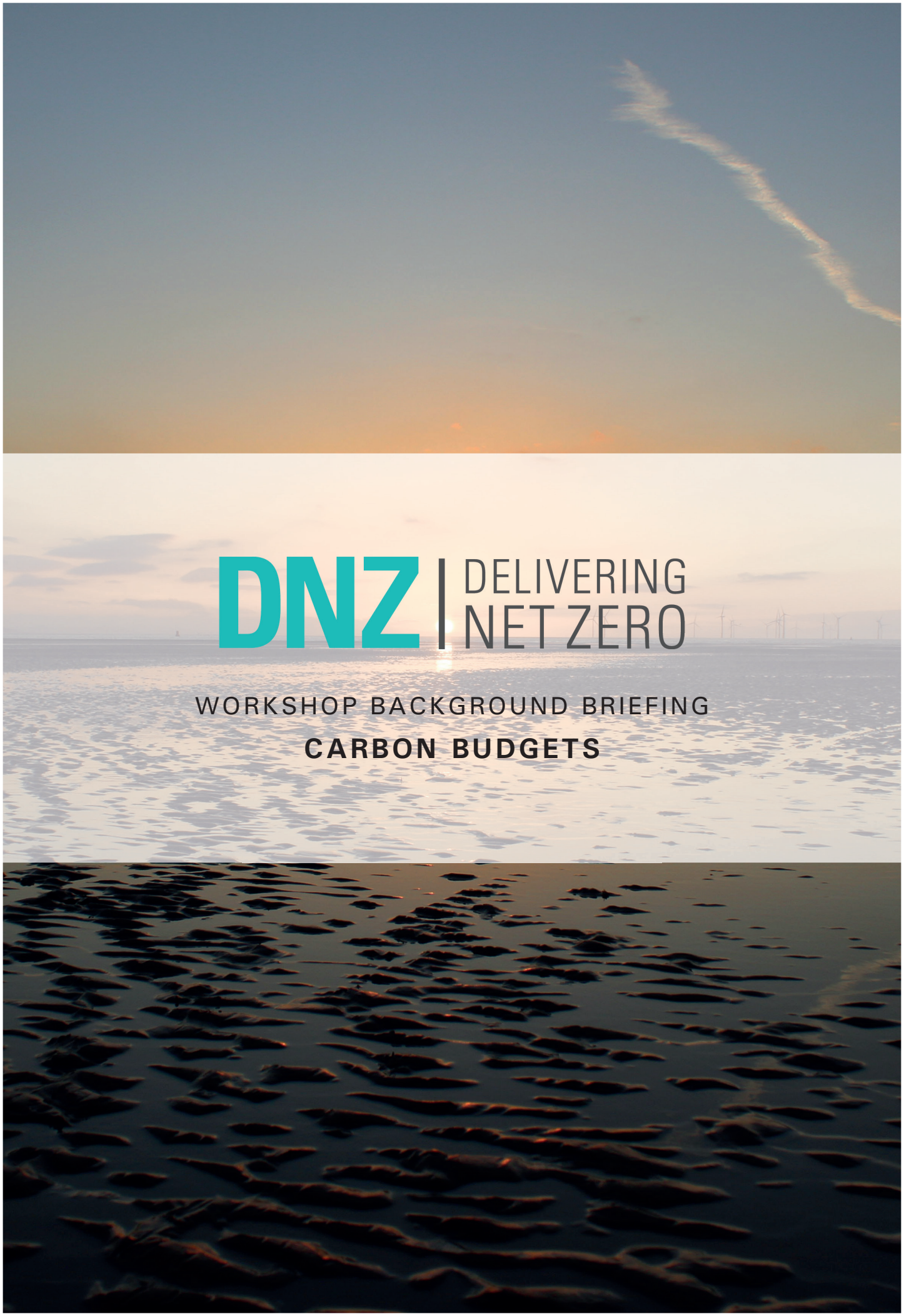


DNZ | DELIVERING NET ZERO

WORKSHOP BACKGROUND BRIEFING

CARBON BUDGETS

THE UK'S REMAINING CARBON BUDGET

The concept of 'carbon budgets' has become a prominent tool in guiding climate policy, particularly since its use in the IPCC's Fifth Assessment Report[1]. Remaining carbon budgets provide an estimate of the total global emissions of CO_2 that might be consistent with a given temperature rise[2,3]. Carbon budgets are based on a roughly proportional relationship between cumulative anthropogenic CO_2 emissions and average global temperature change[2]. This simplicity enables clear communication regarding the potential implications of additional emissions.

