Technical Annex

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UK carbon budgets and international emissions targets

Climate Change Act

1. Parliament passed the Climate Change Act[1] (the Act) in 2008, establishing the UK's 2050 target and the supporting framework of carbon budgets. The Act also established the Committee on Climate Change, now the Climate Change Committee (CCC), an independent statutory body, to advise the Government and the Devolved Administrations on setting and meeting carbon budgets. The CCC advises on the level of each budget, the respective contributions that different sectors could make and the extent to which carbon budgets could be met through the use of permitted "flexibilities" (such as surpluses from previous carbon budgets or the purchase of good quality international carbon credits).

2. Under the Act, the UK was legally required to reduce greenhouse gas emissions by at least 80 per cent by 2050 on 1990 levels. In 2019, on advice of the CCC[2], the UK committed to reaching net zero emissions by 2050 and consequently the target reduction in the Act was increased to at least 100%.

3. To keep the UK on a pathway to achieving the 2050 target, the Government is obliged to set legally binding, five-year caps on emissions – carbon budgets – twelve years in advance and then to publish a report setting out policies and proposals for meeting that budget and those budgets previously set.

4. The Net Zero Strategy is the means by which we satisfy the requirements of the Act in relation to policies and proposals for meeting the current carbon budgets.[3]

Legislated carbon budgets

5. Six carbon budgets have been set to date, covering 2008 to 2037. The sixth carbon budget, the first to be decided under the UK's new net zero target, was set in June 2021. The UK has already met, and overachieved, its first (2008-2012) and second (2013-2017) carbon budgets, and is on track to meet its current third (2018-2022) carbon budget.[4]

6. To show how we will meet our climate targets, including legislated carbon budgets up to and including the sixth carbon budget, the Net Zero Strategy contains both an indicative delivery pathway and illustrative 2050 net zero scenarios. The pathway, which stretches to the end of the Sixth Carbon Budget period in 2037, provides an indicative trajectory of emissions reductions which we aim to achieve through the Strategy and through delivery of the policies and proposals outlined. It therefore indicates the timescales over which we expect those policies and proposals to take effect to deliver our targets. The pathway is designed to be broadly consistent with all three of the illustrative 2050 scenarios set out in the Journey to Net Zero chapter of the *Net Zero Strategy*. There is uncertainty associated with our decarbonisation pathway through to 2037 and the 2050 scenarios – the exact path we take to meet our climate targets is likely to differ and must respond flexibly to changes that arise over time.

International emissions targets

7. The 2015 Paris Agreement[5] under the UN established the goal of keeping the global mean temperature rise to well below 2°C, whilst pursuing efforts to limit the rise to under 1.5°C. Under the Kigali amendment to the Montreal Protocol, the UK has also committed to reducing F-gas emissions by 85% on 2011-2013 levels by 2036.

8. Under the Paris Agreement, the UK announced its Nationally Determined Contribution (NDC) in December 2020, which commits the UK to reduce net greenhouse gas (GHG) emissions by at least 68% by 2030 compared to 1990 reference year levels.[6] This represents an increase of ambition on the fifth carbon budget, which covers the years 2028-2032.

9. The UK will therefore need to overachieve on the fifth carbon budget to meet its international climate targets and stay on track for the sixth carbon budget. Accordingly, the policies and proposals, delivery pathway, deployment assumptions and any other analysis presented in the Net Zero Strategy for the fifth carbon budget period are consistent with the action required to meet the UK's 2030 NDC.

10. The Net Zero Strategy also constitutes the UK's updated Long-Term Low Greenhouse Gas Emission Development Strategy for the purposes of the Paris Agreement.

Accounting for UK emissions

The UK greenhouse gas inventory

11. The UK's performance against its 2050 target and carbon budgets is assessed through the UK's net carbon account,[7] measured in tonnes of carbon dioxide equivalent (tCO_2e). The net carbon account comprises GHG emissions from the UK net of emissions which are captured and stored from land use, land-use change and forestry (LULUCF). The UK greenhouse gas inventory[8] is the basis for calculating the UK's domestic greenhouse gas emissions. Performance against a carbon budget is assessed against the earliest GHG inventory that covers the whole of the carbon budget period, which is published two years after the carbon budget period in question ends. For example, the sixth carbon budget will be assessed in 2039 based on the 1990-2037 GHG inventory.

12. The net carbon account also includes the UK's net purchases/sales of international carbon units, if any. Carbon units include allowances issued under cap-and-trade systems, and international carbon credits issued under international schemes. While the UK intends to meet its climate targets for each of carbon budgets 3 to 6 through reducing emissions domestically and the proposals and policies set out in this Strategy have been prepared on that basis, it reserves the right to use such voluntary cooperation under Article 6 of the Paris Agreement. This could occur through linking the UK ETS to another emissions trading system, or through the use of international emissions reductions or removals units.

13. The net carbon account for each budget is calculated according to rules set in Carbon Accounting Regulations.[9] The accounting regulations that apply to each of the carbon budgets may not be in place until after the carbon budget periods are over, so assumptions are required on what accounting rules will apply. Some key assumptions are outlined in the remainder of this section.

14. The international science behind measuring emissions is continually evolving and the assumptions made here do not preclude future decisions on emissions accounting at both the domestic and international level. If future accounting decisions turn out to differ from the assumptions made here, this would not automatically lead to a change in the budget levels. The Climate Change Act allows for legislated carbon budget levels to be amended if the government believes that, since the budget level was originally set, there have been significant changes affecting the basis on which the previous decision was made. Where such changes happen but no reset occurs, significant policy changes may be needed to meet the carbon budget.

Peatland emissions

15. Emissions from peatlands were only partially captured in the UK GHG inventory when the first five carbon budgets were set. A major revision to the inventory was implemented in February 2021 for the 1990-2019 inventory[10] to represent these emissions with methodologies consistent with the IPCC Wetlands Supplement[11], which will count towards all current and future carbon budgets. All analysis in this document includes peatland emissions in line with the updated inventory. This revision increased estimated emissions in 2019 by approximately 16 $MtCO_2e$ relative to the methods used in the previous inventory.

International aviation and shipping

16. The sixth carbon budget is the first that will include international aviation and shipping (IAS) emissions. Previous budgets have not included IAS emissions but were set such that headroom for IAS emissions was left. We have used bunker fuel sales to calculate IAS emissions for the sixth carbon budget. Under this method, IAS emissions are estimated from the amount of refuelling from bunkers at UK airports and ports, whether by UK or non-UK operators, for onward international journeys.

Global warming potentials

17. Emissions of each greenhouse gas (carbon dioxide, methane, nitrous oxide, fluorinated gases) are expressed in terms of carbon dioxide equivalent (CO_2e), recognising the different global warming potentials (GWP) of the different gases.

18. The UK greenhouse gas inventory currently uses 100-year GWPs published in the IPCC's Fourth Assessment Report (AR4).[12] However, it was agreed by the international community that GHG emissions would be reported under the Paris Agreement transparency framework using an updated set of 100-year GWPs from the IPCC's Fifth Assessment Report (AR5).[13, 14] Two sets of values for 100-year AR5 GWPs were published (with and without climate-carbon feedbacks, which reflect more indirect effects of GHG emissions on the climate system - included in their methodologies) and it is not yet clear which will be used. Therefore, to ensure that carbon budgets can still be met under either methodology, emissions pathways in the main body of the Net Zero Strategy are based on the higher AR5 GWPs with feedback methodology (consistent with the approach taken in setting the sixth carbon budget). However, this does not preclude any future decisions on which methodology will be used, and emissions pathways based on AR5 GWPs without feedback are also presented in this technical annex.

19. The use of AR5 GWPs without feedback results in a lower CO_2-equivalent value for UK GHG emissions compared to AR5 GWPs with feedback, meaning that less abatement would be required to meet the same carbon budget. As a result, it may appear that the policies and proposals in this strategy overachieve on our carbon budgets when based on AR5 GWPs without feedback. However, these provide additional headroom with which the Government could seek to manage uncertainty in emissions projections. We would review the cost effectiveness of maintaining this headroom as the necessary policies and proposals are implemented. Conversely, since the 2030 NDC is a percentage-based target and the base year to which that percentage relates comprises disproportionately high non-CO_2 emissions, slightly more abatement is actually required to meet the NDC under the lower AR5 GWPs without feedback compared to AR5 GWPs with feedback.

