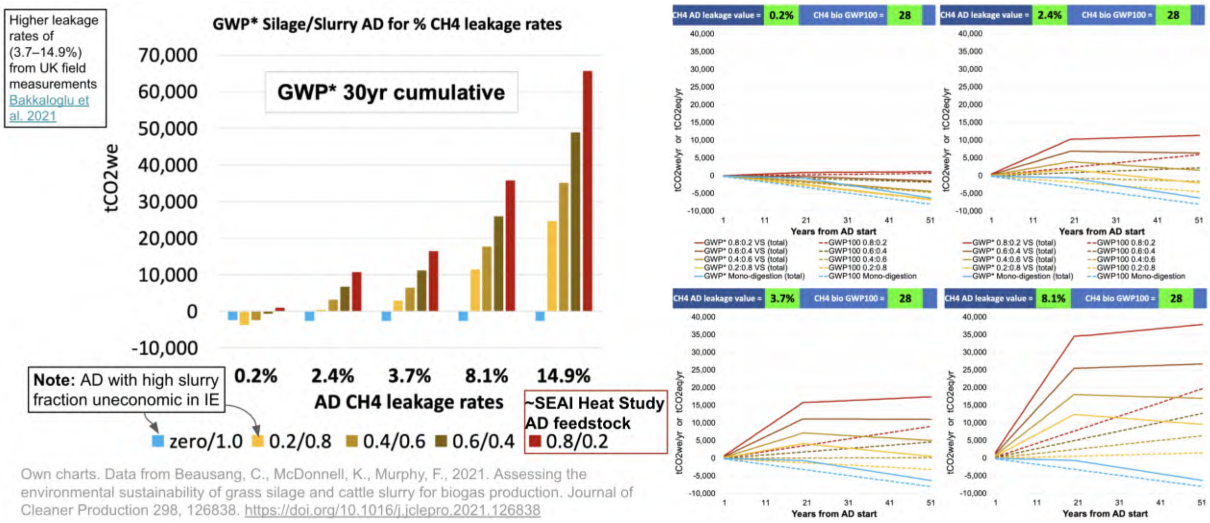

Figure 21. GWP* analysis of AD fugitive CH_4 data with AD fugitive loss field data.

Source data for AD feedstock emissions from Beausang et al. (2021); field measurements of fugitive CH_4 from (Bakkaloglu et al., 2022). Left: cumulative tCO_2we for an AD plant by feedstock mix and CH_4 leakage rate. Right, GWP_{100} (dashed) and GWP (solid) emissions trajectories in terms of tCO_2e and tCO_2we respectively.*

4.3.7.4 Recommendations

- The SEAI Heat Study and Teagasc scenarios relating to planned AD development in Ireland should be reassessed as a matter of urgency because the AD feedstock assumed equates to the worst case slurry:silage AD feedstock mix in the assessment by Beausang et al. (2021), which is not sustainable even in CO_2e GHG terms with a low fugitive CH_4 AD plant leakage rate. As shown, the outcomes are much worse in GWP* terms, ruling out any feedstock *except* the uneconomic slurry-only feedstock.

- This study reinforces the Oireachtas Committee evidence of Beausang (2022) that any roll out of AD would require a strictly enforced regulatory regime of independent and ongoing MRV to ensure minimal fugitive CH_4 loss rates that remain well below those that are being found in field measurements of active AD plants. However, such a regime is liable to add substantial cost to the already high cost of AD biogas (SEAI, 2022) and such enforcement is also likely to be resisted by stakeholders.
- **Given the risks of AD methane emission from a poorly regulated system of hundreds of AD plants, compounded by planned use of high silage feedstock, the main recommendation indicated by this GWP* assessment of possible AD CH_4 leakage warming is to avoid large scale AD roll-out entirely because any claimed climate change benefits are liable to be cancelled out by fugitive CH_4 warming. Therefore, a precautionary reassessment of expansionary national AD plans is strongly advised.**

4.3.8 Rewetting organic soils: assessing methane and aggregate warming

Modelling of rewetting organic soils for the CCAC (2021) technical report assumes considerable potential emission reduction on a GWP_{100} CO_2e basis based on a 98% reduction in CO_2 emissions and a small rise in methane CO_2e emissions.

Research Question

What is the effect of warming from different levels of methane emissions potentially associated with rewetting of organic soils?

4.3.8.1 Methods

The by-gas CO_2, N_2O and CH_4 annual kg ha^{-1} sustained rates for drained and rewetted assumed by the Goblin model in assessment for the CCAC (2021) technical report are used in this study as well as scenarios with CH_4 emissions half or double the 123 kg^{-1} ha^{-1} assumed in the Goblin model.

4.3.8.2 Results

As shown in Figure 22, for the Goblin model's rewetting scenario used in the CCAC's first carbon budgeting assessment CH4 mass emissions (123 kgCH4 $ha\text{-}^{1}$ yr^{-1}), the GWP* analysis indicates that the climate warming outcome in 2050 is considerably worse than the CO_2e analysis indicates. This implies that the mitigation due to rewetting stated in the 2021 CCAC report requires reassessment.

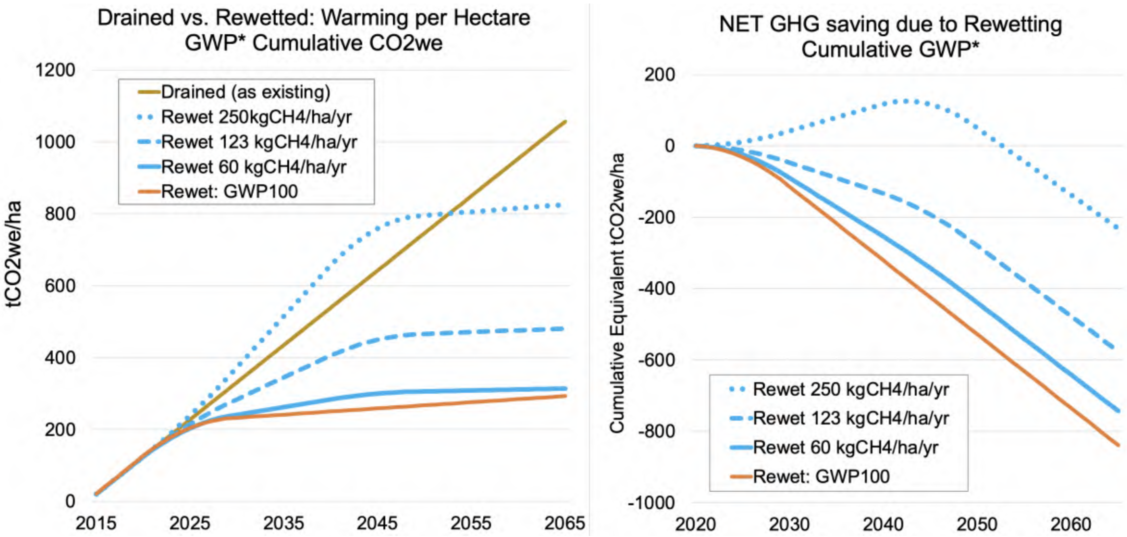

Figure 22. Rewetting scenario warming pathways to 2065 compared using GWP* analysis.