A series of studies have explored the quantity of CO_2 emissions that is likely to lead to a given level of temperature rise, defined as the 'transient climate response to cumulative emissions of CO_2' (TCRE)[2–11]. The TCRE is estimated using several sources of data, including historical observational records of cumulative CO_2 emissions and global average temperature increases, as well as earth system model simulations of historical and future climate[4]. The TCRE is estimated to be 0.2-0.7°C per 1000 $GtCO_2$[2].

ESTIMATING GLOBAL PARIS-COMPATIBLE CARBON BUDGETS: UNCERTAINTIES AND ASSUMPTIONS

Determining global and national remaining carbon budgets compatible with the goals of the Paris Agreement is not an exact science, but a process defined by significant physical and non-physical uncertainties and assumptions. These uncertainties, and their impact on estimating a Paris compatible global remaining carbon budget are unpicked below.

Whilst well established science indicates that anthropogenic emissions of greenhouse gases (GHGs) are increasing concentrations of GHGs in the earth's atmosphere, leading to global temperature rise, there are a range of uncertainties that occur when quantifying the level of emissions that will lead to a specific increased temperature level12. Part of this uncertainty is captured by the range of estimates for the TCRE (0.2°C - 0.7°C per 1000GtCO2). This range represents differences in the modelling of climate feedbacks on temperature rise, such as the loss of albedo effect from melting ice caps as the earth warms. This uncertainty leads to the expression of carbon budgets alongside the probability they have of meeting a particular temperature rise (see Figure 1)[12].

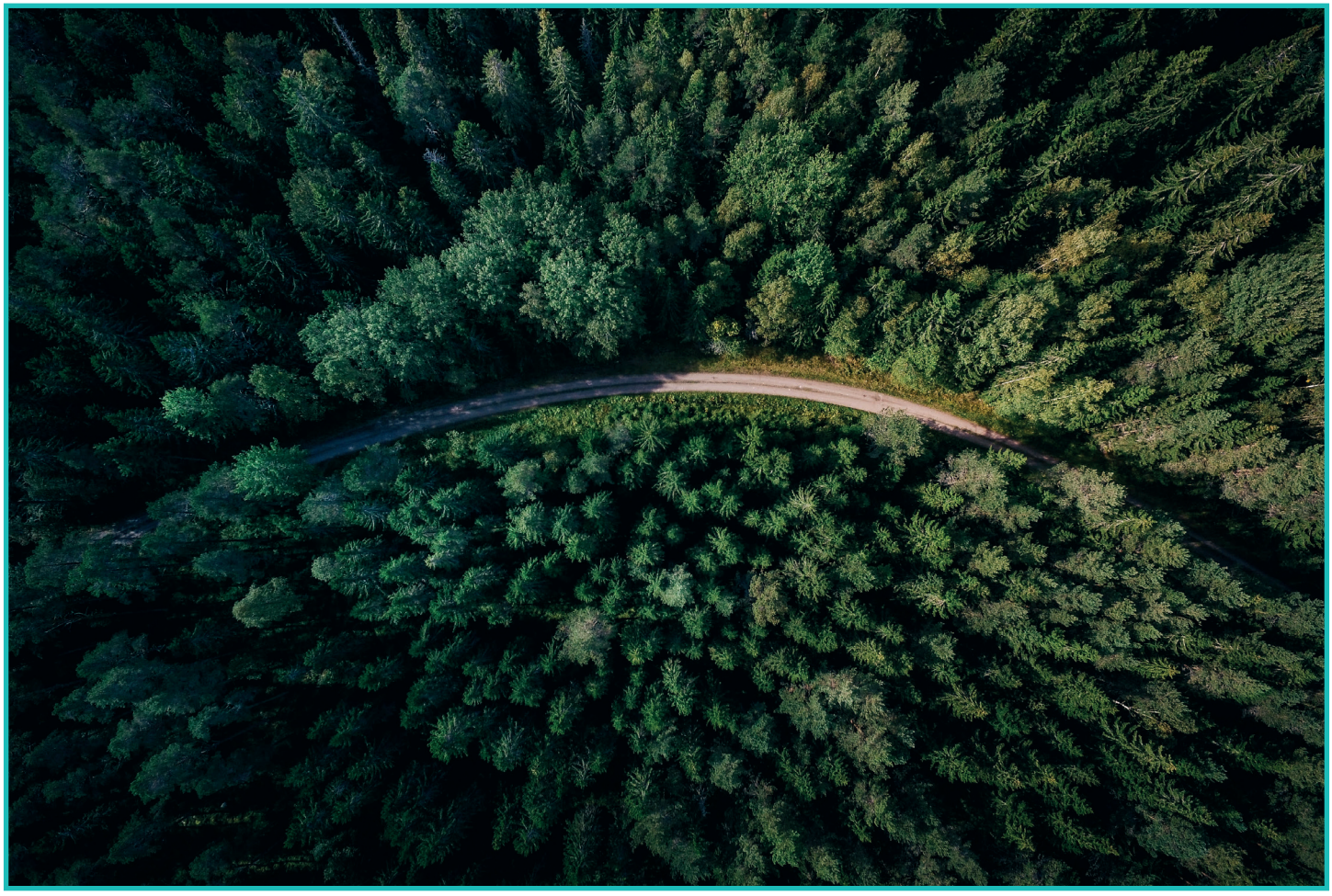
However, there are further physical uncertainties that are not accounted for in the TCRE. As listed in Figure 1 the most significant of these include: the impact of non-CO2 GHGs such as CH4 or N2O on temperature rise, the uncertainty range regarding present levels of historical temperature rise (0.8°C – 1.2°C)[13], and the impact of less well-modelled climate feedbacks such as CO2 released by permafrost thawing, or methane released from wetlands[12,14,15]. These climate feedbacks have the potential to reduce carbon budgets by 100GtCO2, however their impacts are unlikely to occur until 2100. Decisions made as to adjust or account for these factors, in light of the significant uncertainty around them, has a significant baring over the size of the remaining carbon budget presented.