20. The Working Group I Contribution to the IPCC's Sixth Assessment Report (AR6)[15] was published in August 2021, which included updated estimates of 100-year AR6 GWPs. However, it is not yet certain if or when these will be used for GHG emissions reporting under the UNFCCC or Paris Agreement. UK GHG emissions based on AR6 GWPs would be closer to UK emissions based on AR5 GWPs without feedback than based on AR5 GWPs with feedback.

The UK Emissions Trading Scheme (ETS)

21. Calculations of carbon emissions by HMG historically followed a net accounting framework[16] that constructed the total carbon budget as a sum of two individual components: i) emissions covered by the EU Emissions Trading System (ETS), known as traded sector emissions (around one third of all UK emissions); and ii) emissions outside the EU ETS known as non-traded sector emissions. When the UK was part of the EU ETS, the UK share of EU ETS allowances was used to calculate traded sector emissions, and emissions in the non-traded sector were measured as actually emitted. The sum of these was the net carbon account.

22. Now that the UK is no longer participating in the EU ETS, UK operators are not trading emissions allowances with operators outside the UK. The new UK ETS came into operation on 1 January 2021, and it is only currently necessary to count emissions within the UK territory towards carbon budgets. We assume that all years from 2021 onwards will be accounted on this basis. If the UK ETS were later linked with another ETS it may be decided that an adjustment needs to be made to account for any trading of allowances.[17]

The UK's 2030 Nationally Determined Contribution

23. Accounting for the UK's nationally determined contribution is different from that for carbon budgets. In particular, the NDC is a fixed percentage-based target. This means that any changes to the inventory in the baseline year will change the level of effort required to meet the NDC, while the carbon budgets are fixed targets in $MtCO_2e$.

Accounting for UK climate targets

24. The above assumptions are summarised in Table 1, alongside the coverage and level of the UK's climate targets.

Table 1: Accounting basis of UK climate targets

	Carbon Budget 3	Carbon Budget 4	Carbon Budget 5	NDC	Carbon Budget 6
Years	2018-2022	2023-2027	2028-2032	2030	2033-2037
$MtCO_2e$ limit (annual equivalent)	2,544 (509)	1,950 (390)	1,725 (345)	% based target (estimated 262-275*)	965 (193)
Accounting basis	Traded/ non-traded split for 2018-2020 Territorial for 2021-22	Territorial UK emissions	Territorial UK emissions	Territorial UK emissions	Territorial UK emissions
International Aviation and Shipping (IAS)	Excluded	Excluded	Excluded	Excluded	Included
Base year (1990) emissions**	859.6	859.6	859.6	TBC*** (859.6)	883.3****
Percentage reduction on 1990 (implied for carbon budgets)*****	41%	55%	60%	68%	78%

*The range of emissions required to meet the NDC reflects uncertainty over whether AR5 with or without feedback GWPs are used. Uncertainty over baseline emissions in the 1990-2030 GHG inventory means the actual limit may lie outside this range.

**Base year emissions are calculated as emissions of CO_2, N_2O and CH_4 in 1990, and fluorinated gases in 1995.

***The baseline for the NDC will be determined by the GHG inventory 1990-2030, meaning that the abatement required to meet the NDC is dependent on future estimates of baseline emissions. Our estimate of that abatement is based on the UK 1990-2019 GHG inventory.

****The baseline for the sixth carbon budget includes 23.7 $MtCO_2e$ for IAS, based on bunker fuel sales.

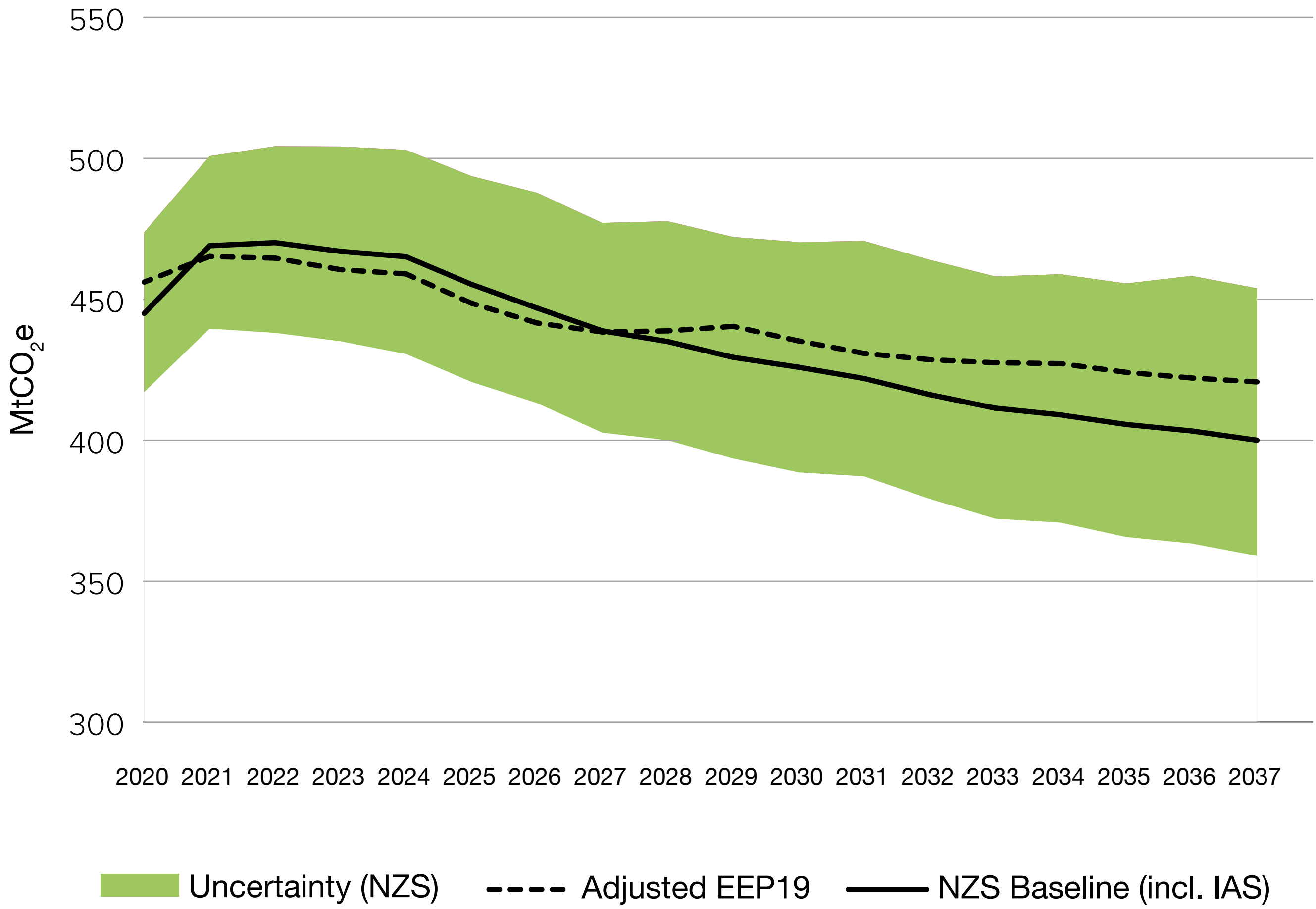
*****Estimates of historic UK GHG emissions are revised annually to incorporate methodological improvements, updated data and changes to international guidelines. The percentage reductions implied by CB levels are therefore subject to change.

Baseline emissions projections

25. While the GHG inventory is the source for historical emissions data, a combination of sector modelling and the BEIS Energy and Emissions Projections (EEP)[18] are used to project future emissions. This section sets out the assumptions about the baseline used for the purpose of this analysis. These projections determine baseline emissions for the indicative delivery pathway, based on policies implemented, adopted, or planned as of August 2019, and thus the further total emissions savings required to meet the carbon budgets. The baseline does not include policies announced in the Ten Point Plan, Energy White Paper, Transport Decarbonisation Plan, or the Industrial Decarbonisation Strategy.

