Supplementary Information (SI)

Defining a "Paris Test" of National Contribution to Global Climate Mitigation: the Irish Exemplar

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1 Introduction

1.1 SI content

Section 2 documents the scenario methodology and data as used by Ireland's independent expert Climate Change Advisory Council (CCAC) and its carbon budget working group in meeting the provisions of the amended Irish Climate Act of 2021 [SI-1] to propose a programme of carbon budgeting providing for a 51% reduction in annual emissions by the end of 2030 (relative to 2018) and achieving a "climate neutral" economy by 2050, consistent with meeting the Paris Agreement temperature and equity goals. These proposals were set out in the Climate Change Advisory Council's *Carbon Budget Technical Report* [SI-2] and an associated Excel spreadsheet analysis [SI-3].

Section 2.1 outlines details of the CCAC scenario definition approach and Section 2.2 provides emission pathway data (directly and indirectly from the CCAC's original Excel analysis). Section 2.3 provides notes on the GWP* tonnage-temperature conversion factor and the fair-share and upscaling usage by the CCAC. Following the CCAC methodology, Section 2.4 tabulates quantitative results of the Critiques of the CCAC analysis identified in the main paper.

Section 3 documents the simple International Aviation and Shipping (IAS) scenario used in our reanalysis (Critiques D and E).

1.2 Limitations

The main paper and this SI aim to explain the CCAC methodology as an internationally useful case study of the Irish exemplar for assessing the consistency of carbon budgeting with meeting a national fair share of greenhouse gas (GHG) mitigation, aligned with the Paris Agreement objectives. Our reanalysis suggests some potential improvements to the CCAC analysis while still following the original CCAC "Paris Test" logic. Therefore the main paper and this SI do not attempt to comprehensively address the detailed literatures relating to wider issues of climate mitigation burden sharing among nations, alternative GHG equivalence metrics, high scientific uncertainty regarding global carbon budgets, or historical responsibility.

2 Climate Change Advisory Council (CCAC) core scenarios

2.1 Scenario definition

2.1.1 Outline of the CCAC approach

Referencing the Climate Change Advisory Council's *Carbon Budget Technical Report* [SI-2] and the related Excel spreadsheet [SI-3], this section details the CCAC's definition of its five, bottom-up, annual national GHG emissions scenarios for Ireland (disaggregated by gas), covering the period from 2021 to 2050.

The scenario label names indicate the approximate reductions in annual "E" or energy-related emissions, mainly carbon dioxide (CO_2) versus "A" or agriculture-related emissions, mainly nitrous oxide (N_2O) and methane (CH_4), in CO_2eq, as of 2030, relative to 2018. For example, "E-61%-A33%" indicates reductions of 61% in annual Energy emissions and 33% in annual Agriculture emissions respectively in 2030 relative to 2018. For simplicity, the CCAC technical report [SI-2] designated all non-LULUCF CH_4 and N_2O as "Agriculture-related" as the sector is responsible for about 90% of each of these gases. As of 2022, this fraction has already increased to over 93% for each gas. As explained further below, "Energy" is taken to include the F-gases on a GWP_{100} CO_2eq basis, net LULUCF CO_2, in addition to fossil and industrial process CO_2. (It is problematic to include some F-gas Short Lived Climate Pollutants in this CO_2eq basket, but the impact on the Paris Test analysis is not material.)

The CCAC constrained its scenarios to meet specific guidance in the Climate Act [SI-1], namely "to provide for" total annual 2030 emissions, aggregated in CO_2eq terms (via GWP_{100}), to be 51% below the 2018 level, and that emissions beyond 2050 should be "climate neutral". The latter was interpreted as requiring that annual total emissions and removals should net to zero in 2050 when aggregated in CO_2we terms, via (a version of) the GWP* aggregation method [SI-4] [SI-5]. The scenarios differed in the distribution of emissions between CO_2, CH_4 and N_2O, while representing similar aggregate emissions in CO_2eq (900-950 MtCO_2eq over 2021-2050). Multiple bottom-up scenarios that differ primarily in CO_2 vs non-CO_2 mitigation were developed because the relationship between GWP_{100}-based scenarios and temperature may vary significantly according to the by-gas breakdown, and Ireland has a relatively high fraction of non-CO_2 (particularly CH_4) in its emissions profile.

The CCAC technical report [SI-2], pp. 22-23, describes the core scenario approach and objective up to 2030, with reference to its Figure 2-1, which shows an illustrative GWP_{100} CO_2e pathway 'adding up to an overall reduction of 51% from 2018 levels'.

2.1.2 Methane (CH_4)

The following outlines the CCAC [SI-2] approach to define the CH_4 mitigation pathway:

- 2018 values: 0.606 MtCH_4 not including LULUCF; 0.018 MtCH_4 from LULUCF.
- CH_4 not including LULUCF: assume linear reduction by the "A" percentage relative to 2018 by 2030.
- CH_4 from LULUCF: in all scenarios reduce linearly by 51% relative to the 2018 annual value by 2030.
- After 2030, reduce annual CH_4 emissions by 0.3%/yr. This reduction rate is further sustained after 2050 and up to the 2100 limit shown in the spreadsheet. Using GWP* CO_2 warming equivalent analysis, this results in no additional CH_4 warming commitment from 2050 onward.

2.1.3 Nitrous Oxide (N_2O) and CDR for N_2O "net zero" balance

The text of CCAC [SI-2] does not explicitly set out the scenario pathway parameters for N_2O from 2018 up to 2030. However, by inspection of the Excel sheets for each scenario it is clear that N_2O follows the same general logic defined for CH_4:

- 2018 values: 0.02434 MtN_2O, not including LULUCF; 0.0013 MtN_2O from LULUCF.
- N_2O emissions, not including LULUCF and including LULUCF, respectively, follow the same fractional reduction pathways as for CH_4 to 2030, and then from 2031 onwards.
- N_2O not including LULUCF: assume linear reduction by the "A" percentage from 2018 to 2030.
- N_2O from LULUCF: in all scenarios reduce linearly by 51% relative from the 2018 annual value to 2030.
- From 2031, reduce annual N_2O emissions by 0.3%/yr.

For N_2O from 2031 to 2050, the CCAC technical report [SI-2], p. 28, provides an illustrative scenario chart in its Figure-2-6 and associated text showing the above outcome for N_2O up to 2030. After 2030, the chart and text show a component of gross carbon dioxide removal (CDR), increasing from zero in 2030, to ultimately balance residual annual N_2O in GWP_{100} terms by 2050, and thereafter, to result in ongoing N_2O "net zero" emissions.

2.1.4 Fossil CO_2

- As per the Excel workbook's TIM_Output worksheet – showing results from cost minimisation energy modelling (see [SI-6]) – starting at 40.266 Mt CO_2 in 2018 for all scenarios, were scaled down by a factor of 1.027 to match the actual 2018 inventory CO_2 value of 39.195 Mt CO_2 excluding LULUCF.
- "CO_2" values in the scenario pathways in fact aggregates the scaled TIM_Output sheet values, a LULUCF CO_2 emissions pathway (cutting emissions by 51% by 2030 and then going to net zero by 2050), and F-gases in CO_2eq following the same fractional reductions over time as for LULUCF CO_2.
- The "E" value for each scenario is obtained from first applying the "A" value to CH_4 and N_2O. The "A" value for each scenario provides linear pathways of CO_2eq values for 2021–2030 for CH_4 and N_2O. Combining the cumulative totals for CH_4 and N_2O gives an aggregate total for 2021–2030 "A" emissions. Subtracting this total from the 495 MtCO_2eq target value for all emissions set by the CCAC initial feasibility analysis for 2021–2030 gives the net CO_2 cumulative total linear reduction from 2021–2030. This then gives rise to the required "E" reduction percentage for CO_2 in 2030 relative to 2018.
- After 2030, the scenarios' CO_2 emissions pathways (separate from the additional CDR to balance continuing N_2O) fall linearly from their 2030 values to (net) zero in 2050.

2.1.5 CDR for balancing residual CO_2 from energy and industry

The CCAC technical report [SI-2], p. 24, notes that 'the residual emissions in 2050 across the TIM Energy sectors are very similar, what differs between scenarios is the pace at which the sector reaches these residual levels of emission'. In general CDR is assumed to rely on non-energy-related processes, such as additional land use removals. The report, p. 84 and 85, expresses specific caution regarding reliance on Bioenergy with Carbon Capture and Storage (BECCS).