FIGURE ONE

Additional Warming since 2006-2015 (°C)*(1)	Approximate Warming since 1850-1900 (°C)*(1)	Remaining Carbon Budget (Excluding Additional Earth System Feedback*(5) GT CO_2 from 1.1.2018*(2)			Key Uncertainties and Variations *(4)					
		Percentiles of TCRE*(3)			Earth System Feedbacks *(5)	Non-CO_2 scenario variation *(6)	Non-CO_2 Forcing and response uncertainty	TRCE distribution uncertainty *(7)	HIstorical temoerature uncertainty *(1)	Recent emissions incertainty *(8)
		33rd	50th	67th	($GTCO_2$)	($GTCO_2$)	$GTCO_2$)	($GTCO_2$)	($GTCO_2$)	($GTCO_2$)
0.3		290	160	80	Budgets on the left are reduced by about - 100 on centennial time scales	+250	-400 to +250	+100 to +200	+250	+20
0.4		530	350	230						
0.5		770	530	380						
0.53	-1.5°C	840	580	420						
0.6		1010	710	530						
0.63		1080	770	570						
0.7		1240	900	680						
0.78		1440	1040	800						
0.8		1480	1080	830						
0.9		1720	1260	980						
1		1960	1450	1130						
1.03	-2°C	2030	1500	1170						
1.1		2200	1630	1280						
1.13		2270	1690	1320						
1.2		2440	1820	1430						

In addition to these physical uncertainties described above, there are further uncertainties relating to definitional decisions, value-judgements and assumptions about the Paris Agreement itself that must be dealt with when defining a global carbon budget consistent with the Paris Agreement. The Climate Change Committee's (CCC) 6th Carbon Budget report[16] (Chapter 8, Section 3) outlines several of these in detail, including the definition of global warming that is used by the Paris Agreement, how global average temperatures are measured[17], the share of CO_2 and non-CO_2 gasses in global mitigation pathways[18], assumptions about future changes in non-GHG climate forcers such as aerosol particles, and whether or not to allow for temporary overshoot of the temperature target. As indicated by the CCC, these factors can have as big an impact as the physical uncertainties relating to climate sensitivity, with regards to the overall size of the global remaining carbon budget. As illustrated by the range of carbon budgets presented in Figure 1, these definitional assumptions and uncertainties mean a wide range of budgets may be consistent with temperature rises defined by the Paris Agreement.