26. In some sectors, adjustments to the EEP 2019 reference case,[19] published in October 2020, have been made to reflect developments in the evidence base since publication and to tailor it to ensure it is suitable as a baseline for the Net Zero Strategy. The adjusted EEP, referred to as the "baseline", incorporates the Office for Budget Responsibility's (OBR) central forecast of economic growth available in July 2020.[20] The baseline also includes some planned methodological improvements and corrections brought forward from the forthcoming EEP 2020, but no updates to policies beyond those included in EEP 2019. Table 2 provides details of these changes, and Figure 1 compares the differences across the series. The uncertainty range is explained further in paragraphs 45-48.[21]

Figure 1: Net Zero Strategy baseline compared to EEP 2019[22]



27. In accordance with the accounting rules represented in Table 1, all baselines are adjusted where relevant to be consistent with accounting assumptions for the relevant carbon budget.

Table 2: Differences between Net Zero Strategy baseline and EEP 2019 reference case

Sector	Change between EEP 2019 and Net Zero Strategy baseline	Impact on total CB6 emissions, 2033-37 ($MtCO_2e$)
All	Update of economic growth projections to the latest available OBR forecasts as of July 2020.	-42
All	Conversion of GHGs to CO_2e using Global Warming Potentials from AR5 with feedback compared to AR4 in EEP 2019.	+75
Buildings	Improvement of energy demand projections for domestic buildings. EEP 2019 did not fully account for technology improvements in new build dwellings beyond those directly attributable to Building Regulations.	-35
Buildings, Industry and Agriculture	Improvement to the methodology for alignment with UK Greenhouse Gas Inventory estimates for mobile machinery and other oil emissions. This results in lower emissions in agriculture and buildings, and higher emissions in industry.	Negligible net impact.
Buildings	Inclusion of estimates of short-term behaviour change in 2020 on energy demand in public buildings.	Impact limited to 2020-2021.
Buildings	Inclusion of estimates of short-term behaviour change in 2020 on energy demand in domestic buildings.	Impact limited to 2020-2021.
Industry	Improvement of energy demand projection methodology for chemicals and construction industry subsectors.	+38
Industry	Alignment of projections of emissions from refineries with the Net Zero Industrial Pathways model to reflect the impact of UK and global decarbonisation under a net zero consistent world scenario.	-22
Fuel supply	Alignment of projections for offshore oil and gas with projections from the Oil and Gas Authority (OGA).	-42
Power	Power sector evidence base has been updated to latest data available. This includes a revision to Energy from Waste (EfW) emissions where EEP2019 underestimated these due to an error in the percentage of EfW that is renewable. In addition, some policies included in EEP2019 have been removed as these are considered to be pre-Energy White Paper, in particular further Nuclear beyond HPC, and building one Gas CCS plant. Offshore Wind capacity is 15 GW higher in 2035 than in EEP2019 as further CfD auctions and planning means more capacity is on track to be built. There is also more large solar capacity building due to lower costs for this technology in up to date evidence.	-9

Sector	Change between EEP 2019 and Net Zero Strategy baseline	Impact on total CB6 emissions, 2033-37 ($MtCO_2e$)
Transport	Inclusion of estimates of short-term behaviour change in 2020 in road transport and domestic aviation.	Impact limited to 2020-2021.
Transport	Correction of a calibration error in EEP 2019 which led to an underestimation of the amount of oil in the historic fuel mix for transport.	+14
Transport	Closer alignment of national navigation and fishing emissions estimates with research commissioned by the Department for Transport.	+<5
International Aviation and Shipping	Inclusion of estimates of short-term behaviour change in 2020 on international aviation.	Impact limited to 2020-2021.
International Aviation and Shipping	Closer alignment of international shipping estimates with research commissioned by the Department for Transport.	+7

28. There is ongoing uncertainty over how the COVID-19 pandemic will affect emissions in the long term. In 2020, emissions fell,[23] but it is not yet clear what the effect will be on future emissions. We have assumed that there is no long-term behavioural change due to the pandemic. However, as stated above, the baseline is adjusted for the reduction in economic growth and the short-term behaviour changes occurring due to the COVID-19 pandemic. [24]

Sector definitions

29. The precise definition of the sectors used by the Net Zero Strategy, marked against IPCC categories, is published separately to this document.[25] A summary of the coverage of each sector is shown in Table 3. Where sector chapters cover more than one of these sectors, the below table shows which sectors are covered by which chapter.

Table 3: Net Zero Strategy sector definitions

NZS Sector	Sector chapter	Sector definition
Power	Power	Emissions from power stations (Major Power Producers only), including those generating energy from waste.
Fuel Supply	Fuel Supply and Hydrogen	Emissions from the extraction, processing, and production of fuels (chiefly oil, coal, gas and hydrogen).
Industry	Industry	Emissions from industrial processes, manufacturing, and production, including fuel combustion and product use in industrial buildings, as well as emissions from refineries and construction machinery. Includes emissions from non-Major Power Producers auto-generation and Combined Heat and Power.
Heat and Buildings	Heat and Buildings	Emissions from public, commercial, and residential buildings, including domestic product use such as garden machinery and composting.
Domestic Transport	Transport	Emissions from all forms of road and rail transport, domestic aviation and domestic shipping (including fishing vessels).
International Aviation and Shipping		Emissions from fuel used in international aviation and international shipping, as measured by UK bunker fuel.
Agriculture	Natural Resources, Waste and F- Gases	Covers emissions from livestock, crop soils and agricultural machinery.
Forestry and Other Land Use		Emissions and removals from land use change, forestry, peatlands and other carbon stock change from land use (e.g. in the biomass pool).
Resources and Waste		Emissions from the treatment and disposal of solid and liquid waste and landfill, including emissions from incineration not used to generate energy (e.g. incineration of chemical waste).
Fluorinated Gases (F-gases)		Fluorinated gas emissions, primarily from refrigeration, air-conditioning, heat pumps, aerosols, and high voltage switchgear.
Greenhouse Gas Removals	Greenhouse Gas Removals	Negative emissions from engineered removal technologies, including direct air and bio-energy carbon capture and storage.

Illustrative 2050 net zero scenarios

30. The Net Zero Strategy explores three possible net zero scenarios in 2050 in chapter 2, building on the pathways developed for the sixth carbon budget Impact Assessment. These have been deliberately selected to illustrate a wide range of outcomes for the economy that are possible by 2050. However, different outcomes within this range or beyond this range are also possible.

31. This analysis has primarily two objectives:

a. First, to examine three different scenarios of economy-wide decarbonisation to understand the range of possible long-term outcomes and therefore inform the short-term delivery pathways. Through previous modelling and research, BEIS has identified three areas of technology and resource uncertainty likely to have a substantial impact on the 2050 energy system.[26] The scenarios have been developed in consultation with internal experts to illustrate feasible avenues to achieving net zero emissions based on:

- The relative role of electrification and hydrogen in fuel switching;
- The role of land-use and bioenergy to produce negative emissions; and
- The role of further innovations to address the hardest to abate sectors of the economy.

b. Second, it confirms that all three scenarios are consistent with the policies and proposals set out in the Strategy to meet the sixth carbon budget.

32. This section explains the methodology that was used for this analysis and summarises the differences between the three scenarios. It also shows illustrative sectoral emissions in 2050 and accompanying deployment characteristics.

Overview of the methodology used to develop the 2050 scenarios

33. The net zero scenario modelling primarily uses the UK TIMES Model (UKTM), a least-cost, optimisation model covering all UK emissions (including land use) and the UK energy system over the period 2010 to 2060.[27] The model includes assumptions about technology costs, availability, performance, and build rates.[28] It also includes assumptions for future fossil fuel prices and energy services demand by end-use sector. These inputs are pre-determined for each model run and do not vary with deployment. Based on the input assumptions, the model identifies the least-cost way of meeting a given GHG reduction trajectory while also meeting assumed end-use demand for energy services. Further information on the methodology and assumptions used in the UK TIMES model can be found in Annex A.2 of the sixth carbon budget impact assessment.[29]

34. An extensive exercise has been undertaken to ensure UKTM is aligned with the latest evidence base and assumptions used across government. Where this was not possible, off-model adjustments have been made to the net zero scenarios.