4.3.8.3 Recommendations

- Although there are strong biodiversity and long-term climate reasons that support rewetting, this study indicates that the amount of increase in methane emission rate can seriously worsen the warming outcome of rewetting up to 2050 compared to the CO_2e case. Indeed, if the average increased long-term methane loss of rewetted land were to be greater than the model assumed rate – as has been observed in some rewetting (Vanselow-Algan et al., 2015) – then warming to 2050 could even be worse than the drained case with no rewetting.
- This study finds that methane emissions can considerably reduce the climate benefit of rewetting in the 2050 time horizon of carbon budgeting assessment, therefore, as per Renou-Wilson (2018) any rewetting requires careful water level management to limit increased methane emission.

5. Integrating national and business-sector carbon budget accounting

5.1 Critical literature review of business carbon accounting and management (BCAM) relative to national carbon budgeting.

5.1.1 Research Question

Can BCAM be usefully integrated with national carbon accounting and management (NCAM) to align with meeting legally binding carbon budgeting commitments consistent with equitably limiting to the Paris Agreement (PA) 1.5ºC long term temperature goal?

5.1.2 Methods

Critical review of research literature to assess BCAM relative to NCAM in the context of constraining emission drivers sufficiently deeply and rapidly to meet Paris-consistent carbon budgets. PA Article 6 ‘voluntary cooperation’ mechanisms involving Non-State Actors (NSAs), such as businesses, must result in higher ambition in Party Nationally Developed Contributions (NDCs), therefore this study compares BCAM and NCAM based on the robust accounting principles required of PA Parties’ NDCs: ‘environmental integrity, transparency, accuracy, completeness, comparability and consistency, and ensure the avoidance of double counting’ (UNFCCC, 2015, Article 4.13).

5.1.3 Results

- Ireland’s NCAM and agreed five-year carbon budgets (to 2025 and 2030) are based on territorial production as reported annually by the EPA following the exhaustive IPCC 2006 guidelines, to meet UNFCCC requirements via standardised inventory data tables and detailed explanatory reports that are subject to international technical review.
- By contrast, literature on business carbon accounting (BCA) shows that it relies on voluntary and highly uneven corporate data disclosure, using GHG “scopes” that risk double-counting, inconsistent complex standards, and carbon markets, developed in part by industry actors, which remain lightly regulated by international bodies. Business carbon accounting disclosure is often optional and BCA scopes are not aligned with sectors in national reporting. Multinational firms typically do not report emissions on a national basis.
- Corporate long-term climate targets are typically based on self-assessed alignment with “science-based” pathways that are only associated with the Paris temperature goal through highly-

inequitable contraction-and-convergence revenue or sectoral bases, which also lack the transparency in normative assumptions and accounting necessary to demonstrate the necessary enhanced ambition of NDCs.

- Moreover, in BCAM the upstream and downstream value chains of multinational corporate entities operating across sectors are not aligned in any robust way with Ireland's national aggregate carbon accounting (territorial emission five-year carbon budgets) or sectors (sectoral emissions ceilings, SECs). In short, given the mismatch in sectoral and territorial coverage between BCA and NCA, and BCA's lack of necessary transparency, clarity, and accountability, BCAM cannot be usefully aligned with national carbon accounting through UN reporting to meet these PA.4.13 robustness principles to increase NDC ambition as required of 'voluntary contributions' in PA Article 6.
- The so-called "science based targets" being adopted by business do not take account of equity in any way that is aligned with literature-justified interpretations of fair sharing based on CBDR-RC principles. Instead, they unfairly grandfather additional carbon budget share to corporate actors based on current sectoral emissions shares, emissions, or revenues.
- In short, relative to national carbon budgeting, business carbon accounting and management is misaligned, unclear and incomplete. The complexity and inadequacy of BCAM relative to the requirements of NCAM and Ireland's carbon budget targets indicates it is more performative than effective, suggesting that, in effect, it acts as a non-transformative "discourse of delay" that is liable to distract from and delay regulation sufficient to limit emissions intensive activities in accord with climate justice and Paris-consistent carbon budgeting.

5.1.4 Recommendations

- This study finds that business carbon accounting and management is largely opaque, partial, and inequitable, so it <u>cannot</u> currently be usefully integrated with national carbon accounting and management (NCAM) to align with meeting Paris-consistent carbon budgeting commitments.
- This study recommends that the business sector in Ireland no longer relies on existing BCAM approaches, based on scope accounting and "science based targets", and instead commits full support for the urgency now required to achieve Ireland's legally binding carbon budgets to 2025 and 2030 without fail. This implies that, as a matter of urgency and with expert advisory guidance, the government, society, and the business sector need to plan for societal transition explicitly and openly within limits of inputs of fossil fuel energy, land carbon extraction, and agricultural nitrogen use that do not breach a Paris-consistent carbon budgeting programme, starting with the budgets to 2025 and 2030.

5.2 Concept mapping of business carbon accounting and management (BCAM) relative to national carbon budgeting relative to the economy

Research question

Using concept mapping of accounting nodes and relations, schematically assess BCAM relative to NCAM in accounting society-wide emissions and managing the economy to constrain emissions within Paris-consistent carbon budgets?

5.2.1 Methods

Concept mapping using graphic representation to identify relationships between conceptual nodes or node aggregates allows system visualisation and knowledge organisation (Chang, Hwang & Tu, 2022; Rebich & Gautier, 2005). Concept maps are drawn for global carbon accounting, and, using the simple, free *Cmap* tool[1], for Ireland's economy and emissions in detail, and for a generalised and simplified case of a national economy and its emissions.

5.2.2 Results

- Current BCA scope emissions categories are intended largely for company decision-making regarding mitigation options, which often primarily target corporate structural or process cost savings, so BCA is not typically intended to be aligned with NCA inventory or NCAM to achieve national climate action or carbon budgets.
- The concept maps in Figure 23 and Figure 24 graphically illustrate the mismatch between BCA and NCA totals and sectors. Therefore, meaningful alignment is not possible unless corporate disclosure of scope 1 and 2 emissions became mandatory, reported on a national territorial basis using IPCC guidelines, and reported in categories directly aligned with NCA sectors.