In summary:

- CDR to balance energy and industry CO_2 increases from zero at the start of 2040 to fully balancing residual gross CO_2 emissions from 2050 onwards.

2.2 CCAC core scenario emission pathways

2.2.1 Data availability

A copy of the original CCAC Excel workbook [SI-3] with added calculations supporting Critiques B-E in the main paper, and a separate copy with added calculation worksheet tabs (magenta colour with white text) for the additional Figures in this Supplementary Information file, are all available as part of the open data release for the paper [SI-7].

2.2.2 Annual emission pathways

In the detail of the CCAC [SI-3] workbook, the separate worksheets for the five scenarios each include annual emission values for CO_2, CH_4, and N_2O for 1850 to 2100 in columns B, C, and D, respectively. These are the basis for the all derived emission pathways and estimated warming commitment of the gases individually and in aggregate. Recorded historical values for the gases are the same in all scenarios up to 2018, the most recent EPA inventory year then available for the CCAC carbon budget work. From these values GWP_{100} values are derived, using the AR5 GWP_{100} factors of 28 for CH_4 and 265 for N_2O.

Note that the E-69%-A-19% scenario does not appear in the TIM_Output (cost-optimisation energy system modelling) data, and this scenario shows a slight discrepancy in annual CO_2e up to 2025 (see Figure 2) relative to the other scenarios. However, this does not substantially affect the CCAC assessment or the critiques in the main paper – individually quantified in Table 1 of section 2.4 below.

The GWP* equation given by Lynch *et al* [SI-4] (with $\Delta t=20$) is used to calculate the annual MtCO_2we values for CH_4 in column I of the scenario worksheets, which is then added to the CO_2 and N_2O CO_2eq values to provide aggregate all-GHG GWP* CO_2we values in column J.

However, this usage in CCAC [SI-2] does not follow Lynch [SI-4] exactly because the latter used a GWP_{100} factor of 32 for CH_4 – which would generally provide a very similar outcome to using the updated Smith *et al* [SI-5] GWP* g-value scaling parameter of 1.13 multiplied by the AR5 GWP_{100} factors of 28 for CH_4. This means that the GWP* annual CO_2we values given in the CCAC scenarios column I are too low, whether compared to Lynch *et al* [SI-4] or Smith *et al* [SI-5], and should be corrected by the 1.13 g-value factor.

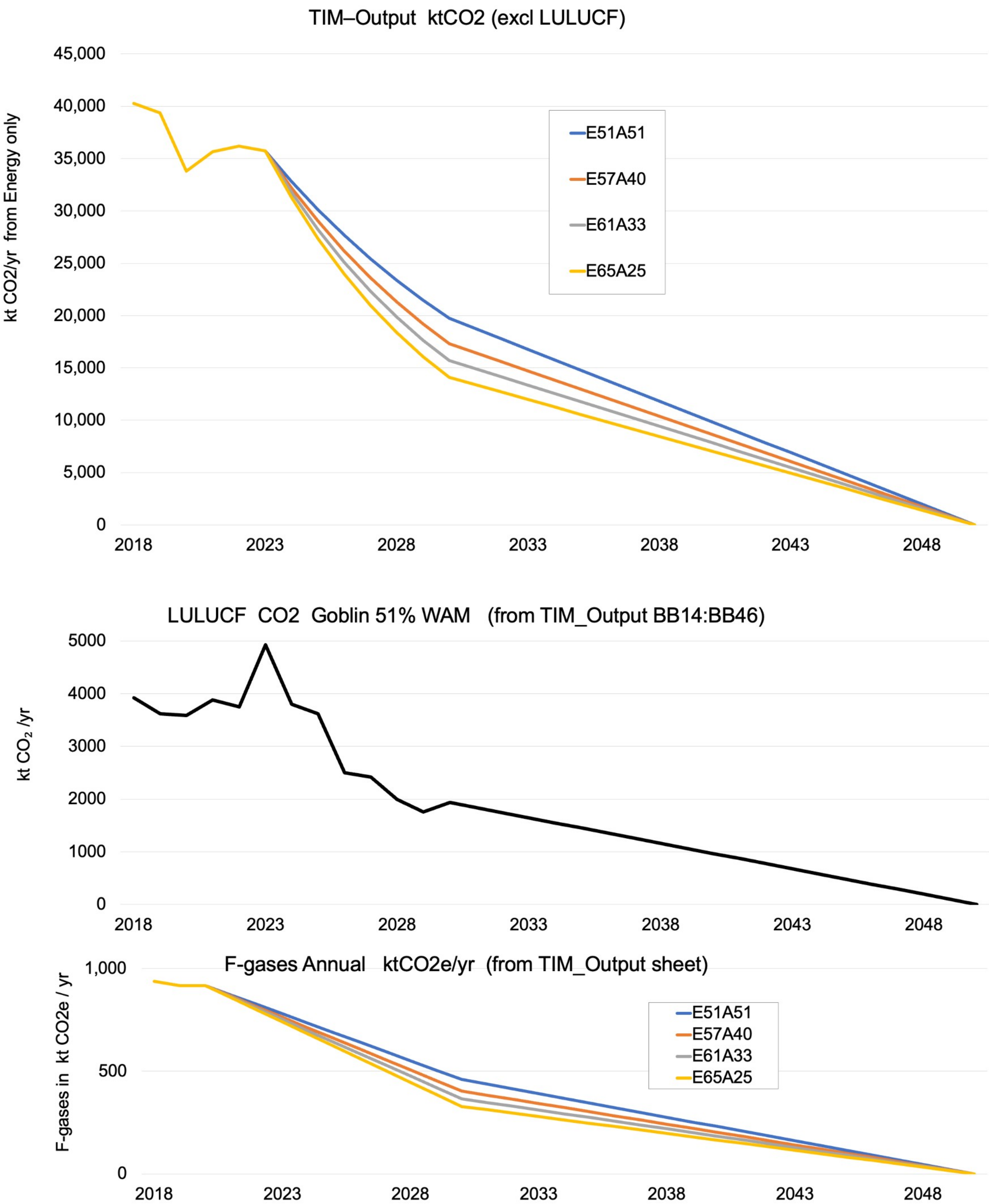

Figure 1. Charts of energy CO_2 (from TIM-Output), land use (LULUCF) CO_2 and F-gases CO_2eq emission pathways, generated from the original CCAC workbook data [SI-3]. After scaling TIM-Output values to match the recorded national inventory reporting, these three emission pathways are aggregated as "CO_2" in the scenarios (see Figure 2 below). Note that the scenario for E69-A19 was developed separately, and does not appear here. The single LULUCF pathway shown was used in all five scenarios.

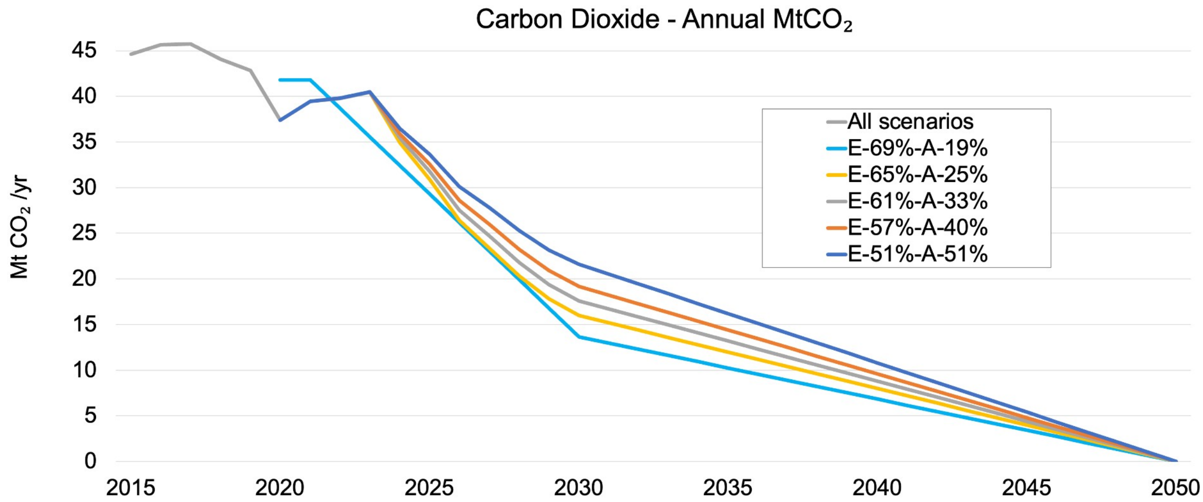

Figure 2. Chart of "CO_2" emission (including F-gas CO_2eq) pathways used in the scenarios, generated from the original CCAC workbook data [SI-3]. These are generally the sums of the pathways shown in Figure 1, but with the addition of the separately developed E69-A19 scenario.