35. A particular advantage of UKTM is that it identifies the least-cost technology pathway for a given set of assumptions, taking account of interactions across energy supply and end-use sectors over time. The model is therefore useful for identifying which technologies could be essential or important in the long run for achieving a low cost, net zero consistent energy system. It also helps identify the appropriate sequencing of abatement opportunities.

36. However, there are a number of limitations to the modelling:

- The model does not directly take account of uncertainty of any kind over future technology costs and availability. Uncertainty is only displayed through the range of outputs given by the different scenarios.
- Technology cost reductions over time are based on fixed assumptions and do not directly account for cost reductions through widescale deployment in the model. i.e. costs are not a function of deployment.
- No additional barriers beside cost and technical build rates are considered, no potential industrial benefits from developing and deploying new low-carbon technologies are considered. Modelling does not consider any upside or downside risks to the economy arising from the transition.
- Behavioural or other practical considerations that might make certain pathways more or less expensive to achieve are not accounted for (other than where they are reflected in costs or build rates).
- The model varies in detail by sector. In some areas only high-level representations are provided and the model is not spatially disaggregated.

37. The three scenarios are summarised below:

- **High electrification:** explores the impact of using widespread electrification to support transport, heating, and industry decarbonisation coupled with deep decarbonisation of electricity supply.
- **High resource:** explores the impact of using low-carbon hydrogen more extensively, particularly for decarbonising buildings and heavy vehicles. It assumes higher levels of tree-planting are achievable, increasing the ‘negative emissions’ available from land-use sinks.
- **High innovation:** explores a world in which successful innovations, such as synthetic fuels and zero emission aircraft, enable lower residual emissions to be reached sooner in aviation. Higher capture rates – above baseline assumptions – increase the impact of carbon capture technologies, particularly higher deployment of direct air capture.

38. The scenarios were constructed in the UKTM by varying input assumptions for:

- The extent to which technologies can be rolled out. For example, in the high electrification scenario 100% of buildings are set to be heated by electricity in 2050, whereas in the high resource scenario heat pump deployment is constrained and this figure drops to 40%.
- Availability of resources and technologies. For example, in the high resource scenario, we assume 50kha afforestation per annum by 2050 (compared to 30kha in the other scenarios). Higher efficiency capture technologies are only available in the high innovation scenarios (for example CCUS capture rates of 99% compared to 95% in most cases in the other scenarios).
- For sectors such as industry and aviation, where the UKTM does not represent the full range of known abatement options, supplementary adjustments to emissions, energy demand, and key deployment requirements have been made. These have been taken into account in the optimisation of other sectors via the specification of the emission targets.

39. Other assumptions were kept the same across the scenarios. For instance, projections of final demand for end-use sectors are consistent with those used in the central 2037 delivery pathway and are the same for each of the modelled 2050 scenarios. Technology and resource cost assumptions, including fossil fuel prices, are also the same across each scenario. Sensitivity analysis conducted as part of the sixth carbon budget Impact Assessment showed that the impact of economic growth and fossil fuel prices on the technology mix in 2050 is relatively small, therefore these effects were not considered further.[30] Finally, sector emissions to 2037 were aligned to those in the delivery pathway described in the Strategy. For further key assumptions by sector see the evidence base section of this annex.

40. Table 4 shows the level of emissions in 2050 implied by each of the three illustrative scenarios. All scenarios meet net zero in 2050, with removals technologies compensating for any residual emissions.

Table 4: Illustrative total territorial emissions under the different scenarios

Sectors	2019 emissions ($MtCO_2e$)	2050 illustrative emissions ($MtCO_2e$) High electrification	High resource	High innovation
Power	58	3	2	1
Industry	78	3	3	10
Fuel Supply	26	0	5	8
Heat and Buildings	88	0	0	2
Domestic Transport	122	3	4	5
International Aviation and Shipping	45	35	35	21
Agriculture and LULUCF	63	20	14	21
Waste and F-gases	40	12	13	13
Greenhouse Gas Removals	0	-75	-76	-81
Total emissions	**520**	**0**	**0**	**0**

41. Given the long-term scientific uncertainty and to err on the side of caution, the analysis above assumes AR5 with feedback GWPs. On the basis of AR5 without feedback GWPs the scenarios would reach c.-9 $MtCO_2e$ in 2050 as a result of primarily lower emissions from methane. This uncertainty represents less than 2% of the overall abatement requirement. Because of this, detailed sensitivity analysis on GWPs has not been carried out for the purposes of this strategy. However, lower GWPs could allow less reliance on removals in 2050 thereby lowering the requirements for sustainable biomass, or alternatively slightly higher end-use sector emissions.

Characteristics of the 2050 scenarios

42. To illustrate the assumptions underpinning the 2050 scenarios, Table 5 shows deployment characteristics for each sector. These are illustrative of the levels of deployment required for each of the three scenarios. Not all technology deployment required to meet net zero is represented.

Table 5: Illustrative characteristics in 2050

Sector	Deployment assumptions	Unit	2019	2050 illustrative range
Power	Electricity generation	TWh	320	610-690
	Low carbon GB generation as a percentage of total projected generation	%	56%	99-100%
Industry	Low carbon fuel switching*	TWh	110	190-210
	Resource and energy efficiency savings	$MtCO_2e$	0	13
	Industry demand for industrial CCUS (not including BECCS)	$MtCO_2e$	0	6-9
Fuel Supply	Low carbon hydrogen production	TWh	0	240-500
	Steam methane reformation with CCS (as a percentage of total hydrogen generation)	%	0	0-75%
	Electrolysis as a percentage of total hydrogen generation	%	0	15-75%
	Biomass gassification with CCS as a percentage of total hydrogen generation	%	0	0-20%
Heat and Buildings	Cumulative heat pumps installed domestically	Million installations	0.2	12-28
	Cumulative homes converted to 100% hydrogen	Million homes	0	0-14
	Demand reduction as a result of energy efficiency measures	%	0	15-20%
	Low carbon fuels* consumption as a percentage of total fuel consumption in commercial buildings	%	62%	90-100%
	Heat supplied via heat networks	TWh	14	70
	Biomethane injected into gird	TWh	3	0-20
Agriculture and LULUCF	Total area of peatland under restoration	kha	n/a	380
	Yearly area of afforestation UK	kha	13.6	30-50
	Yearly area of perennial energy crop and short rotation forestry planted	kha	0	53
	Farmers engaging with low carbon farming practices as a percentage of total farmers	%	60%	100%
Waste and F-gases	Level of HFC consumption relative to a 2015 baseline level	%	63%	15%

Sector	Deployment assumptions	Unit	2019	2050 illustrative range
Greenhouse Gas Removals	BECCS (all technologies)	$MtCO_2e$	0	52-58
	DACCS	$MtCO_2e$	0	18-29
Transport and IAS	ZEVs as a percentage of total car fleet	%	0.3%	96-97%
	ZEVs as a percentage of total van fleet	%	0.2%	88-90%
	ZEVs as a percentage of total HGV fleet	%	0%	95-97%
	ZEVs as a percentage of total bus and coach fleet	%	0.3%	91-95%
	Low carbon fuels* use in road transport as a percentage of total fuel use (in litres)	%	5%	30-60%
	SAF use in domestic and international aviation as a percentage of total fuel use (in tonnes)	%	0%	5-30%
	Low carbon fuels use in domestic and international shipping as a percentage of total fuel use (in TWh)	%	0%	97%
Overall	GDP carbon intensity	tCO_2e/ GDP £m2020	194	0
	GDP energy intensity	MWh/ GDP £m2020	700	270-310

*The table includes several deployment assumptions covering relevant low carbon fuels in different sectors. The low carbon fuels included are the following: electricity, biofuels, solid biomass, hydrogen, ammonia, and methanol. All these deployment assumptions include electricity and hydrogen both in the numerator and denominator, with the exception of low carbon fuels used in road transport (from which electricity and hydrogen are completely excluded).