5.2.3 Recommendations

- **Unless the government, the business sector or others can show a clearly accounted plan aligned with meeting Ireland's carbon budgets without fail, then effective government regulation is likely needed in the very near-term to directly and fairly ration and limit economy inputs of key emission drivers, meaning the total <u>amounts</u> of imported (or nationally extracted) fossil and land carbon and reactive nitrogen.**

[1] https://cmap.ihmc.us/

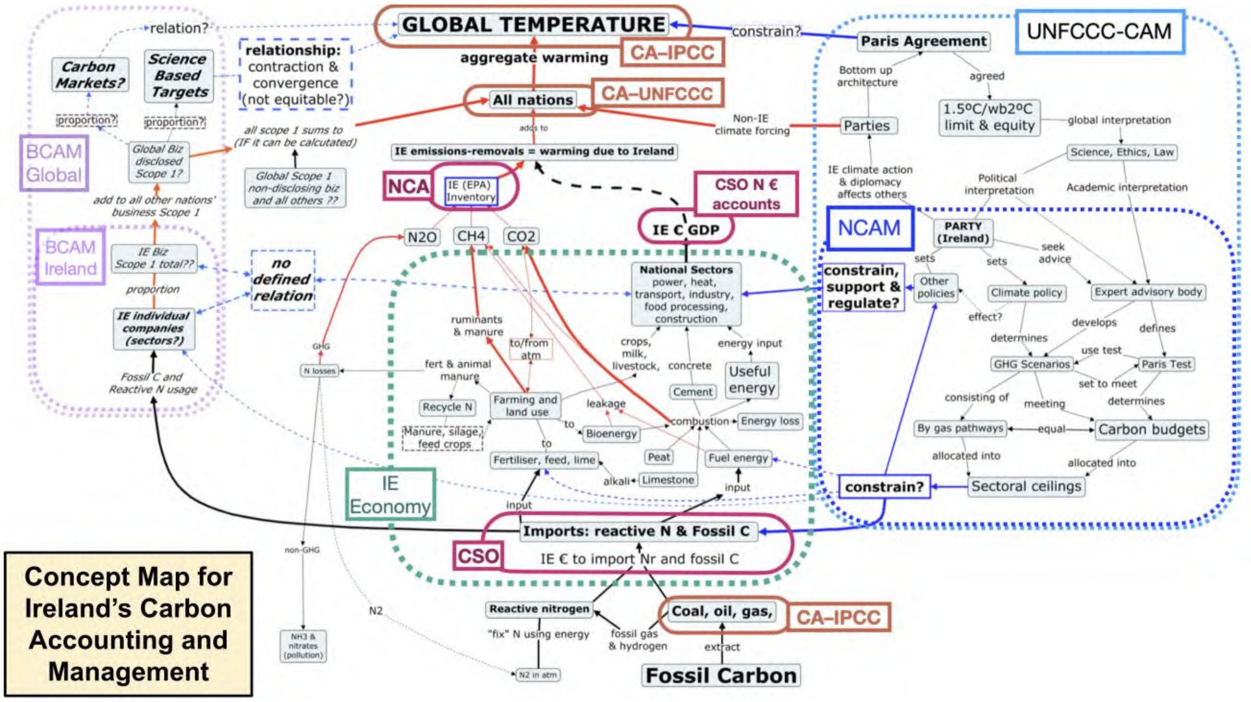

Figure 23. Detailed concept map for BCAM and NCAM in relation to Ireland economy.

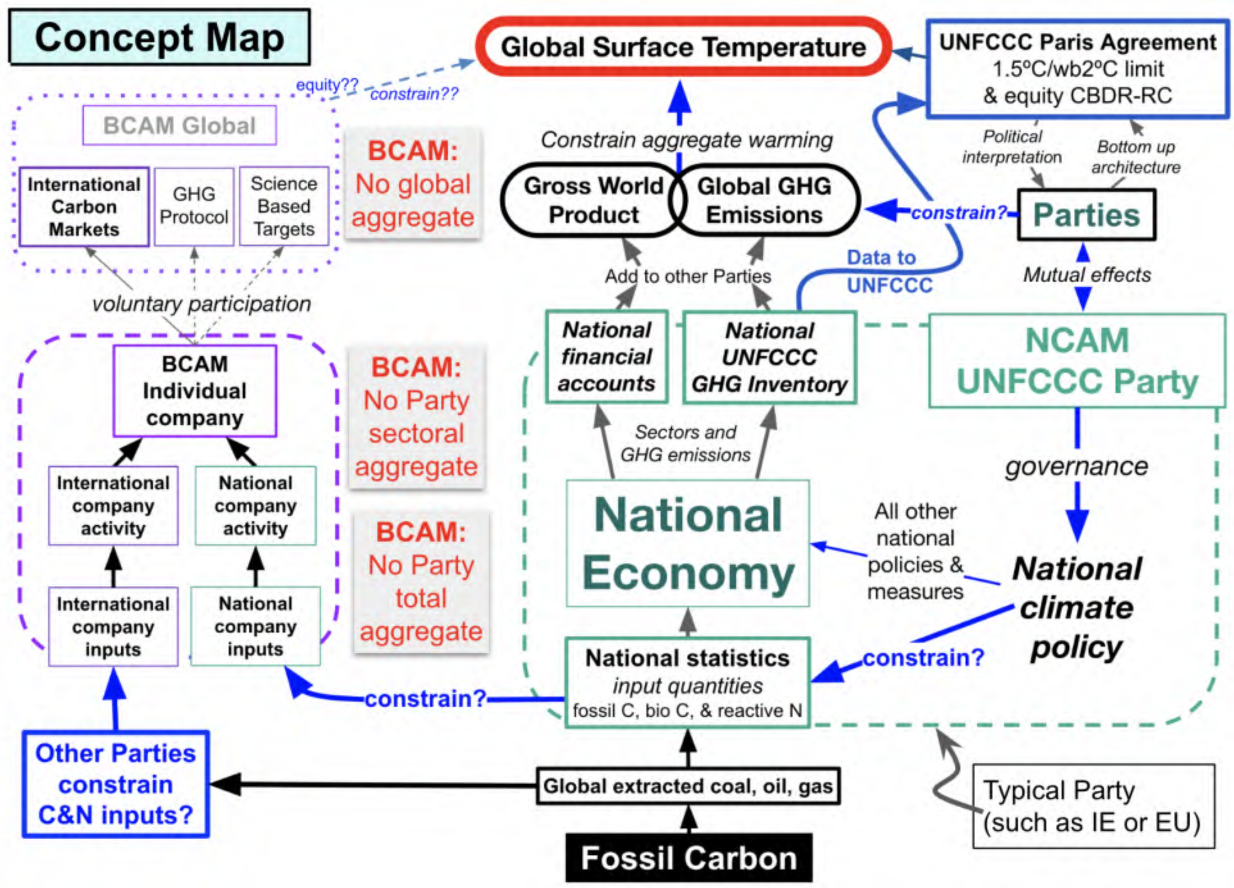

Figure 24. Concept map of BCAM and NCAM relative to national and global climate action.