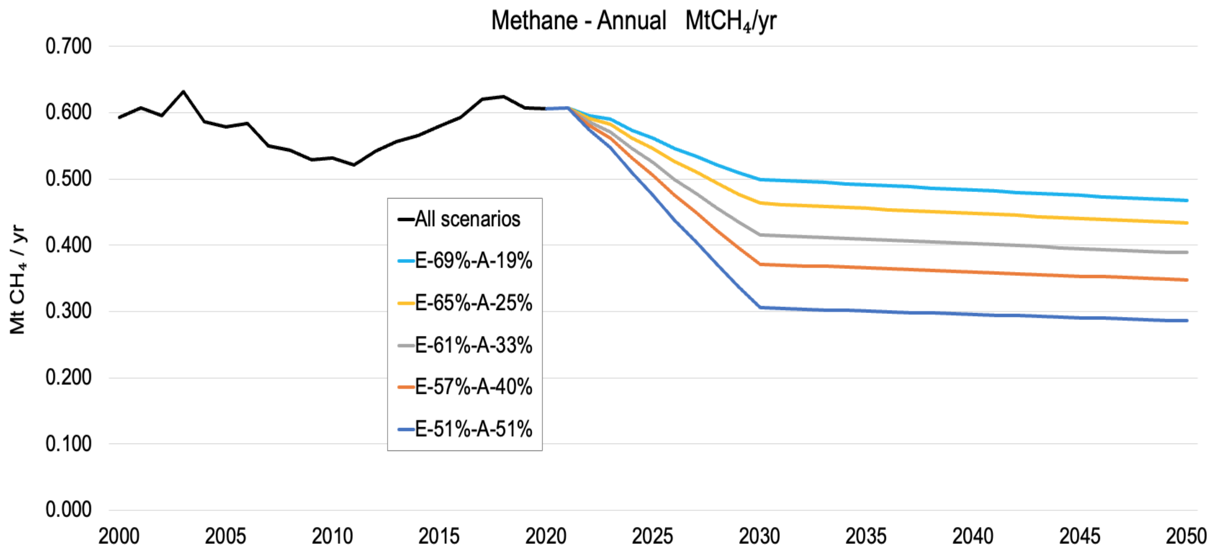

Figure 3. Chart of CH_4 emissions, generated from the original CCAC workbook data [SI-3]. These pathways provide for the "A" percentage reductions in CH_4 (excluding LULUCF) in 2030 relative to 2018 for each scenario plus reductions in LULUCF CH_4 following the same fractional reductions over time as for LULUCF CO_2. Note that this chart is deliberately extended to include historical CH_4 emissions over 2001-2020 because, under GWP with Δt=20, the mass emissions in this period will affect the assessed GWP* emissions in the scenario period 2021-2040 (see Figure 7).*

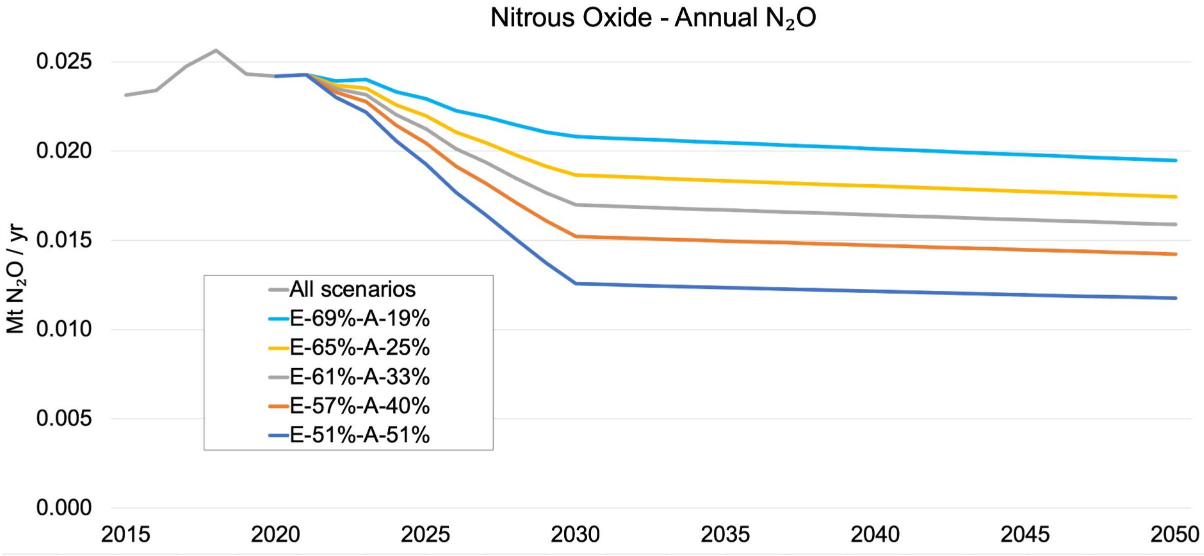

Figure 4. Chart of N_2O emissions, generated from the original CCAC workbook data [SI-3]. These pathways provide for the "A" percentage reductions in N_2O (excluding LULUCF) in 2030 relative to 2018 for each scenario plus reductions in LULUCF N_2O following the same fractional reductions over time as for LULUCF CO_2.

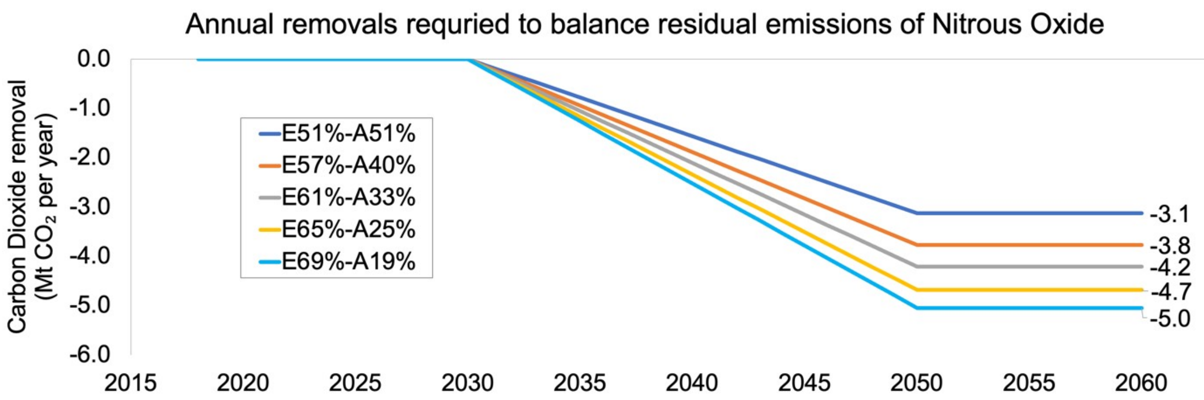

Figure 5. Annual CDR in $MtCO_2$/yr required to balance residual gross N_2O emissions by 2050 and thereafter. Chart generated from the original CCAC workbook data [SI-3].