Meeting the carbon budgets

43. This section sets out historic performance against carbon budgets and future performance implied by the delivery pathway, including emissions broken down by sector for each future carbon budget. Deployment assumptions that illustrate some of the real-world changes required to meet carbon budgets are also presented.

44. The UK has overperformed on its carbon budgets so far, by 37 Mt CO_2e for the first carbon budget and 384 Mt CO_2e for the second carbon budget. Table 6 shows the current baseline projections for future carbon budgets (reflecting policies as of August 2019),[31] and also the overall pathway for emissions as set out in the *Net Zero Strategy*.

Table 6: Projected emissions implied by pathway against current and future carbon budgets

	CB3	CB4	CB5	CB6 (incl. IAS)
Years covered	2018-2022	2023-2027	2028-2032	2033-2037
Baseline	2,499	2,052	1,889	2,029
Budget limit	2,544	1,950	1,725	965
NZS emissions pathway	2,499	1,854	1,312	962
Performance against carbon budget	-45	-96	-413	-3

Uncertainty over future emissions

45. Table 7 shows an indicative annual range over the sixth carbon budget period.[32] The lower and upper ranges are based on Monte Carlo analysis of the EEP, conducted in 2018 and assessed to represent the best evidence of the uncertainty in the projections for the sixth carbon budget period.[33] The analysis reflects a 95% confidence interval around the baseline to reflect uncertainty in future macro trends (such as GDP, and population size), uncertainty in the impacts of certain existing policies on emissions and uncertainty in the current evidence base on emissions (such as land use emissions). It also uses regression residuals to account for structural modelling uncertainty in the EEP. The analysis does not capture uncertainty in the policies and proposals brought forward under the Strategy.

46. Due to accounting changes, further emissions have recently come in scope of the sixth carbon budget period. The Monte Carlo analysis has therefore been augmented to include these emissions. The range around historical emissions for international aviation and shipping is estimated based on statistical volatility in historical emissions. Emissions added following the adoption of the Wetlands Supplement assume the uncertainty is proportional to the overall uncertainty in the LULUCF sector.[34]

47. The pathway is highly ambitious meaning there are downside risks to the estimated policy savings (for example, delays to delivery), as well as upside risks (for example, no long-run behavioural impacts are assumed as a result of the COVID-19 pandemic). Government will monitor progress against the pathway as set out in the Embedding net zero in Government chapter, and will prepare further proposals and policies to enable the carbon budgets to be met as necessary.

Table 7: Provisional indicative range of the carbon account over the sixth carbon budget

	2033	2034	2035	2036	2037
Upper	279	265	240	226	207
Central	232	215	190	171	153
Lower	193	177	150	131	112

48. Emissions across the period prior to the sixth carbon budget are also uncertain: the Government will provide further analysis in future Energy and Emissions Projections.

Sectoral emissions over the carbon budgets

49. Table 8 shows an indicative emissions pathway, broken down by sector across the fourth, fifth and sixth carbon budgets. The fifth carbon budget figures are aligned with the UK's NDC, and 2030 values have been used for this column. To reflect uncertainty from macroeconomic trends and in underlying baseline emissions, emissions for each sector are shown as a range. These ranges are calibrated to the uncertainty range set out in the economy wide EEP Monte Carlo analysis.[35]

50. Whilst the ranges below represent our current assessment of the right trajectory to meet our carbon budgets, developments in climate science, accounting regulations, baseline emissions, technological progress and/or policy impacts may alter the expected impact of policies set out in the strategy, or the optimal distribution of policy effort across sectors. Future climate strategies will update this sectoral emissions pathway where necessary using the latest evidence.

Table 8: Sectoral emissions across the carbon budgets: $MtCO_2e$ per year (using AR5 with feedback GWPs)

Sector	Current (2019)	CB4 (average 2023-27)	NDC (2030)	CB6 (average 2033-37)
Agriculture and LULUCF	63	51 to 57	44 to 52	38 to 48
Buildings	88	73 to 82	55 to 66	34 to 47
Domestic Transport	122	100 to 111	67 to 80	29 to 43
Fuel Supply	26	18 to 20	14 to 16	10 to 12
Industry	78	58 to 65	36 to 45	19 to 29
Power	58	28 to 31	14 to 17	9 to 11
Waste and F-gases	40	24 to 27	17 to 20	12 to 15
Greenhouse Gas Removals	0	0 to 0	-12 to -1	-33 to -11
Intl Aviation and Shipping*	45	(42 to 46)	(44 to 50)	39 to 46
Total (incl. IAS)	**520**			**192**
Total (excl. IAS)	**476**	**371**	**262**	

*Figures in parentheses indicate that IAS is not counted towards that target

51. As set out above, there is some uncertainty which set of Global Warming Potentials the UK will adopt. We have therefore also translated these pathways using alternative AR5 without feedback GWPs, assuming it were optimal in cost- and non-cost terms to implement the same set of policies and proposals modelled in the AR5 with feedback pathways.

Table 9: Sectoral emissions across the carbon budgets: $MtCO_2e$ per year (using AR5 without feedback GWPs)

Sector	Current (2019)	CB4 (average 2023-27)	NDC (average 2030)	CB6 (average 2033-37)
Agriculture and LULUCF	54	43 to 48	37 to 44	31 to 39
Buildings	88	73 to 82	55 to 66	34 to 47
Domestic Transport	122	100 to 111	67 to 80	29 to 43
Fuel Supply	25	18 to 20	13 to 16	10 to 11
Industry	78	58 to 65	36 to 45	19 to 29
Power	58	28 to 31	14 to 17	9 to 11
Waste and F-gases	34	21 to 23	14 to 17	10 to 13
Greenhouse Gas Removals	0	-1 to 0	-12 to -1	-33 to -11
Intl Aviation and Shipping*	44	(42 to 46)	(44 to 50)	39 to 46
Total incl. IAS	**503**			**182**
Total excl. IAS	**458**	**359**	**251**	

* Figures in parentheses indicate that IAS is not counted towards that target[36]

Illustrative deployment assumptions to meet the carbon budgets

52. To illustrate some of the deployment assumptions underpinning the emissions pathway, Table 10 below shows real-world deployment assumptions for each sector. Not all of the policies and proposals underlying the delivery pathway are represented by these assumptions. Ranges indicate where values differ between the electrification and hydrogen pathways set out in the strategy for the heat and buildings sector. In some cases, these assumptions represent early-stage assessments based on maximum technical potential. Given ongoing uncertainties, the policy mix that will meet carbon budgets, and related deployment assumptions, are subject to change; these are illustrative and should not be interpreted as government targets.

Table 10: Deployment assumptions underpinning pathway

Sector	Deployment assumptions	Unit	2019	2025	2030	2035
Power	Electricity generation	TWh	320	315	370	460*-510
	Low carbon GB generation as a percentage of total projected generation required in 2035	%	29%-33%*	38%-42%*	62%-69%*	99%
Industry	Low carbon fuel switching[a]	TWh	110	115	125	157
	Resource and energy efficiency savings	$MtCO_2e$	0	1	10	11
	Industry demand for Industrial CCUS (not including BECCS)[b]	$MtCO_2e$	0	2	5	7
Fuel Supply	Low carbon hydrogen production	TWh	0	10**	40	80-140*
	Electrical power demand from offshore oil and gas installations as a percentage of their total power demand	%	0%	0%	31%	43%
Heat and Buildings	Cumulative heat pumps installed domestically	Million installations	0.2	1.1	4*- 4.3	6.9* - 11.3
	Cumulative homes converted to 100% hydrogen for heat	Million homes	0	0	0-0.2*	0-4*
	Yearly homes treated by new domestic energy efficiency measures	Million homes	0	0.5	1	0.5
	Low carbon fuels[a] consumption as a percentage of total fuel consumption in commercial buildings (excluding heat networks)	%	62%	63%	67%	78%-81%*
	Yearly heat supplied via heat networks	TWh	14	16	22	29
	Yearly biomethane injected into the grid	TWh	3	8	12	12