5.3 Correlation of global warming and the world economy 1850–2021

5.3.1 Research Question

Does the correlation of global warming and the world economy since 1850 indicate progress toward limiting warming?

5.3.2 Methods

Different graphical presentations of the correlation of global warming and the global economy are based on spreadsheet analysis of CO_2 emissions, from CDIAC (2017) and the Global Carbon Project (Friedlingstein et al., 2022), and gross world product (GWP) data, in 2011 US$ Purchasing Power Parity terms, from Bolt and van Zanden (2020)

5.3.3 Results

- Contrary to assertions that global mitigation efforts, primarily focused on efficiency gains, have already been successful in substantively changing the trajectory of warming, Figure 25, indicates that, up to 2021 at least, little if any progress has been made to avoid dangerous warming and highly damaging global climate change. In fact, “business-as-usual” continues.
- The current rate of increase in global warming (+0.1ºC in 5 years), resulting from fossil carbon combustion for energy use, is faster than at any time since 1850. Over the past two decades, a faster rate of gross world product ($GWP) increase has compensated for flattened global CO_2 emissions, and recent analysis indicates that the lessening in the rate of CO_2 forcing increase has been offset by increased non-CO_2 forcing (Fig. 5 in Hansen et al., 2021).
- The major recent economic interruptions, the Global Financial Crisis and the Covid Pandemic, each only resulted in a single year deviation from the ongoing correlation trend that is heading rapidly toward substantial PA LTTG overshoot.
- The near-linear correlation of global warming and economic activity is indicative of the system dynamics of an ongoing emergent society-climate feedback mediated by economic flows (profits, transfers, investments) that translate into system lock-ins to sustain energy use from fossil fuel carbon combustion. The minimal bending of the curve toward “green growth over the decades since the “Great Acceleration” after World War II continues confirm that the rate of global economy decarbonisation remains far too slow to avoid substantial PA LTTG overshoot.
- If so, then substantial and urgent system change appears to be required to deviate from this trend toward a safe future that avoids substantial overshoot and yet maintain societal stability in a low carbon transition that limits the potential for unmanageable global societal collapse (Steel et al., 2022).

- Due to rebound effects, the common and ongoing policy and economics focus on efficiency improvement and economic growth through technology and innovation around the world simply perpetuates the trajectory toward an increasing likelihood of system failure unless strong constraints on fossil fuel use in particular are enforced to limit warming (Alcott, 2010). However, if imposed, such strong mitigation policy is itself liable to have serious economic system impacts globally through restricting or reversing $GWP growth.

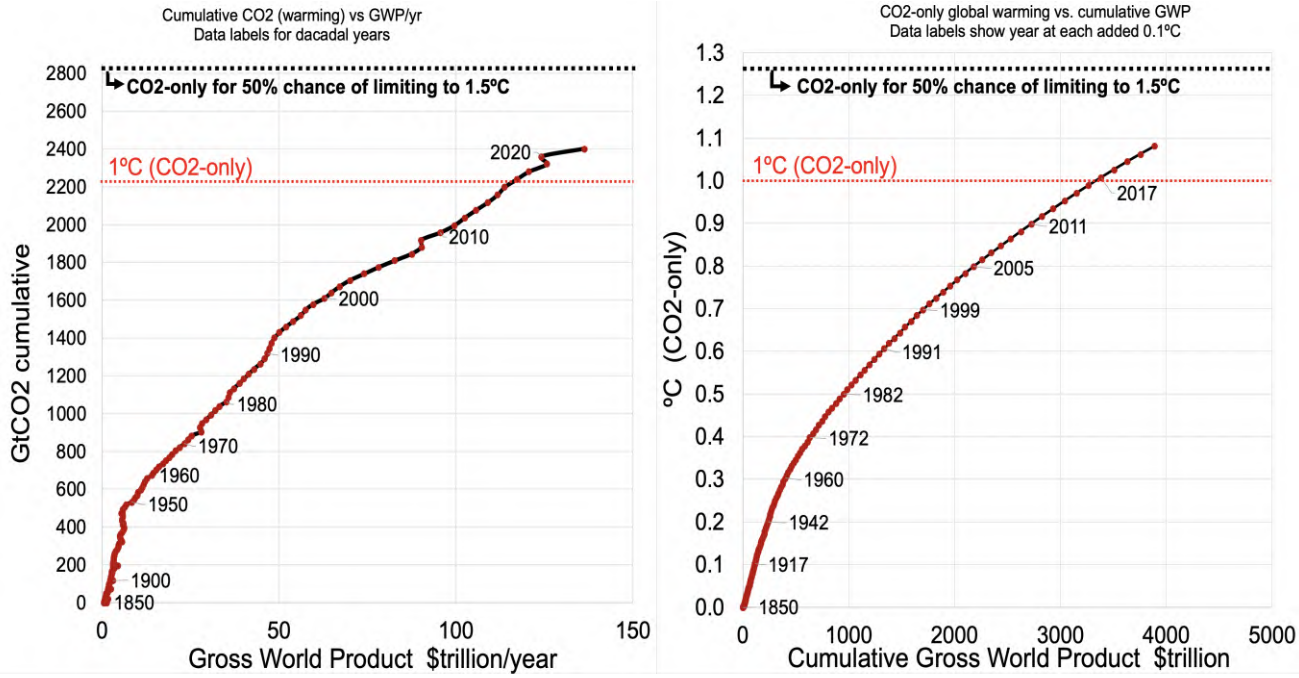

Figure 25. Cumulative CO_2 emissions (warming) relative to Gross World Product (PPP).

Left: Own chart of cumulative $GtCO_2e$ vs. annual GWP Purchasing Power Parity charts for 1850–2018, time progresses along the graphed black line with one red dot per year.

Right: Chart, using same data as at left, but with a vertical axis converted to warming ºC via TCRE and a horizontal axis stated in cumulative GWP (PPP) from 1850.

Data: CO_2 from CDIAC (2017) and Global Carbon Project (Friedlingstein et al., 2022), GWP data derived from Bolt and van Zanden (2020).

- To date, in Ireland as elsewhere, mainstream neoclassical economics, with its core assumption of equilibrium correction toward continued long-term economic growth (ESRI, 2017) and dependent advisory energy modelling, has not adequately considered the potential for system failure due to escalating climate impacts as an escalating threat multiplier (Keen, 2020).
- As evident in Figure 25, the apparent lock-in relationship between global warming and global economic output continues. The global economy strongly depends on the basis of past infrastructure and ongoing energy and land inputs, resulting in energy and cement CO_2

emissions, (Garrett et al., 2022). This creates a double bind for societal transition between the economy-energy demand lock-in and the urgency now required to meet Paris-consistent climate targets (Jarvis et al., 2012). Transition will 'involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade' to navigate the 'rapidly closing window of opportunity to secure a liveable and sustainable future for all' (IPCC, 2023).