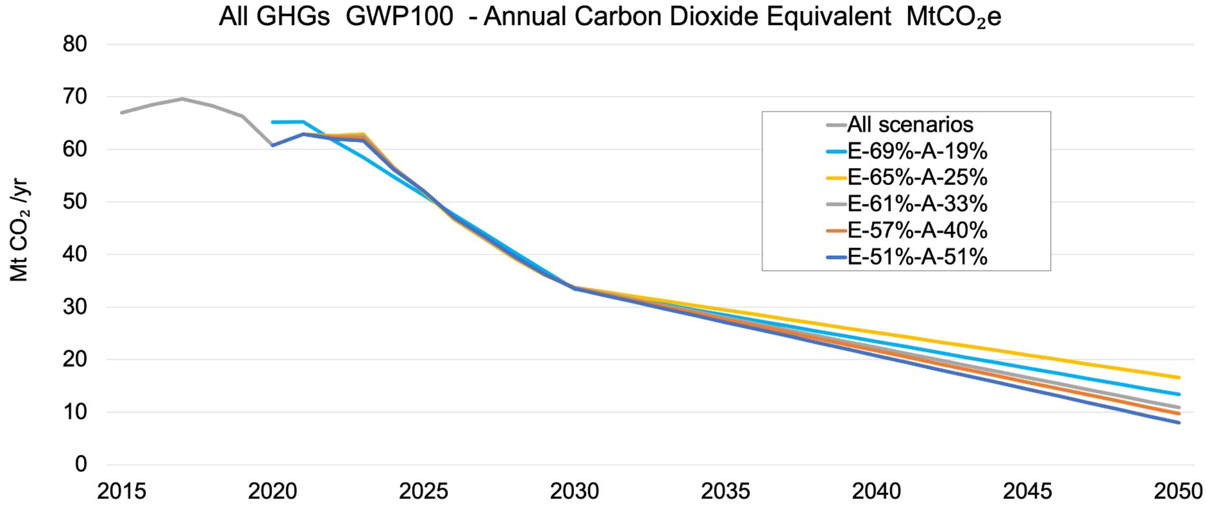

Figure 6. All-GHGs annual aggregate CO_2eq pathways 2015 to 2050. Chart generated from the original CCAC workbook data [SI-3].

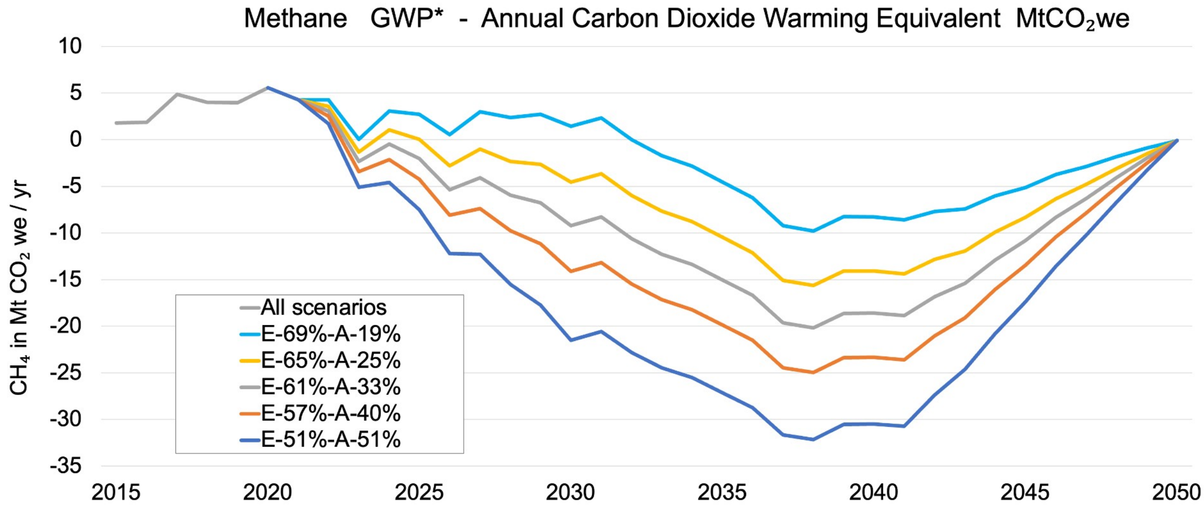

Figure 7. CH_4 GWP annual $MtCO_2$we. Chart generated from the original CCAC workbook data [SI-3]. This is based on GWP* as per Lynch et al [SI-4] (with Δt=20: see section 2.2.2 above). Note that the significant short term variability seen here over the period 2021-2040 is therefore a consequence of the historical variability in mass emissions of CH_4 over the preceding historical period, 2001-2020 (see Figure 3).*

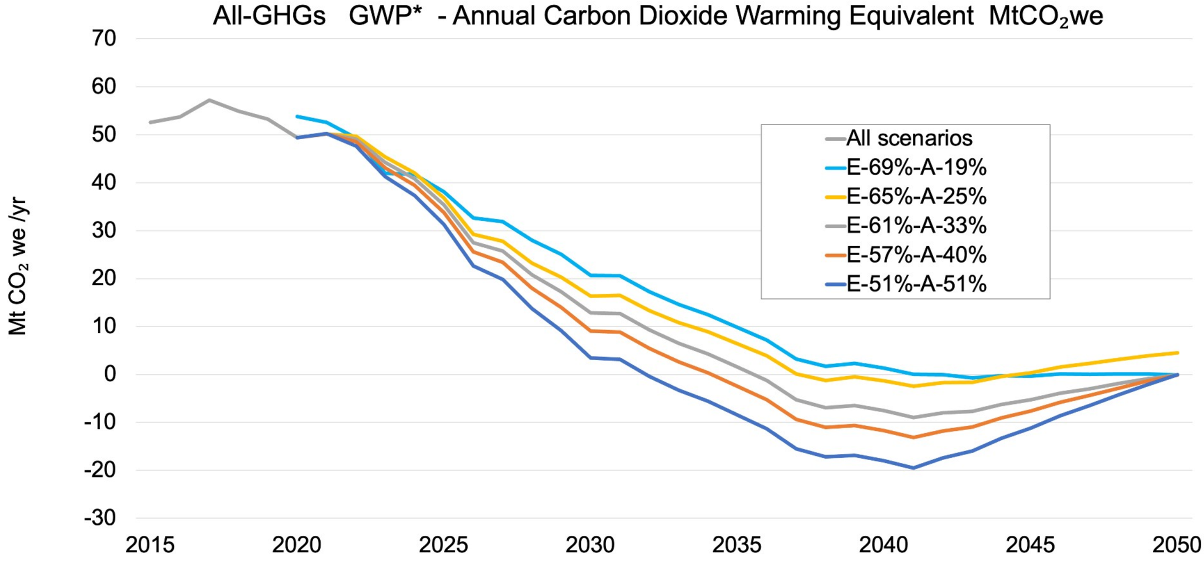

Figure 8. All-GHGs annual aggregate CO_2we pathways. Chart generated from the original CCAC workbook data [SI-3].

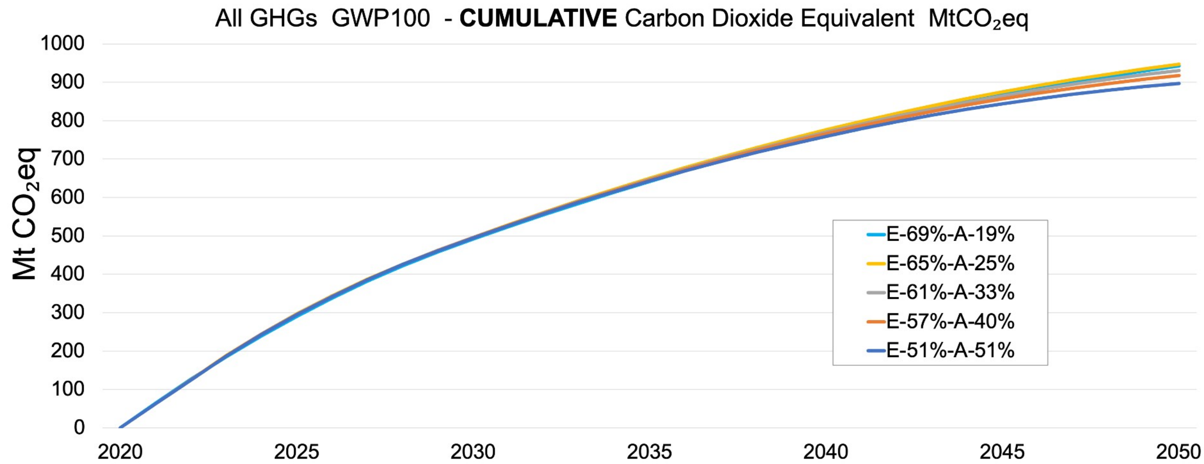

Figure 9. All-GHGs aggregated by GWP_{100} cumulative $MtCO_2eq$. Chart generated from original CCAC [SI-3] workbook data.

2.2.3 Cumulative pathways

The annual emissions data shown above are summed to produce the cumulative emission pathways from the start of 2021 to the end of 2050 shown in Figure 9 to Figure 17.