Nonetheless, this uncertainty in defining specific global carbon budgets should not discourage attempts to quantify these, or prevent these carbon budget targets from guiding policy. After all, there is certainty that GHG emissions, caused by anthropogenic activity is leading to rising global temperatures. And that as temperatures rise, the impacts on human and ecological systems gets exponentially worse. More so, we understand the broadly linear relationship between emissions of CO_2, and increasing temperatures[2–11]. In other words, the more cumulative emissions of CO_2 produced, the higher temperatures will rise. The urgency generated by these established scientific facts suggests that so long as the carbon budgets used to guide policy are ambitious, are targeting temperature levels that may mitigate against the very worst climate impacts, and are acting by the precautionary principle to give a likely chance of achieving that target, carbon budgets can be a useful tool to help define the pace and ambition of reducing GHGs.



ALLOCATING NATIONAL PARIS-COMPATIBLE CARBON BUDGETS: FURTHER UNCERTAINTIES AND VALUE-JUDGEMENTS

Determining national level carbon budgets that are compatible with the Paris agreement requires many value-judgements, in addition to assumptions and uncertainties discussed above. After discussing some of these value judgements, this section compares two examples of UK-based carbon budgets and decarbonisation pathways from the literature: the CCC's latest 'Balanced Net-Zero Pathway'[16] and the pathways developed by Anderson et al.[19].

TERRITORIAL VS CONSUMPTION EMISSIONS ACCOUNTING

One important choice that impacts the size of the UK's remaining carbon budget is the method of accounting used to measure the UK's emissions. The Paris Agreement determines that parties are responsible for reducing their territorial emissions, i.e. those emissions produced within the UK's territorial boundaries. This emissions accounting method is open to criticism, as it omits emissions embodied in traded goods[20]. This presents issues when comparing countries with divergent emissions trends, because significant links between them are hidden. For example, developed countries have shifted significant amounts of production to developing countries, where labour and environmental standards can be weaker. The territorial emissions of developed countries subsequently decreases, yet they still derive benefit from the cheaper consumption of the goods produced[21–24]. Consumption-based accounting aims to solve this problem by attributing embodied emissions to the consuming country. Whilst territorial emissions are used in the Paris Agreement, for the UK to extend its climate action, methods to reduce emissions embodied in imported products and services should be considered as complementary to measures aimed at reducing territorial emissions[25].

INTERPRETING THE PARIS AGREEMENT

In order to derive national carbon budgets consistent with the Paris Agreement, several value judgements must be made to interpret the wording of the Paris Agreement. The first of these is deciding on a temperature rise target that best represents the Agreement. The Paris Agreement aims to limit temperatures to 'well below 2°C above pre-industrial levels, and pursuing efforts to limit the temperature increase to 1.5°C'[26]. Given the ambiguous nature of this temperature target, studies that quantify and assess Paris-aligned carbon budgets often use different temperature targets and select different probability levels for the likelihood of the carbon budgets to limit temperatures to that target. Alcaraz et al.[27] use a carbon budget aligned with 2oC (>66% chance) whilst Anderson et al.[19] target 1.7oC (50% chance). This judgement is important to defining the estimated remaining global carbon budget available that would be consistent with the Paris Agreement.

Another important interpretation of the Paris Agreement necessary to allocate national carbon budgets comes from the interpretation of the principle of 'common but differentiated responsibilities & respective capacity in light of national circumstances' (CBDR&RC)[26]. This principle is often understood to refer to socioeconomic differences between nations, differences in historical contributions to present levels of CO_2 concentration and the differences in countries respective capacities to reduce emissions[19]. This distributive justice principle has led to a significant number of methods employed distributing mitigation responsibilities, each emphasising a different interpretation or facet of equity. Summaries of these methods are given by Raupach et al.[28] and Du Pont et al.[29]. Given the Paris Agreement does not determine a method by which to internalise the CBDR&RC principle and apportion global carbon budgets to nations, whichever method is chosen has a significant impact on the size of national remaining carbon budgets.