5.3.4 Recommendations

- **The continuing strong correlation of global warming with global economic activity strongly suggests that global emissions responsibility could reasonably, if theoretically, be assigned based on financial flows (specifically GDP for countries or value-added for corporations and other Non-State Actors). This implies that the tacit complete exclusion of non-territorial GDP from Ireland's climate responsibility assessment – essentially accepted in CCAC (2019, section 2.3) and unaddressed since – could be revisited as being in conflict with climate justice.**
- In future work a simple responsibility assessment in regard to climate justice could assess global emissions by entity (country, bloc, company) on the basis of its fractional share of $GWP multiplied by global emissions and assess a carbon tax for equitable distribution among nations as a benchmark for climate finance.
- **Advisory adoption of a greater range of climate risk horizon scanning assessment through non-equilibrium, system dynamic modelling is recommended to complement current equilibrium economy-energy-emissions modelling. All such national assessment modelling should include energy and AFOLU pathways that combine to meet Paris-consistent ("fair share" 1.5ºC) carbon budgets without fail. Examination of worst case scenarios in assessments is essential to plan for future system resilience.**

6. Synthesis summary

The expert advisory process for climate action in Ireland, as in most countries, has generally been to assess the near-term economic feasibility of mitigation options first, by initially focusing on technical efficiency measures. More recently, assessments commonly also focus on reaching “net zero” or “climate neutrality” goals. The range of research for this project strongly indicates that these approaches risk avoiding consideration of what is now actually required in the near-term to achieve good faith commitment to meeting the Paris Agreement temperature goal equitably. This research finds that doing so first requires expert advisory attention on clearly providing a view of “fair share” Paris quota range for Ireland, even though this requires unavoidable normative judgments and, crucially, a clear definition of “climate neutrality. Therefore, the *Paris Test* (PT) set out in the 2021 CCAC Carbon Budgeting Technical Report represents an internationally valuable example of serious attempt to set a quantified, equitable test of Paris-consistency, but, based on this research, budget assessment clarity requires setting out the PT before, or at least in parallel, with examining feasibility through technical modelling and other advice. Otherwise, opposite to primary focus on the urgency now required to meet the Paris goal indicated by climate science equitably, there is a strong sequencing bias in the carbon budgeting assessment process toward a primary focus instead on *feasibility* – narrowly judged in notional cost terms and aligned with a socio-economic near-term preference for incremental change. Given the rapidly shrinking global carbon budget and imminent 1.5ºC overshoot soon after 2030, it is more likely that structural system changes are required to achieve the necessity of severely restricting physical system driver amounts – of fossil carbon inputs, reactive nitrogen imports, and land carbon extraction – to enable the required transition. Noting that the Climate Act references ‘cost-effective’ action (stated as ‘the social and economic imperative for early and cost-effective action in relation to climate change’), such a ‘necessary-first, costing-second’ approach is the accepted order of process in *Cost Effectiveness Analysis*, as defined by Ireland’s Public Spending Code (DPER, 2019), where a necessary policy outcome is agreed first and only then are the costs of alternatives to meet it *without fail* considered. This approach is recommended.

This fellowship research has found that achieving a “fair share” 1.5ºC goal is likely considerably more difficult than was indicated by the initial Paris Test (CCAC, 2021) due to quantitative adjustments found necessary: to align the test’s assessment period and GHG scope, and to allow for international aviation and shipping or an earlier reference year. In turn, this finding implies that the five-year carbon budgets provided for in the 2021 assessment are too large to achieve the 1.5ºC *Paris Test* on the EPC basis used in the CCAC (2021) Carbon Budget Technical Report. It is now extremely difficult for any developed nation, such as Ireland, to achieve this target, even on only a “minimally equitable” basis, *unless* all possible mitigation levers are now employed immediately to the maximum extent possible to reduce society-wide emissions, especially from high emitting activities. Under the Climate Act and the PA in respect of climate justice and equitable implementation by Parties, any failure to follow the required trajectory to meet the goal implies a requirement to redouble efforts rather than to accept failure. To meet the PA LTTG equitably, the urgency required for actual achievement of radical emission reduction is therefore escalating rapidly, first and foremost in developed nations.

As confirmed in the CCAC (2021) report's core scenario all-GHG temperature impact charts, and again shown in this report, methane mitigation in addition to radical CO_2 emission reduction is now crucial to meeting a stringent fair share temperature objective before 2100. This fellowship research has clarified the meaning of carbon neutrality for Ireland by showing that an early, deep, and then sustained cut in the rate of annual emissions has a substantial temperature impact reduction equivalent to that from CDR. If a prudent estimate of the cumulative CDR removal potential is limited, this study finds that only the CCAC (2021) core scenario with similar deep 51% reductions for Energy <u>and</u> Agriculture in CO_2, N_2O, and CH_4 by 2030 meets the 2050 EPC goal aligned with a 50% likelihood of 1.5ºC if a reasoned scenario for international aviation and shipping is accepted.

As for energy sector activities, meeting the 1.5ºC goal therefore now implies major changes in agricultural activities, particularly reductions in dairy and beef production, in favour of tillage and horticulture on better soils and forestry on less good soils. The Sectoral Emission Ceiling for agriculture target's a 25% reduction in agricultural emissions on a CO_2e basis but current Climate Action Plan agricultural measures prioritise N_2O reduction and have lesser and questionable CH_4 mitigation. This plan fails to align with the balanced mitigation scenarios submitted to the CCAC in 2021 and we find it liable to fall far short of what is required to meet a 1.5ºC goal. Analyses in this study suggest that rewetting of organic soils to reverse carbon losses and anaerobic digestion to supply biomethane, may well underperform in achieving the GHG savings indicated in other research in the near-term due to the warming impact of increased methane emissions relative to the 1.5ºC goal, unless great care can be guaranteed to monitor and control rewetted organic soil water levels.