Figure 9 for all-GHGs cumulative $MtCO_2eq$ via GWP_{100}, shows that all five scenarios result in five-year budgets of 295 $MtCO_2eq$ for 2021–2025 and 200 $MtCO_2eq$ for 2026–2030, equating to a ten year budget of 495 $MtCO_2eq$ for 2021–2030. These became the initial two five-year carbon budgets proposed by the CCAC to meet the Climate Act requirements. By 2050 all five scenarios reach similar values in cumulative GWP_{100} terms of 900 to 950 $MtCO_2eq$

By contrast with the GWP_{100} representation of the scenarios in Figure 9, the pathways shown in Figure 10, Figure 11 and Figure 13, respectively, show the by-gas GWP* cumulative CO_2we pathways for CO_2, N_2O, and CH_4. It should be noted that for CO_2 and N_2O there is, by definition, no difference between GWP* and GWP_{100} outcomes; whereas GWP* and GWP_{100} yield significantly different outcomes for CH_4. Figure 12 shows the sum of CO_2+N_2O (the long-lived gases), which shows a maximum cumulative spread among the scenarios of 65 $MtCO_2$we by 2050. This can be contrasted with Figure 13 showing the much larger effect of 2021–2030 CH_4 mitigation resulting in a cumulative spread of 426 $MtCO_2$we by 2050.

Therefore, even though the GWP_{100} cumulative CO_2eq totals show only modest spread across the scenarios, the GWP* analysis shows that relatively deeper 2021–2030 CH_4 mitigation gives rise to very significant variation in the 2050 forcing and ultimate warming commitment. Since cumulative GWP* does act as a crude model of climate forcing [SI-8], the cumulative GWP* pathways present a meaningfully skillful estimate of warming commitment and ultimate temperature impact as compared to the cumulative GWP_{100} pathways.

Figure 14 shows the cumulative sum of all-GHG annual GWP* values in column J of the CCAC scenario worksheets [SI-3]. The all-GHG pathways shown are the sum of the net CO_2, N_2O, and CH_4 pathways shown in Figure 10, Figure 11, and Figure 13, respectively. Figure 15 shows the scenario pathways for aggregate all-GHG cumulative CO_2we for 2021-2050 in tonnage values from the original CCAC scenario worksheets (column AR). These pathways directly scale to the estimated temperature impact values in the CCAC technical report's Figure 4-3 chart for all GHGs [SI-2] (see detail on the conversion via TCRE set out in 2.3 below). However, the GWP* annual CO_2we values shown here are actually calculated using a variant of the GWP* equation, of the same general form as in Smith *et al* [SI-5] but with a Δt of 1 year (immediate response); whereas all of the literature we have identified from the originators of GWP*, and especially all their testing and calibration of parameters against (reduced complexity) climate models, has used $\Delta t=20$ [SI-4] [SI-5] [SI-9] [SI-10].

Thus, as per Critique A in the main paper, the temporal effect of the scenario emissions is more properly (skillfully) estimated by the *warming commitment* pathways in Figure 14 than in Figure 15. The two are directly overlaid in Figure 16. Finally, the effect of the further improvement in GWP* parameters (g value of 1.13) is additionally shown in Figure 17. This latter is the basis for Figure 1(b) in the main paper.

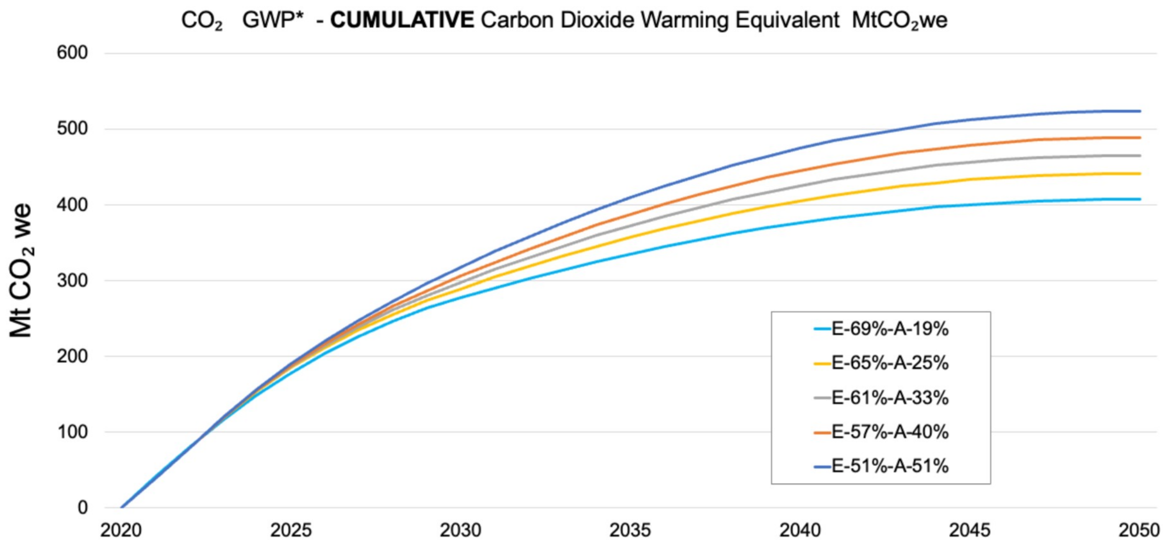

Figure 10. CO_2 GWP cumulative $MtCO_2$we. Chart generated from the original CCAC workbook data [SI-3]. The cumulative spread across scenarios is 116 $MtCO_2$we by 2050.*

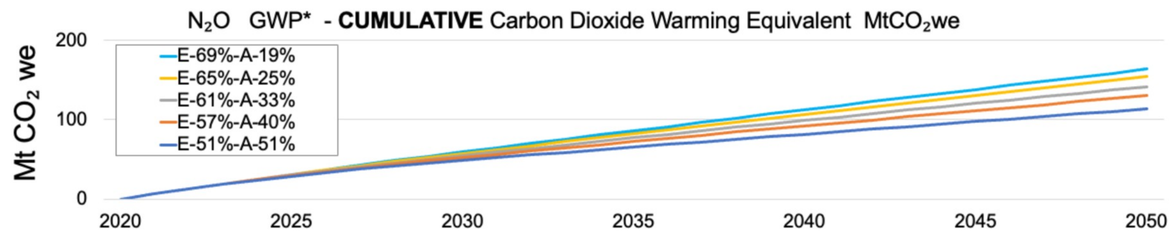

Figure 11. N_2O GWP cumulative $MtCO_2$we. Chart generated from the original CCAC workbook data [SI-3]. The cumulative spread across scenarios is 50 $MtCO_2$we by 2050.*

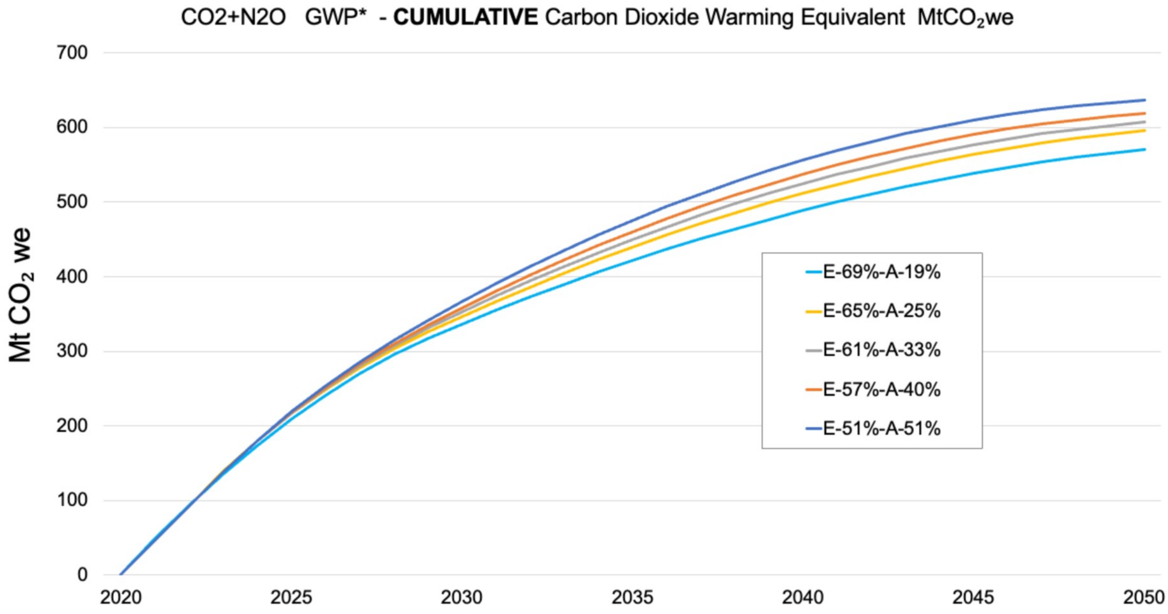

Figure 12. CO_2+N_2O GWP cumulative $MtCO_2we$. Chart derived from the original CCAC workbook data [SI-3]. The cumulative spread across scenarios is 65 $MtCO_2we$ by 2050.*