This ambiguity in the Paris Agreement about how global emissions should be divided up between nations leads to very different budgets and decarbonisation pathways for the UK all claiming to be 'Paris aligned'. Below, two examples of UK carbon budgets & decarbonisation pathways that claim to be 'Paris aligned' are highlighted. They employ contrasting methods, value judgements, definitions and assumptions. One utilises a top down carbon budget methodology, allocated to the UK based on a resource-sharing approach[19], and a second developed by the CCC uses a bottom up method[16]. Whilst it is difficult to compare these approaches directly, their differences are illustrative of the broader point that varying UK carbon budgets and mitigation pathways can simultaneously claim to be aligned with the Paris Agreement.

Firstly, the CCC's 'Balanced Net-Zero Pathway'[16] employs a bottom up approach to setting carbon budgets and decarbonisation pathways. Rather than start at a global carbon budget consistent with the Agreement and divide this up using an allocation mechanism (as described by Du Pont et al.[29] or Raupach et al.[28]), the CCC conduct an analyses of the specific options available to reduce or offset emissions in each UK sector. These sectoral pathways are then aggregated to an economy wide level to arrive at a pathway to net-zero by 2050. This approach leads to a cumulative emissions carbon budget for 2020-2050 of 6976MtCO2e (including all GHGs) or 4696MtCO2 (CO_2 only). Via this bottom up methodology, the CCC argue that this budget represents the 'highest possible ambition' for the UK, as required by the Paris Agreement. They also argue this is consistent with the CBDR&RC principle, as the net-zero date is two decades earlier than the date at which global emissions need to reach net-zero (according to the IPCC SR1.5 50% emissions pathways[13]).

Whilst undoubtedly presenting a narrative of significant climate action for the UK, the CCC's scenario is largely made up of economically cost-effective measures of emissions reductions, only considering non-cost effective options where they support broader policy objectives. Additionally, it assumes relatively slow rates of change to societal practices such as reduced car kilometres or shifting diets compared with other studies[16,30–32]. This highlights another choice with regards to how terms in the Paris Agreement such as 'highest possible ambition', 'in light of national circumstances' and 'respective capacities' are interpreted, and the impact this has on the resulting mitigation pathways.

By contrast, Anderson et al.[19] employ a contrasting top down resource-sharing method of allocating national carbon budgets. After selecting a global carbon budget aligned with 1.7oC (50% chance), emissions are allocated to 'developing' countries first, allowing emissions to peak in 2025, and decline sharply from then . The remaining emissions are then divided up between 'developed' based on a country's present share of emissions relative to other 'developed' nations. This leads to a UK carbon budget of 3874MtCO_2 (CO_2 only). This method aims to take into account the CBDR&RC principles of the Paris Agreement by allowing a later peak and slower initial decarbonisation rates for developing countries. Whilst still very ambitious, this gives consideration to their smaller responsibility for historical emissions and lower capacities to decarbonise as a result of lower rates of socio-economic development. The key conclusion from these two contrasting methodologies and carbon budgets is that a wide range of carbon budgets for the UK can be considered 'Paris aligned', given the broad wording of the Paris Agreement and the numerous assumptions and value judgements necessary for producing carbon budgets. Moreover, due to the scientific uncertainties and definitional assumptions which produce a wide range of global carbon budgets that may by consistent with the Paris Agreement, assigning a singular carbon budget consistent with a specific temperature rise is not possible.

This uncertainty in providing a specific remaining carbon budget for the UK cannot be taken as a cause for inaction. In order to meet the urgency required to mitigate the worst impacts of climate breakdown, the most ambitious action must be pursued with an urgency that meets the scale of the crisis. This requires the pursuit of maximum possible reductions that stretch beyond significant political, economic, technical or social barriers present today. Pursuing these emission reductions, and overcoming these barriers will involve policy leavers not yet fully explored by government or industry, as explored further in the remaining Delivering Net Zero briefing documents.

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