Sector	Deployment assumptions	Unit	2019	2025	2030	2035
Agriculture and LULUCF	Yearly area of peatland under restoration in England	Ha	2,000-5,000***	7,000	10,290	10,290
	Yearly area of afforestation in the UK	Ha	13,600	30,000	40,000	50,000
	Yearly area of perennial energy crop and short rotation forestry planted	Ha	0	7,440	21,275	26,350
	Farmers engaging with low carbon farming practices as a percentage of total farmers	%	60%	70%	75%	85%
Waste and F-gases	Level of HFC consumption relative to a 2015 baseline level	%	63%	31%	21%	15%
Greenhouse Gas Removals	BECCS and DACCS	$MtCO_2e$	0	0	6	23
Domestic transport	ZEVs as a percentage of total car fleet	%	0.3%	6%	24%	53%
	ZEVs as a percentage of total van fleet	%	0.2%	2%	14%	40%
	ZEVs as a percentage of total HGV fleet	%	0%	0%	9%	37%
	ZEVs as a percentage of total bus and coach fleet	%	0.3%	9%	25%	48%
	Single track kilometres electrified per year	Km	0	350	650	650
	Low carbon fuels[a] use in road transport as a percentage of total fuel use (in litres)	%	5%	7%	8%	8%
	Journeys in towns and cities that are cycled and walk as a percentage of total journeys in towns and cities	%	42%	46%	50%	55%
	SAF use in domestic aviation as a percentage of total fuel use (in tonnes)	%	0%	1%	3%	6%
	Low carbon fuels use[a] in domestic shipping as a percentage of total fuel use (in TWh)	%	0%	0%	1%	42%

Sector	Deployment assumptions	Unit	2019	2025	2030	2035
International Aviation and Shipping (IAS)	SAF use in international aviation as a percentage of total fuel use (in tonnes)	%	0%	1%	3%	6%
	Low carbon fuels*** use in international shipping as a percentage of total fuel use (in TWh)	%	0%	0%	1%	28%
Overall	GDP carbon intensity	tCO_2e/ GDP £m2020	194	144	93	62
	GDP energy intensity	MWh/ GDP £m2020	700	600	480	380-400*

* Reflects deployment in hydrogen pathway.

** Figure reflects hydrogen demand in the mid-2020s (rather than 2025 specifically).

*** The 2019 range for peat reflects different estimates of peat restoration in England, including both public and externally funded work.

[a] The table includes several deployment assumptions covering relevant low carbon fuels in different sectors. The low-carbon fuels included are the following: electricity, biofuels, solid biomass, hydrogen, ammonia and methanol. All of these deployment assumptions include electricity and hydrogen both in the numerator and denominator, with the exception of low-carbon fuels used in road transport (from which electricity and hydrogen are completely excluded).

[b] Industrial carbon capture deployment starts in the mid-2020s, reaching a total of 6Mt in 2030 and 9Mt in 2035 including carbon capture from biomass use.

Costs and economic impacts of the transition

Costs of the transition

53. Table 11 shows the additional investment costs for the indicative delivery pathway in each of the future carbon budgets relative to a baseline of existing policies. These represent in-year capital expenditure requirements, excluding financing costs, and do not cover operational costs or savings, or policy costs. Costs are expressed in real 2020 prices as average annual values over the carbon budget periods. The costs of the delivery pathway remain highly uncertain and will depend on factors such as technology costs and fuel prices. Ranges, where given, represent the implication of higher or lower demand from end-use sectors consistent with the electrification and hydrogen scenarios.

Table 11: Estimates of additional investment requirements for Net Zero Strategy pathway (£bn pa, undiscounted, 2020 prices)

Sector	Carbon Budget 3 (average 2020-2022)	Carbon Budget 4 (average 2023-2027)	Carbon Budget 5 (average 2028-2032)	Carbon Budget 6 (average 2033-2037)
Power*	1	7-8	11-22	12-23
Fuel Supply	0.3	2.0	1.3-2.3	0.6-1.9
Industry	0.0	0.9	1.1	0.9
Heat and Buildings**	2	12	12	14
Transport	2	8	17	18
Natural Resources, Waste, and F-Gases[37]	0.6	1.2	1.7	2.6
Greenhouse Gas Removals	0.0	0.7	1.6	1.7
CCUS (T&S Infrastructure)	0.0	0.6	1.2-1.4	0.8-1.0
Total	5-6	32-33	48-59	52-61

*Figures exclude additional Transmission and Distribution Network investment requirements.

**Costs represent a scenario where heat is predominantly decarbonised via electrification through heat pumps.

54. Table 11 excludes operating costs to avoid double counting (e.g. where CAPEX in an energy supply sector is OPEX in an end-use sector). Over the same period, we could see additional resource savings of around £180 billion as a result of our reduced use of oil/petroleum products and natural gas. This has been calculated by multiplying the change in energy demand (relative to the baseline) by the corresponding long-run variable cost of energy supply (LRVCs) from The Green Book. This is based on the central price and the savings could be higher or lower, depending on how future prices evolve.

Other economic and fiscal considerations

Economic considerations

55. There are many economic impacts of the transition to net zero to consider. As shown above, there are significant capital investment requirements, and although the exact requirements are uncertain it is clear that patterns of investment will have to change. New jobs will also be created, and these jobs may require different skills and education. Consumption and production behaviours will shift towards greener choices, and different places and sectors in the UK could face different economic opportunities and challenges.

56. Previous cost benefit analysis of the sixth carbon budget showed that there are significant co-benefits to the transition to net zero.[38] As well as the benefits from reduced greenhouse gas emissions, improvements to air quality were valued at £35 billion to 2050, fuel savings at £123 billion and other benefits to natural capital at £5 billion. The net present value of meeting the sixth carbon budget and net zero target, compared to no further action, was estimated as a net benefit of £266 billion.[39] This calculation does not include many other potential co-benefits, such as reduced noise pollution from cars, improved health from walking and cycling and warmer homes from energy efficiency measures, nor indirect costs from macroeconomic impacts.

57. In terms of the macroeconomic impact of the transition to net zero, the Office for Budget Responsibility (OBR) finds that the costs of failing to get climate change under control, which relies on global effort, would be much larger than those of bringing emissions down to net zero.[40] In terms of transition costs, the OBR has presented scenarios in which the level of UK GDP changes relative to the baseline by between -4.6% and +1.6% by 2050, with a central estimate of -1.4% for early action on climate change compared to -4.6% for late action. These changes are small when set against expected growth of over 50% in real GDP to 2050 compared to today's levels. Further information on the economic impacts of the transition to net zero are set out in the HMT ***Net Zero Review***.[41]

Competitiveness

58. The transition to net zero can stimulate innovation that increases domestic competitiveness and global comparative advantage for some UK industries, providing potential export opportunities. Updated internal analysis based on the Energy Innovation Needs Assessment estimates that just over half of the £60 billion GVA potential from sectoral decarbonisation in 2050 comes from export related opportunities.[42] However, there will also be risks to sectors and industries susceptible to competitiveness impacts, particularly those that are trade-exposed and/or carbon intensive. Where UK firms lose market share to international firms with lower environmental standards, there is a risk of carbon leakage. There is little empirical evidence of this occurring in the UK to date, but risks could increase as further policy is implemented.

59. Historically, the UK's approach to mitigating competitiveness impacts and carbon leakage risk has been through issuing free allowances under the EU ETS.[43] This approach has been carried over to the UK ETS, and possible changes to free allowances are currently under review.[44] BEIS also provides compensation to certain energy intensive industries for the indirect emission cost due to the UK ETS and some sectors receive a reduction in energy consumption tax via Climate Change Agreements. The eventual impact of decarbonisation on firms at risk will depend on future policy development, particularly relating to the UK ETS.

60. The magnitude of competitiveness effects in international markets is dependent on global climate ambition as well as domestic policy. If other countries, particularly the UK's trading partners, increase their industrial decarbonisation ambition in line with the UK's, and face similar transition impacts, then competitiveness effects will be smaller. Similarly, where the UK's path to net zero creates export opportunities for UK businesses, the size of these will depend on the actions of the rest of the world. High global climate ambition will result in a large market for decarbonisation technologies and services but may also result in more global competition in those markets.