The IPCC Synthesis Report states that 'overshoot entails adverse impacts, some irreversible, and additional risks for human and natural systems' (IPCC, 2023, B.7). Therefore, as shown in this research in section 3.1, Ireland's "climate neutrality" goal now requires a <u>climate negative</u> societal 2050 objective, achieving sufficient negative emissions (in CO_2we terms) to limit overshoot and return to a fair-share *quota net zero* that is justifiably consistent with the Paris temperature goal. Merely targeting a "net zero" goal that is in substantial and indeterminate overshoot of 1.5º is not Paris-aligned. To meet the 1.5ºC goal with minimal overshoot and return to the target level climate science indicates that, globally, cutting agricultural non-CO_2 emissions (especially methane) and ensuring net land use removals is crucial to allow any remaining fossil fuel budget. For Ireland, the climate negative agriculture sector requirement is illustrated in this research using a simple spreadsheet AFOLU model for Ireland, relating land use activities to emissions and five-year carbon budgeting. It shows that weak land use policy – which fails to reduce agriculture non-CO_2 (especially CH_4) emissions substantially in the near-term and fails to prevent or reverse the projected increase in land use GHG emissions – greatly reduces the Ireland's 1.5ºC quota share fraction available for energy transition. Nitrogen fluxes are a key measure of nutrient input, protein output, and pollution losses from agriculture, therefore a land-nitrogen-emissions (LNE) reanalysis of 2008–2015 benchmark farm-type data, presents the areal N flux (kgN ha^{-1}) and related national *effective platform* areas for Ireland's key agricultural production-types (*Milk*, *Cash crops*, and *Livestock*). *Milk* and *Livestock* are far less N and GHG efficient than *Cash crop* production, so the model indicates that the past decade of agricultural policy has substantially decreased national system NUE, by increasing milk and maintaining meat production and reducing tillage area, requiring increased nitrogen imports in fertiliser and feed.

Standards and practices for business carbon accounting and management (BCAM) have evolved in response to international attention to climate change, to claim that BCAM contributes to Paris-aligned climate mitigation. However critical literature review and concept mapping find that BCAM does not meet PA robust accounting principles, fails to align with national or sectoral carbon accounting (as used in UN reporting and for carbon budgeting), facilitates local cost-saving measures that are liable to system rebound effects which can entirely cancel out mitigation, and supports inequitable grandfathering of global carbon budget share to existing business interests. These findings indicate that BCAM standards and practices conflict with the climate Act's requirement for climate justice and PA implementation *by Parties* to reflect equity and the principle of CBDR-RC (PA2.2). Therefore, this study recommends that the business sector focuses attention instead on fully supporting climate action to meet the first two carbon budgets without fail and enabling open disclosure of all scope 1 and scope 2 emissions, using accounting fully aligned with EPA and UN emissions inventory accounting. As suggested by Hoepner and Rogelj, 2021, for precautionary action and to encourage corporate emissions disclosure, non-disclosing firms could be assumed to be "worst in class".

Overall, this carbon budgeting fellowship's research presents a stark picture of the climate situation and Ireland's limited, and sometimes counterproductive, climate action and planning to date. Nonetheless, acknowledgement of these issues and facing the urgent reality of what is now required to meet the agreed climate goal can better inform carbon budgeting and meaningful society-wide action to benefit future well-being in Ireland and the world.

7. Policy and advisory recommendations

7.1 Integrated carbon budget assessment of existing policy

- In effect, the two five-year carbon budgets to 2030 are limits on the sum of: total system input amounts of fossil carbon that can be burned for energy or industry, land use carbon that can be "harvested" and emitted, and reactive nitrogen that can be used wastefully. Therefore, advisory research and modelling should clearly identify these immediate supply limits and the near-term effectiveness of technical and policy alternatives to meet them.
- A national, rapid response, climate governance mechanism is required to ensure societal inputs of these emission drivers and likely resulting emissions are constantly and speedily updated, so that advisory research and expertise can quickly advise on mitigation course-correction options. This would enable decision-makers and society to decide on the most acceptable scenario to meet the carbon budgets on a timely basis.
- Further assessment of the existing Paris Test and alternative definitions is advised. It is strongly recommended that the same CCAC technical report (2021) Paris Test basis of a prudent global goal set as a 50% chance of limiting to 1.5ºC is maintained because this also equates to 'a >80% chance of not exceeding 1.75ºC' (Matthews and Wynes, 2022). To avoid inequitable emissions grandfathering it is also strongly recommended that the Paris Test reference year is not moved forward from 2021 to a later year. It would be best to report any new Paris Test results on the current test definition with a reference period 2021–2050 [CO_2&N_2O&CH_4] basis, but with an additional assessment from 2015 or earlier, to better communicate and discuss interactions with equity and historical responsibility (as informed by this research in section 2.4).
- Research, sectoral policy, and advisory assessment should avoid any misleading focus on "net zero" as a *primary* mitigation target, either on a national or (worse) on a sectoral basis, because the primary objective of the Paris Agreement is meeting the temperature limit and the agreement only mentions equitable CBDR-RC implementation by Parties, not by individual sectors or non-state actors. Similarly, policy, advisory and research assessments should not focus on net zero or GHG emissions/removals "balance" in GWP_{100} CO_2e terms because reaching net zero in CO_2e terms is not required for temperature stabilisation, even at the target PA.2-consistent *quota net zero* level. Moreover, any CO_2e balance target has ambiguous peak and 2100 temperature outcomes depending on the CH_4 emissions pathway taken relative to cumulative net CO_2+N_2O in CO_2e terms.

7.2 Assessing alternative integrated emissions scenarios including methane and CDR

- To meet a national fair share climate action goal of climate neutrality consistent with meeting the PA2 temperature goal, radical reductions in fossil carbon energy emissions are essential, but are now insufficient unless deep reductions in methane emissions are also achieved in the near-term. Therefore, policy is needed to enable early, deep, and sustained reduction in annual methane emissions. Failure to do so is highly liable to ensure that a Paris-consistent carbon budgeting programme becomes impossible.
- Comparative temperature impact analysis of all scenarios, policies and measures is advised through step-pulse analysis, such as GWP*, and/or use of simple climate models, such as MAGICC or FaIR, is also recommended, as a complement to CO_2e. It is important that the priority of meeting a Paris-consistent target, with an explicit CBDR-RC reference year and LTTG prudence definition, is always made clear in any analysis.
- Costs of climate mitigation relative to meeting a climate neutrality level aligned with reaching a fair share PA LTTG temperature quota should include the cost of achieving *certainty* in future delivery of sufficient *permanent* CDR if sufficient mitigation of GH gases, especially CO_2 and CH_4, is not achieved in a scenario.

7.3 Agriculture, forestry, and land use (AFOLU) scenarios within Paris-consistent pathways

- Given substantial sectoral methane emissions and the rising importance of near-term methane mitigation in meeting a fair share PA goal, CO_2e aggregation is potentially deeply misleading – especially for Ireland's emissions profile with substantial methane emissions – so it is essential that all agricultural research and advisory scenario modelling very clearly sets out separate by-gas mass emission pathways over time for each of CH_4, N_2O, and CO_2 for every scenario.
- Further development of this study's LNE and AFOLU modelling would enable simplified coarse-grained exploration of land use futures for Ireland that substantially improve system nitrogen use efficiency and increase food protein production (compared to the current inherently inefficient agri-food system) while greatly decreasing GHG emissions and nitrogen pollution.