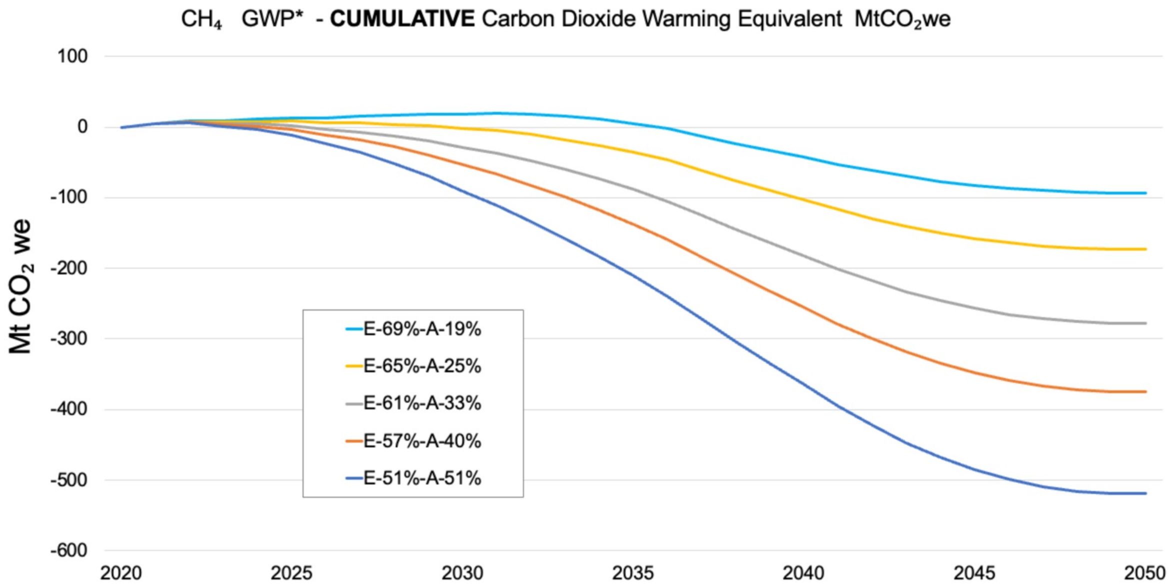

Figure 13. CH_4 GWP cumulative $MtCO_2we$. Chart derived from the original CCAC workbook data [SI-3]. The cumulative spread across scenarios is 426 Mt $MtCO_2we$ by 2050.*

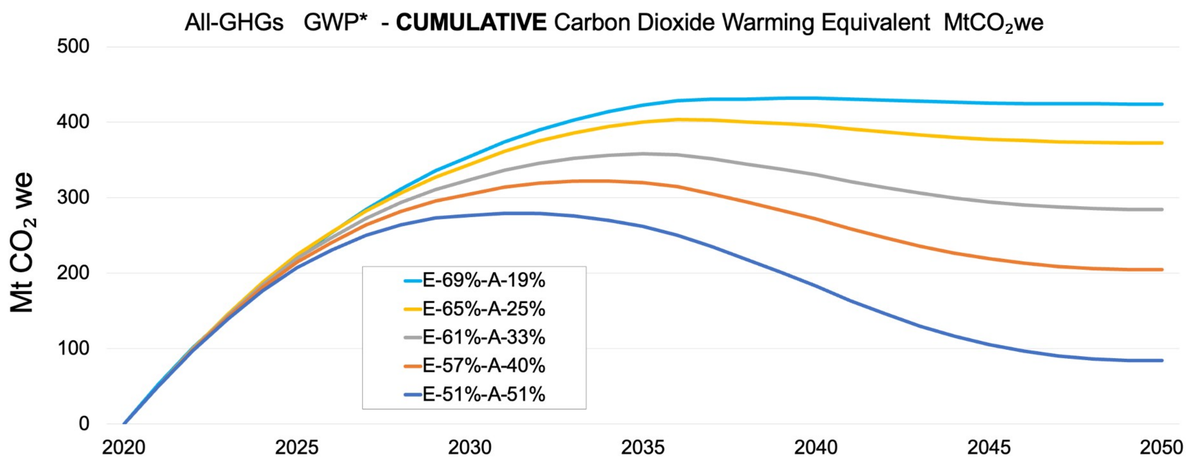

Figure 14. All-GHGs GWP cumulative $MtCO_2we$ pathways based on the cumulative sum of all-GHG annual GWP* values in column J of the CCAC scenario worksheets [SI-3].*

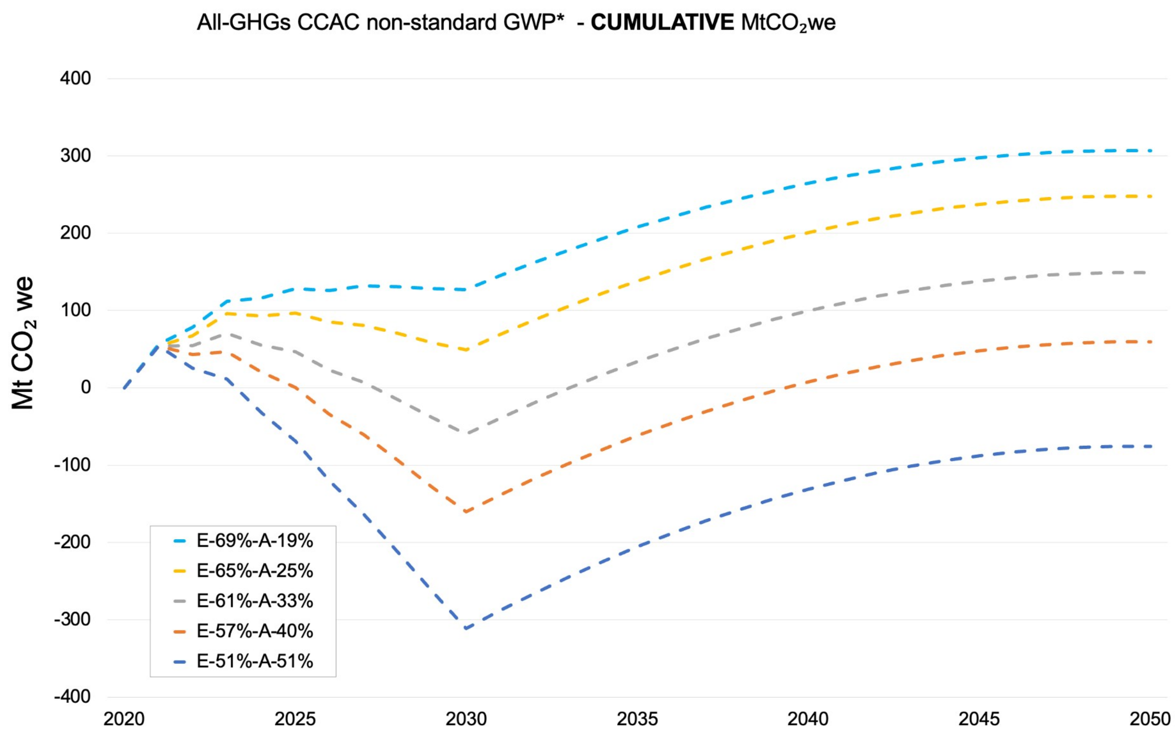

Figure 15. All-GHG cumulative CO_2we tonnage pathways, equivalent to scaled versions of the ºC pathways shown in Figure 4-3 of the CCAC Technical Report [SI-2]. Chart generated from the original CCAC workbook data [SI-3]. The CCAC values here are derived from a notional GWP calculation in column AR of the scenario spreadsheets, but using a GWP* equation with $\Delta t=1$ rather than $\Delta t=20$. Whereas, as noted in section 2.2.3 above, all of the identified literature from the originators of GWP* has used $\Delta t=20$.*