Fiscal considerations

61. The overall fiscal impacts of the transition to net zero will depend on many as yet unknown factors, including the financing mechanisms used to fund the policies and proposals set out in the Net Zero Strategy, and the macroeconomic impacts of the transition, for example through changes in GDP growth or inflation. There are some known fiscal impacts, such as the erosion of direct tax receipts like fuel duty that depend on carbon intensive activity, and increased tax receipts from other policies, such as revenue from the UK ETS.

62. HMT's *Net Zero Review*[45] and the OBR's recent fiscal risks report[46] provide a more detailed overview of the channels through which the net zero transition can impact the UK's fiscal position, and the factors which will determine the overall magnitude of this impact. While noting uncertainties, the OBR concluded that there could be significant fiscal benefits from transitioning to net zero sooner rather than later. However, governments public spending will be dependent on the economic, fiscal and decarbonisation context of the time.

Jobs

63. The policies and sectoral ambitions across the *Net Zero Strategy* are estimated to support up to 190,000 jobs in low carbon and green sectors by the middle of the 2020s, and up to 440,000 by 2030. The breakdown of jobs by chapter is as follows. Information on the methodology used to calculate these numbers can be found in the evidence base section of this annex.

Table 12: Estimate of jobs supported in Net Zero Strategy pathways, by sector and date

Sector	Jobs supported by 2024/5	Jobs supported in 2030
Power	59,000	120,000
Fuel Supply	N/A	10,000
Industry	5,000	54,000
Heat and buildings	100,000	175,000
Transport	22,000	74,000
Natural resources, waste and F-gases (forestry only)	2,000	2,000
Greenhouse Gas Removals	N/A	N/A
Total	190,000	440,000

64. *The Ten Point Plan for a Green industrial Revolution*[47] published in November 2019 set out plans to support up to 250,000 jobs by 2030, which was based on specific sectors included within the *Ten Point Plan*. The figures in this *Net Zero Strategy* include areas not covered by the *Ten Point Plan*, such as solar and onshore wind. In several cases, most notably around Heat and Buildings and Transport, figures have been updated since the *Ten Point Plan* was announced.

65. Government has also set out its ambition to pivot towards a green economy supporting up to 2 million green jobs by 2030. This is a wider ambition which includes areas of economic activity not included in the Net Zero Strategy but which support other environmental goals, such as climate adaptation and the circular economy.

Wider impacts of the transition to net zero

66. Section 10 of the Climate Change Act lists various factors that must be taken into consideration by all decisions relating to carbon budgets, while Section 13 requires that the policies and proposals set out in the *Net Zero Strategy* as a whole contribute to sustainable development. These factors have been taken into account in relation to proposals and policies that will enable the UK to meet its carbon budgets, as set out throughout this annex and in the main body of the Strategy.

Table 13: Summary of wider considerations

Factor	Consideration in Net Zero Strategy	Conclusions
Scientific knowledge	See Climate Science Annex	The scientific case for strong action on climate change remains definitive.
Technology	See Journey to Net Zero, sector chapters, Technical Annex	The latest evidence on relevant climate technologies has been used for all analysis across the strategy.
Economic	See Technical Annex, Why Net Zero, Green Jobs, Skills, and Industries, Investment, Innovation, Green Choices and Local Climate Action chapters	There are many economic and competitiveness impacts of the transition, some of which are positive and some negative. We make no overall conclusion.
Fiscal	See Technical Annex	The full fiscal impact of the transition is not yet known and will depend on varied policy decisions and economic outcomes.
Sustainable development	See Reducing Emissions across the Economy chapters, Technical Annex, Embedding Net Zero chapter	There are both positive and negative natural capital impacts associated with emissions reduction policies but the overall contribution to sustainable development is likely positive. Other aspects of sustainable development are addressed in the economic, fiscal and social sections.
Energy policy	See Journey to Net Zero and Power chapters, and Technical Annex	Delivering our carbon budgets has the potential to reduce demand for gas, coal, oil and transport fuels which could improve security of supply by diversifying away from primarily imported fossil fuels. Other measures will mean increases in electrification and the simultaneous deep decarbonisation of electricity supply, which carries security of supply risks. Estimations of the future energy and carbon intensity of the economy are presented in Table 10 of the Technical Annex.
Social	See Technical Annex, Green Choices, and Buildings chapters	Price and bill impacts will depend on electricity market developments and consumption patterns. Policies that improve energy efficiency of homes will reduce bills and benefit fuel poor households.
IAS	See Technical Annex, Transport chapter	IAS emissions will be included from the sixth carbon budget onwards and will use the bunker fuel sales method to calculate emissions. Projected IAS emissions are set out in Table 8.
International and European	See International climate leadership and Why Net Zero chapters	The UK has world leading ambition on climate change and is committed to advancing global climate action. The UK has now left the EU and is no longer bound by EU climate policies.

Factor	Consideration in Net Zero Strategy	Conclusions
Devolved circumstances	See sector chapters and Technical Annex	The NZS pathway analysis includes modelling of the scope to reduce emissions in each nation, considering their differing circumstances. These assumptions are broadly in line with the CCC's distributions of abatement by nation. Key assumptions are outlined in the evidence base section below.

67. The following section considers two of these impacts in more detail: sustainable development, which is considered through analysis of the effects of policies and proposals on natural capital; and social considerations, including the potential impacts on energy bills and fuel poverty.

Sustainable development and natural capital

68. Sustainable development concerns the stability and prosperity of society, and its capacity to provide for future generations. Sustainable development also incorporates social, economic, and environmental dimensions of sustainability. The Act requires carbon budget proposals and policies as a whole to contribute to sustainable development. The main outcomes of the policies and proposals in this Strategy will have a positive impact on the UK's contribution to the global Sustainable Development Goals, in particular goal 7, targeting affordable and clean energy, and goal 13, targeting climate action.

69. In this section, we assess the sustainability implications of the net zero transition in terms of its impact on the continuation and improvement of environmental functions, and stability and renewal of natural assets. This is most relevant to the Sustainable Development Goals 6, 14 and 15, which target protection of water and life on land and marine habitats.

70. In line with HM Treasury Green Book, a natural capital perspective is taken to analyse these implications, whereby the impact of policies and proposals on the natural assets on which the economy depends is assessed.[48] It is not yet possible to provide a complete assessment of the delivery implications of policies and proposals, as many are still subject to designs and implementations upon which the impacts are dependent. The extent that the natural capital impacts are mitigated will be dependent on the options considered in policy specific delivery analysis.

71. To assess the potential natural capital impacts of a policy, a series of screening questions are used.[49] Following this, the main benefits and risks associated with net zero policies are listed for different natural capital stocks. This is an indicative assessment of the natural capital impacts due to the limitations described above. As such, the large majority of measures in this strategy require further natural capital assessment. All policies will be assessed for natural capital benefits and risks in their impact assessments and business cases according to Green Book guidance. This includes considering the implications of policies for natural assets and any associated effects on wider economic welfare. More information on the natural capital approach can be found in the Green Book supplementary guidance and the Enabling a Natural Capital Approach guidance.[50]

72. Delivery of net zero policies and proposals will need to consider the UK's other legally binding environmental commitments (for example, new legally binding targets stemming from the Environment Bill), and any trade-offs against these acknowledged and mitigated through careful planning policies and actions can be designed that deliver multiple outcomes in support of the UK's net zero and 25 Year Environment Plan ambitions. For instance, the planting of broadleaf trees and restoration of peatland or grassland can deliver carbon sequestration as well as environmental benefits including improved biodiversity and water quality, if done in the right way. Conversely, certain interventions such as planting of maize for biomass or food may risk soil health and water quality. It will be important to assess the wider impacts of proposed net zero actions and seek synergies with environmental ambitions wherever possible, so that the twin challenges of biodiversity loss and climate change are tackled in an efficient way.