7.4 Integrating national and business-sector carbon budget accounting

- This study finds that business carbon accounting and management cannot currently be usefully integrated with national carbon budgeting, therefore society and business need to reassess how

Ireland’s business sector can demonstrate a robustly accountable commitment to meeting Ireland’s carbon budgets.

- The continuing strong relation of global warming with global economic activity suggests that taxation or emissions responsibility based on GDP (or corporate value-added) fractional share of global GDP provides a straightforward gauge of annual climate change responsibility. Therefore, it is recommended that government and advisory agencies should not simply exclude the implied emissions for non-territorial activity (the GDP in excess of GNP*) from Ireland’s responsibility for global warming and climate justice.

8. Future research

8.1 Integrated carbon budget assessment of existing policy

- Using and furthering the Paris Test framework offered by this research (section 2), transdisciplinary research to support CCAC *Paris Test* assessment of Paris-consistent carbon budgeting can aim to strengthen the justification of unavoidable normative choices, clarify quantification of Paris Test assessment necessary, and better examine whether carbon budgets are Paris-consistent in a clearly reasoned way.

8.2 Assessing alternative integrated emissions scenarios including methane and CDR

- Future economics research in mitigation assessment needs to assess the full costs of CDR relative to the cost of methane reduction given defined Paris Test threshold level(s) and scenarios CO_2 and N_2O emissions pathways.

8.3 Agriculture, forestry, and land use (AFOLU) scenarios within Paris-consistent pathways

- The preliminary AFOLU analysis explored in this research demonstrates proof of principle for coarse-grained national Land-Nitrogen-Emissions (LNE) modelling to support land use planning, therefore, further development of AFOLU-LNE modelling is recommended.

8.4 Integrating national and business-sector carbon budget accounting

- If Ireland’s carbon budgets are to be met, then further research could address how Ireland’s multinational businesses can robustly align business goals with meeting Ireland’s carbon budgets and whether some form of rationing of emission-driver inputs among businesses will be necessary.

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Acronyms, Annotations and Glossary

$1.5^oC_{50\%}$	A 50% likelihood of limiting global warming to 1.5ºC, which is approximately equivalent to more than a 95% chance of limiting to 2ºC.
AD	anaerobic digestion, in AD plants using bio-feedstocks to produce biomethane.
AFOLU	Agriculture, Forestry, and Land Use.
BCAM	business carbon accounting and management
Cash crops	Tillage crops that are exported from a farm for food or feed, rather than being used within the farm-gate system boundary as feed.
CB1 and CB2	The first two national five-year carbon budgets approved by the Oireachtas: CB1, 295 $MtCO_2e$ for 2021–2025; and CB2, 200 $MtCO_2e$ for 2026–2030.
CBDR-RC	'common but differentiated responsibility and respective capabilities in light of different national circumstances' (PA2)
CBTR	*Carbon Budget Technical Report* (CCAC, 2021), as issued in October 2021 by the CCAC to inform Ireland's carbon budgeting programme.
CCAC	Climate Change Advisory Council, the statutory independent EAB in Ireland.
Climate Act	Climate Action and Low Carbon Development (Amendment) Act 2021.
CO_2e	carbon dioxide equivalent via GWP_{100}.
CO_2we	carbon dioxide warming equivalent via GWP*.
[CO_2&N_2O&CH_4]	denoting inclusion in global and national mitigation scenarios of separate emission pathways for each of these three dominant GHGs.
EAB	expert advisory body for climate change at the level of a single Paris Party.
EP	effective platform, the notional national area, in aggregate or by farm-type, associated with the Milk, Cash crop, or Livestock farm-gate production-types.
EPA	Environmental Protection Agency, Ireland.

EPC	equal per capita, a global carbon budget allocation principle based on global population in the reference year. Multiply by national population gives the national EPC quota which is depleted from then by annual GHG emissions.
FAO	United Nations Food and Agriculture Organisation
GCB_{2015}	global carbon budget for CO_2-only, remaining as of start of 2015.
$GCB*_{2015}$	global carbon budget for a multi-GHG basket of CO_2, N_2O and CH_4, remaining as of start of 2015. Expressed in CO_2we (GWP* aggregation).
GHG-WE	A spreadsheet tool developed at Dublin City University to show by-gas and aggregate warming for scenarios using GWP* analysis and test national scenario outcomes relative to meeting a defined “fair share” Paris goal.
GWP_{100}	Global Warming Potential over 100 years relative to CO_2.
GWP*	Step-pulse method used to approximate warming from short- and long-lived climate pollutants.
HWP	Harvested Wood Products
IAS	international aviation and shipping
IPCC	Intergovernmental Panel on Climate Change
LNE	land-nitrogen-emissions, as used in this study, a land use assessment of agricultural or AFOLU activities over time relative to a benchmark period.
LTTG	long term temperature goal (PA 4.1) of the PA, as set out in PA2.1a.
LULUCF	Land Use, Land Use Change, and Forestry.
NCAM	national carbon accounting and management, including carbon budgeting.
$NCQ*_{2015}$	national (Paris Party) carbon quota remaining from 2015 for a multi-GHG basket of CO_2, N_2O and CH_4, related to a GCB*2015 value by a stated effort sharing principle. Expressed in CO_2we (GWP* aggregation).
N_r	reactive (or “fixed”) nitrogen that is available to plants in soils, particularly to make proteins, in which nitrogen is the key element.
NUE	nitrogen use efficiency (N output divided by N input) NUE can be defined in multiple ways depending on the N flows and system boundary chosen.
PA2.1a	Paris Agreement Article 2, Paragraph 1, Sub-paragraph (a)

Party	A nation or bloc that is a signatory to the Paris Agreement
PT	Paris Test, a pass-fail test of national mitigation achieved over a stated time period relative to a defined global effort sharing threshold, stated temperature and likelihood or GHG budget terms.
SM	Supplementary Material
TCRE	Transient Response to Cumulative CO_2 Emissions (MacDougall, 2016)

Appendix: Abstracts of papers submitted for peer-review

On the following pages are four abstracts for full papers that have been submitted to academic journals for peer-review for the four work packages of this fellowship research. As of this report submission the full journal papers will remain under embargo, but the peer-reviewed edited articles will be made available on an open-access basis through the CCAC and DCU websites as they are published.