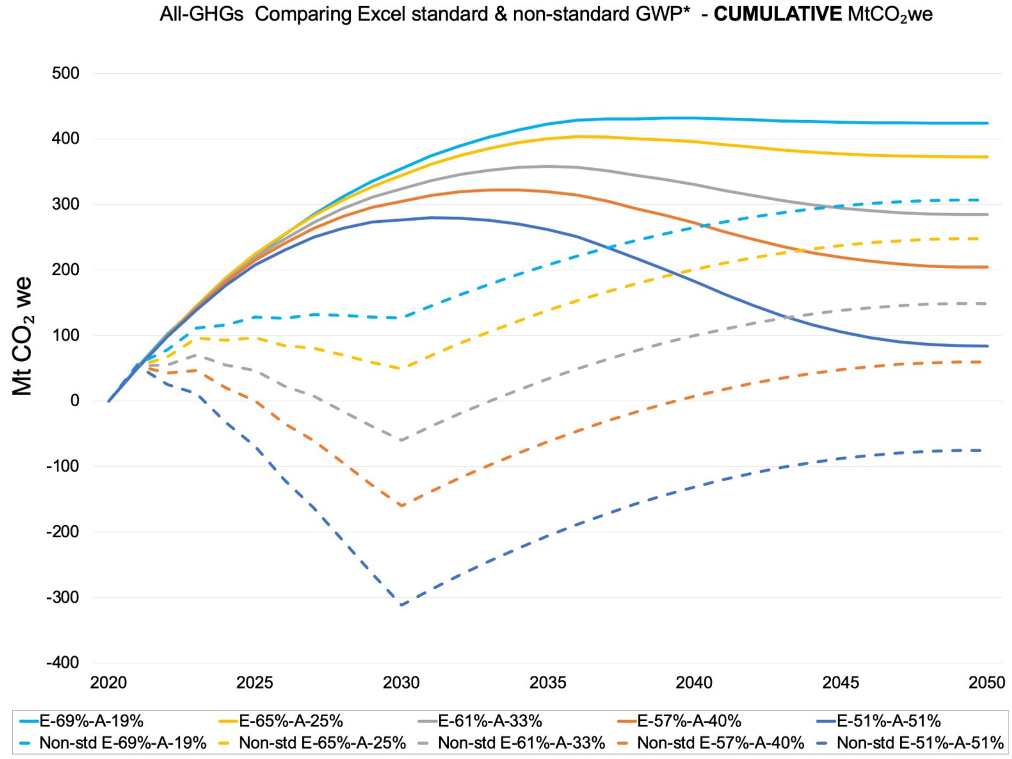

Figure 16. Comparing the CCAC aggregated all-GHG scenario pathways (Δt=1) as dashed lines (as also shown in Figure 14) relative to the GWP cumulative CO_2we pathways (Δt=20).*

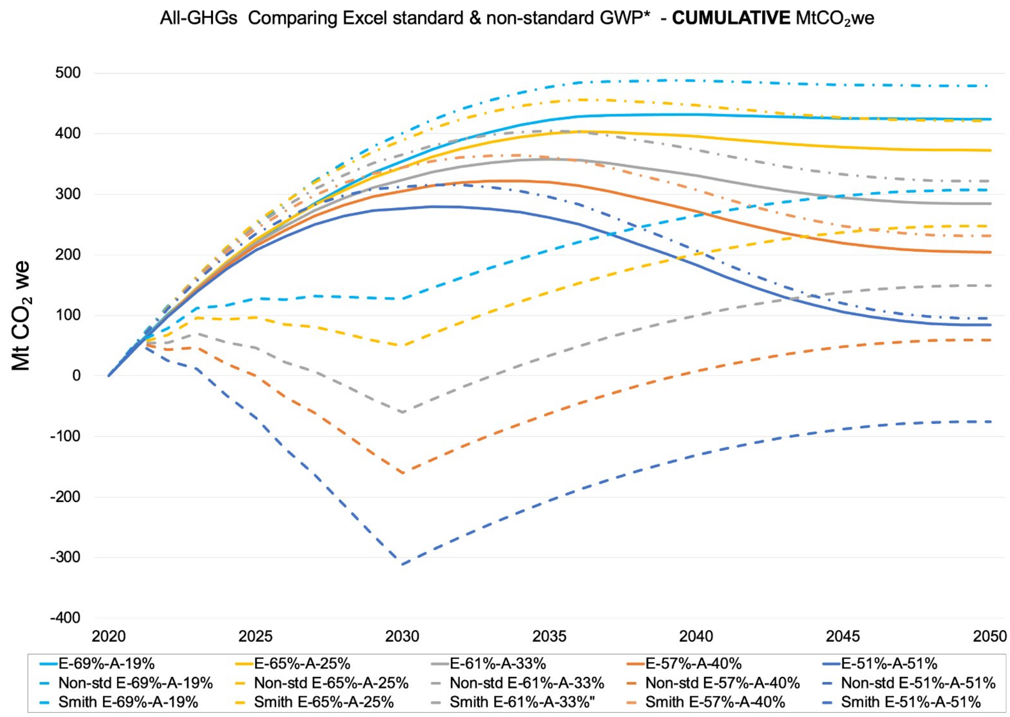

Figure 17. Showing the temperature commitment (solid lines) pathway and the non-standard GWP (dashed) forcing commitment pathways in Figure 16, but also overlaid with the addition of GWP* cumulative CO_2we pathways (dashed and dotted lines) given by the parameters as per the updated GWP* equation shown by Smith* et al *[SI-5]. The Smith* et al *[SI-5] GWP* cumulative CO_2we values (dashed and dotted lines) are each 1.13 times the Figure 14 (solid line) values.*

2.3 Note on TCRE conversion and equal per capita (EPC) upscaling

2.3.1 TCRE tonnage–temperature conversion

The CCAC methodology uses the IPCC AR6 [SI-11] value for transient climate response to cumulative CO_2 emissions (TCRE) to convert cumulative GWP* tonnage values into the estimated impact on global warming commitment of Ireland's emissions for 2021 to 2050, by-gas and for aggregate CO_2+N_2O+CH_4, as shown in the charts in Figure 4-3 in CCAC [SI-2]. The "best estimate" AR6 TCRE value of 1.65ºC per 1000 PgC equates to 0.45ºC per $TtCO_2$ or 2220 $GtCO_2$ per ºC. Therefore, all of the GWP* annual or cumulative CO_2we tonnage charts in the previous section can be directly converted to "best estimate" warming commitment charts in ºC by dividing $MtCO_2$we values by 2,220,000 $MtCO_2$.

2.3.2 Equal per capita (EPC) upscaling

The CCAC global Paris Test threshold is assessed as a global multi-gas emissions budget, in tonnes of cumulative CO_2 warming equivalent (CO_2we) or, equivalently (via TCRE scaling) as a global temperature increase (ΔT) contribution from that basket of gases (ºC). CCAC [SI-2] identifies a CO_2-only value of 500 $MtCO_2$ from Table SPM.2 of AR6 WGI [SI-11] corresponding to limiting global temperature increase to 1.5ºC with 50% likelihood. Therefore, in assessing Ireland's carbon budgeting, this 1.5ºC with 50% likelihood goal is the CCAC's interpretation of global action consistent with the Paris Agreement temperature goal.

As a "Paris Test", the CCAC technical report [SI-2], p. 75, compares the temperature impact of the carbon budgets with the 1.5ºC goal by upscaling Irish 2021-2050 cumulative CO_2we emissions, for CO_2+N_2O+CH_4, to the global level on a population basis and comparing the outcome with an estimated "available" global temperature budget for these gases remaining as of start-2021.

Therefore, the CCAC Paris Test methodology requires an assessment of the global CO_2+N_2O+CH_4 budget, the threshold corresponding to a 50:50 likelihood of limiting to 1.5ºC, that remains available from a given starting reference date for the emission scenarios (defined as the start of 2021)[1]. This global absolute budget threshold can be divided by the reference year global population (7,860 million) giving a common, available global equal per capita CO_2we value applicable to all Parties. In the CCAC approach, as in previous work by McMullin and Price [SI-12], Ch. 7. the Paris Test threshold for each UNFCCC Party is given by dividing the absolute global EPC value (tonnage CO_2we or ºC) by the fraction of the global population in each Party territory in the reference year. CCAC [SI-2]) used a value of 5.003 million for Ireland's population in 2021.

To actually implement the Paris Test at a global ("upscaled") or a Party ("downscaled") level, in either emissions (CO_2we) or temperature (ºC) terms, the transformations involved are all linear: EPC scaling between national and global levels via relative population; and scaling between emissions and temperature via TCRE. The Test *outcome* will thus be the same in either upscaled or and downscaled form.

To express the test at global level, a national scenario value for 2021–2050 impact ($MtCO_2$we or ºC) is *upscaled* to global level (multiplied by the ratio of global to national populations). Such an upscaled test, using global-level ΔT commitment contribution in ºC, is presented for Ireland in the CCAC technical report [SI-2]. However, it is arithmetically equivalent, and would arguably be more straightforward and comprehensible for national-level stakeholders, to use a Paris Test expressed directly in *national emissions* ($MtCO_2$we) terms. That is, to compare the scenario CO_2we tonnage value with a corresponding Paris Test threshold value, which is effectively the population weighted EPC *downscaling* of the assessed global absolute value.

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[1] This methodology thereby enables a common but differentiated responsibility budget approach to emissions from the reference year onwards (common to all Parties in the reference year and differentiated by actual Party emissions thereafter). However, it is crucial to understand that this approach still implicitly grandfathers all Party historical responsibility for emissions prior to the reference date. It is a separate question as to how much of this should be addressed by additional efforts under the Paris Agreement to ensure equitable implementation as required by Article 2; but the scale of this "still outstanding" differential historical responsibility is clearly critically dependent on the specific choice of reference year.

2.4 Critiques A-E: Tabular summary of effects

Table 1 shows the Paris Test thresholds and scenario values following the CCAC technical report [SI-2] Paris Test *methodology*, with the assessed quantitative improvements (Critiques A-E) in both upscaled (a) and equivalent downscaled (b) forms.

Table 1:Section (a) shows upscaled Paris threshold values in ºC for PT as of 2050, with PT pass/fail differences for each scenario, firstly, showing the CBTR PT threshold and outcomes, followed by successive quantitative adjustments, (A) to (E). Section (b) shows the downscaled values in $MtCO_2we$, equivalent to the corresponding values in (a) via national population-weighting and TCRE. Pass/Fail in Green/Red sharing respectively.

		National Scenarios (NS)				
(a) Global ΔT (°C): Upscaled PT for NS		**E51-A51**	**E57-A40**	**E61-A33**	**E65-A25**	**E69-A19**
CBTR warming contribution (in 2050) =		-0.05	0.05	0.11	0.17	0.25
Paris Test threshold basis (NCQ*)	**PT Threshold**	**Scenario 2050 minus PT threshold**				
CBTR PT outcome	0.23	-0.29	-0.19	-0.12	-0.06	0.02
(A) Adjusted NS warming contribution (in 2050) for validated GWP* =		0.01	0.11	0.17	0.24	0.31
		Scenario 2050 minus PT threshold				
(B) Align global budget to implicit sharing NS reference year of 2021	0.21	-0.20	-0.10	-0.04	0.02	0.10
(C) Adjust GCB^*_{2021} from CO_2-only to $[CO_2+N_2O+CH_4]$	0.15	-0.14	-0.04	0.03	0.09	0.16
(D) Adjust NCQ*_2021 for projected national IAS scenario	0.07	-0.06	0.04	0.11	0.17	0.24
(E) Adjust NCQ*_2015 for projected national IAS scenario	-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
Paris Test threshold basis (NCQ*)	**PT Threshold**	**Scenario 2050 minus PT**				
CO_2-only (CBTR)	330	-410	-260	-170	-80	30
(A) Adjusted NS warming contribution (in 2050) for validated GWP* =		20	160	250	330	440
		Scenario 2050 minus PT				
(B) Align global budget to implicit sharing NS reference year of 2021	300	-290	-150	-50	30	140
(C) Adjust GCB^*_{2021} from CO_2-only to $[CO_2+N_2O+CH_4]$	210	-190	-50	40	120	230
(D) Adjust NCQ*_2021 for projected national IAS scenario	90	-80	60	150	240	350
(E) Adjust NCQ*_2015 for projected national IAS scenario	-50	70	210	300	390	500

3 An illustrative national scenario for International Aviation and Shipping (IAS)

To include IAS in national Paris Test assessment, a *global* IAS scenario could be used and the global budget (in CO_2we terms) could then be adjusted down *prior* to applying global EPC distribution from a given sharing reference year. However, since both access to aviation and the resultant emissions is highly differentiated on a global basis (i.e., highly unequal) there is a strong equity argument that such a globalised distribution of IAS emissions responsibility would be contrary to the Paris Agreement CBDR-RC commitment. A preferred alternative would therefore be to include at least projected national IAS CO_2 emissions (on the standard UNFCCC "bunkering" basis) in the national scenarios before applying the Paris Test (albeit still neglecting non-CO_2 effects). However, in the case study context of Ireland, the current legislative framework explicitly excludes IAS emissions from the domestic "carbon budgets", even though they still necessarily impact on consistency with national effort to meet the Paris temperature goal [SI-13]. Accordingly, in Critique D and E the main paper adopted a methodology of maintaining separate national scenarios for territorial emissions and for IAS and then adjusting the Paris Test threshold (for territorial emissions only) downward by the cumulative amount of projected national IAS emissions up to the specified time horizon (2050). The ultimate test result (at the horizon year) is equivalent; albeit this methodology has the distinct disadvantage of obscuring the *temporal* evolution of total national warming contribution (particularly the amount and duration of threshold overshoot, which would certainly be affected by the temporal details of the projected IAS emission pathway).

For Ireland, Figure 18 shows an illustrative IAS CO_2-only scenario comprising the most recent recorded inventory and *With Additional Measures* projections [SI-14] from 2015–2040, and then followed by a (steep) linear decline to a presumed net zero in 2050. This is still an underestimate of this IAS scenario's resultant warming as it does not account for the additional non-CO_2 warming effects arising from aviation [SI-15]. This IAS scenario equates to a cumulative total of 115 $MtCO_2eq$ for 2021–2050 (upscaled ΔT of 0.08ºC), or 135 $MtCO_2eq$ for 2015–2050 (upscaled ΔT of 0.09ºC).

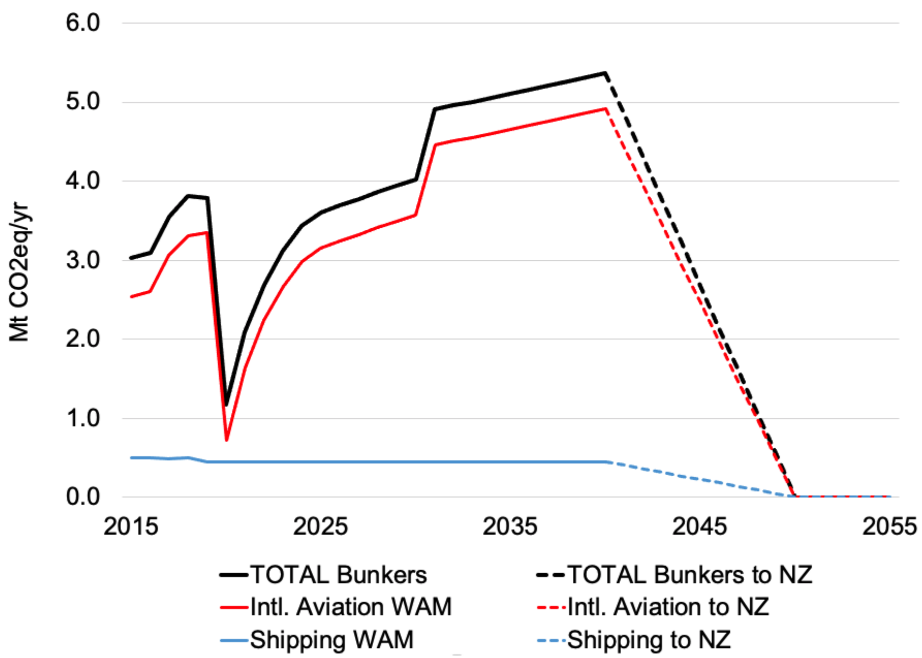

Figure 18. An illustrative IE IAS scenario in $MtCO_2eq/yr$ (mostly CO_2) comprising WAM projection to 2040 [SI-16] then assumed to proceed linearly to zero by 2050. Excludes non-CO_2 warming effects from aviation emissions. The areas under the curve from 2015 and from 2021 are the cumulative emissions values used for downward adjustment of Ireland's NCQ for strictly territorial emissions.*

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