Setting a "Paris Test" of national carbon budgeting: An assessment framework for equitable alignment with meeting the Paris Agreement long term temperature goal

Paul R. Price Barry McMullin Aideen O'Dochartaigh

Abstract

The Paris Agreement (PA) bottom-up architecture implies an onus on UNFCCC Parties to set out a defined and quantified "Paris Test" (PT) to assess whether national climate mitigation action is consistent with meeting the long-term temperature goal (LTTG) 'in accordance with best available science' and 'implemented to reflect equity'. However, most developed nations have only set "net zero" targets, with indeterminate overshoot of a national LTTG fair share. By contrast, Ireland provides a valuable case study of a serious attempt to set a quantified, equitable PT as its climate legislation requires a programme of five-year carbon budgets 'consistent with' PA Article 2. Ireland's independent statutory Climate Change Advisory Council therefore evaluated multiple 2021–2050 scenarios – aggregating warming contribution from carbon dioxide, nitrous oxide, and methane emissions [CO_2&N_2O&CH_4] – tested against an allowable threshold PT value based on equal per capita national carbon quota (NCQ*) sharing of an assessed available global budget for 1.5ºC warming.

Here, we develop and utilise a literature-derived framework to identify the key normative and quantitative choices required for consideration in any national PT and apply it to Ireland's initial PT. Adopting such a transparent framework supports national advisory clarity, societal debate, and public accountability for climate mitigation action. Application of the framework to Ireland's initial PT identifies necessary clarifications and potential quantitative adjustments. Our findings starkly illustrate how fair share LTTG action by developed nations now requires achievement of rapid, deep, and sustained absolute reductions in emissions of all greenhouse gases to limit and reverse LTTG overshoot.

Keywords

Paris Agreement; business carbon accounting; science-based targets; climate change; national carbon accounting

Early CH_4 mitigation, including agriculture, can be crucial to limit dependence on uncertain carbon dioxide removal in national climate action consistent with meeting a fair share 1.5ºC quota

Paul R. Price Barry McMullin Aideen O'Dochartaigh

Abstract

Overshoot of the global 1.5ºC Paris Agreement temperature goal is likely soon after 2030. Therefore, for climate action 'on the basis of equity', developed nations need to outline mitigation options, including non-CO_2 and carbon dioxide removal (CDR), that limit maximum carbon debt at overshoot net zero, and, after a period of net negative emissions, quickly return to a 1.5ºC "fair share" at their quota net zero level. However, national 1.5ºC overshoot-and-return scenarios have not been widely assessed. Using Ireland as a case study, we leverage the GWP* method to estimate temperature impact based on cumulative CO_2 warming equivalent (CO_2we) of [CO_2+N_2O+CH_4] from 2015 to assess: a "fair share" 1.5ºC national GHG quota to be met by illustrative policy-relevant multi-gas scenarios. This enables assessment of mitigation trade-offs between gross [CO_2+N_2O] mitigation; and, separately, the temperature impact reduction trade-offs between methane mitigation and limited national CDR potential. We find use of cumulative CO_2we (via GWP*) allows rapid and informative, Paris- aligned temperature analysis of alternative national scenarios, but note it is essential that any GWP* analysis clearly states its reference year, normative and quantitative parameter assumptions. In addition to the primary focus on CO_2 mitigation, the certainty of early, deep methane mitigation – primarily by cutting fossil fuel use and setting declining limits on intensive agriculture – has crucial mitigation value, limiting national reliance on uncertain CDR. Study results illustrate how the common use of CO_2e (via GWP_{100}), to assess "climate neutrality" and CDR reliance, undervalues, and risks deterrence of, effective early methane mitigation.

Keywords

Negative emissions; Paris Agreement; Carbon budget; Fair share allocation; Methane mitigation; Carbon dioxide removal

Land-nitrogen-emissions reanalysis of national farm data by production-type for land use planning and sustainable agriculture assessment

Paul R. Price Barry McMullin Aideen O'Dochartaigh

Abstract

National assessments of alternative pathways equitably meeting the Paris Agreement (PA) and Sustainable Development goals (SDGs) require advisory research that clearly identifies the critical relationships between land use, agricultural production, and pollution outcomes. However, existing analysis and modelling typically focuses on the economic productivity and emissions intensity of existing farm-types, which can each include a mix of dairy, crops, and livestock. By contrast, agricultural protein output, emissions and environmental impact are more directly to the land area, reactive nitrogen (N_r) input, and pollution losses related to the production of milk, crops, and meat outputs. To assess its usefulness to national decision-makers, using Ireland as a case study, we present a method for coarse-grained, land-nitrogen-emissions (LNE) reanalysis of existing farm-type data (farm-gate basis) to obtain LNE totals and intensities for the three key production-types: Milk, Cash crops, and Livestock. Reanalysis of 2008–2015 reference data by production-type shows that Ireland's farm-gate N_r use efficiency (NUE) of milk and livestock production (~20%) is far lower than for crop production (~95%). *Milk* has per hectare greenhouse gas (GHG) emissions of about double the values given for the dairy farm-type. *Cash crop* production of protein in Ireland is found to be ~65 times more nitrogen-efficient than *Milk* or *Livestock* production. Overall, national food system NUE for was 26% for 2008–2015, but since then Ireland has further reduced its food-system NUE through dairy expansion by increasing *Milk* production while maintaining *Livestock* output and reducing *Cash-crop* output. We find that the coarse-grained LNE reanalysis can informatively contribute to improved assessment of national agricultural production sustainability and future land use alternatives for decision-makers. Reducing both *Milk* and *Livestock* production would spare land for *Cash-crop* food production, biodiversity restoration, renewable energy and forest carbon storage, thereby maximising protein per hectare output while minimising N_r losses and GHG emissions.

Limits or bust? Business carbon accounting and management in a time of climate crisis

Paul R. Price Aideen O'Dochartaigh Barry McMullin

Abstract

The paper examines the little understood relationship between Business Carbon Accounting and Management (BCAM), national and global accounting frameworks and climate mitigation targets under the Paris Agreement. Drawing on the accounting and climate science and policy literatures, the paper develops a framework to provide a basis for comparison of these parallel accounting systems and conducts a schematic analysis of BCAM and National Carbon Accounting and Management (NCAM) (mis)alignment.

The analysis reveals that BCAM falls short of both true and fair accounting principles and compares unfavourably to NCAM based on the accounting and equity principles of the Paris agreement. Further, schematic representation of BCAM and NCAM boundaries and governance indicates a lack of defined integration points that would enable accurate measurement and allocation of responsibility, particularly for Scope 3 emissions. The Science Based Targets initiative represent an attempt to integrate business emissions with global targets, but a deeply flawed methodology means that it instead enables business to set inadequate and inequitable targets and supports a discourse of climate delay. The research provides scholars, practitioners, and policymakers with pathways toward the development of an equitable business carbon accounting that is more clearly aligned with the urgent achievement of global emissions reduction targets.

Keywords

Paris Agreement; business carbon accounting; science-based targets; climate change; national carbon accounting