73. The independent Natural Capital Committee defined natural capital as 'those elements of the natural environment which provide valuable goods and services to people'.[51] Nature underpins the UK's economy and society: the energy, food, and water we consume; the air we breathe; our access to green space; and biodiversity, which is crucial in underpinning all our ecosystem and abiotic services, and in maintaining ecological function.[52] Nature is a major economic sector in its own right – as a productive asset it provides market and non-market services of £25 billion each year.[53]

74. The policies and proposals taken together within the Net Zero Strategy are expected to have a significant net benefit to natural capital and thus sustainable development. Moving away from i) fossil fuels towards a greater share of renewable energy, ii) petrol and diesel cars towards green alternatives such as electric vehicles iii) gas boilers to lower carbon heating sources and iv) high carbon land uses towards afforestation and other land-based carbon dioxide removals, are just a few examples that will provide significant benefits.

75. However, some negative impacts to some natural capital stocks are likely to arise from realising climate targets; impacts will likely be specific and localised. For example, the development of BECCS technology could lead to a rise in PM2.5 released in these areas. The direction of impact from the significant land use change required to meet net zero will depend on how and where this change is enacted, with a systemic and spatial approach more likely to deliver on net zero while providing natural capital benefits. Further in-depth exploration of the natural capital impacts of specific policies and policy mixes will need to be undertaken through the normal channels of Impact Assessments and Business Cases, to ensure trade-offs are managed and impacts mitigated.

76. Air Quality: As climate change and air pollution have many of the same contributing emission sources, the decarbonisation of the UK economy offers major opportunities to significantly reduce air pollution and therefore improve human health and reduce the impact of some air pollutants on ecosystems. This is primarily driven through the reduction of petrol and diesel cars towards green alternatives, as well as the continual shift away from fossil fuels in heat and power generation. However, some policies and proposals could result in significant negative air quality impacts at both regional and local scales, for example emissions of fine particulate matter from biomass combustion, ammonia from the use of anaerobic digestion, and NOx emissions from hydrogen combustion in domestic or industrial settings. These are likely to impact our ability to reach statutory national emissions ceilings, increase exposure to harmful pollutants and cause some uneven health burdens. Furthermore, the impacts of air pollution can also impact the delivery of net zero. For example, all of England's forests and peatlands continue to be damaged by harmful emissions – particularly ammonia – which impact their ability to provide the ecosystem services required to meet net zero, including carbon sequestration and flood mitigation. Historic pollution loading across all habitats may also need to be ameliorated to maximise the potential of restoring them to meet the biodiversity targets in the Environment Bill. Further work will be undertaken to assess this and provide advice on tailoring our pathway to minimise these impacts. Continuous improvements in emission requirements and innovation in abatement technologies will also be necessary to deliver a pathway to net zero that maximises environmental benefits.

77. **Recreation:** Achieving climate targets could have positive impacts for recreation and the provision of landscape amenity, with a transition to a low carbon economy providing spaces to enjoy nature. This will primarily be driven by new woodland creation for recreation and forestry more widely (where access permitted), woodland management and restoring peatlands. Green transport will also provide the opportunity to regularly access green spaces, parks and woodlands. Some policies may cause landscape issues for example, solar and onshore wind generation.

78. **Biodiversity:** In the long-term, net zero policies, for example, afforestation and peatland restoration, can be positive for biodiversity, preservation, connectivity, resilience and reducing ecological stress caused by climate change. However, biodiversity and habitats are spatially explicit, meaning locations and extent of future policies must seek to minimise any negative impacts, including displacement, air and noise pollution, and habitat loss, for example through housing or industry development. This could be minimised through further work on net gain principles which would seek to leave the environment in a better position. Other risks include ensuring land use changes (i.e. afforestation, biomass feedstocks, settlement expansion) do not lead to biodiversity loss. Mitigating actions and trade-offs will be considered when designing policies for reaching climate targets, including for low carbon technologies, greenhouse gas removals, marine policies, land management, and agricultural intensification.

79. **Floods:** Global temperature rise is leading to increased precipitation levels within the UK. There are a number of nature-based solutions such as the creation of new woodlands, planting of biomass crops such as willow, increased levels of upland peatland restoration, and strategically located natural flood management measures which can have positive impacts on flood risk management. For example, increased upland water storage improves the capacity of the UK's waterbodies to prevent floods downstream. This will have varied benefits through reducing damages from floods to property, agricultural land and health, and reduced carbon emissions from floods. Conversely, rewetting lowland peatlands may reduce the water storage capacity of those landscapes with possible impacts on local flood risk.

80. **Water availability and quality:** Whilst many policies have positive impacts on water availability and quality, for example through upland peatland restoration and strategic planting of trees, some low carbon technologies are water-intensive and large-scale implementation could result in pressures on water demand. For example, nuclear power and hydrogen production require high levels of water input for cooling and electrolysis, respectively and certain biomass crops (for use in BECCS) have high water demand. This is set against a backdrop of increasing global water scarcity in a changing climate. The UK is no exception, with increasing likelihood of warmer, drier summers. Therefore, water demand both regionally and nationally should be considered at a systems level, to ensure sustainable demand.

81. **Raw materials:** Resource efficiency policies will have a net benefit to pressures on raw material availability, reducing raw material demand and consumption. Reduced resource extraction and processing will also benefit other natural capital assets. For example, 90% of global biodiversity loss and water stress is caused by resource extraction and processing.[54] Moving towards a circular economy, where priority is placed on extending the lifetime and lifecycle of a product through sharing, reusing, repairing, redesign and recycling, is likely to have a positive impact on a number of natural capital stocks, primarily water quality and availability, air quality and reducing pressures on land use.

82. **Rare metals:** Materials are finite. Some low carbon technologies are dependent on critical raw materials, many of which are rare, found in unique locations and in high demand globally, for example cobalt, lithium and nickel. Many of these rare metals are sourced internationally and extraction of them may place pressure on the natural capital stock in the country of origin. There are risks associated with overreliance on specific technologies where raw material scarcity may grow and geopolitics may determine access, for example, rare earth elements such as neodymium for use in magnets. These risks will be assessed in relevant policy delivery analysis.

83. **Land Use:** Land is finite. Meeting climate targets will require significant and competing demands from land, for example, for food, shelter, goods and service production, ecosystem services and greenhouse gas abatement. This will result in large changes to land use and management. The pathway in the Net Zero Strategy is reliant on land use change linked to tree planting, peat restoration and growing perennial energy crops or short rotation forestry for use as biomass. This change will impact on the extent and condition of natural capital assets and the ecosystem services they provide. The direction of impact (positive or negative) and its magnitude will depend on how and where land conversion happens. A systemic and spatial approach to land use, that considers net zero, socio-environmental objectives, and various socio-economic factors such as population and economic growth, is necessary to enact land use changes that delivers net zero as well as environmental outcomes in line with the 25 Year Environment Plan. Such an approach enables trade-offs to be managed among different objectives while facilitating win-win outcomes- for instance with flood protection and recreation.

Social considerations

84. Over the last decade there have been changes in the underlying costs of energy bills, which have been mitigated through energy efficiency measures, helping consumers to use less energy. Electricity prices have trended upwards due to rising network costs and support for low carbon infrastructure and vulnerable households. Gas prices have fluctuated due to international wholesale gas prices, which in recent months have been particularly volatile.

85. Government energy saving schemes have been targeted towards low-income or vulnerable households, and the retail energy price cap has helped protect those customers on default energy tariffs. Steps have also been taken to protect industries most exposed to the UK's relatively higher industrial electricity prices.

86. The policies set out in the *Net Zero Strategy* will help insulate consumers from the over-reliance on fossil fuels which they face today, and help to shield households, business, and the wider economy from the destabilising effects of this reliance.

87. How electricity and gas bills will change on the path to net zero depends on factors such as technology costs, patterns of consumer energy use and the government's gradual approach to rebalancing where social and policy costs fall. The nature of costs in a smart, clean energy system will be different. The largest part of the electricity bill is currently the cost to energy suppliers from buying power. This cost has traditionally been determined by the underlying price of gas or coal, but this is changing. Gas will continue to play a role in setting the electricity price for some years to come but, over time, will do so less frequently, as more and more low carbon generation (such as wind and solar) connect to the electricity system - consistent with the commitment to a fully decarbonised power system by 2035. This will help put downward pressured on wholesale electricity prices.

88. Patterns of energy consumption will also change. Most households and businesses are likely to increase their use of electricity, but reduce gas and petrol/diesel consumption, as they shift to low carbon forms of transport and heating (such as electric vehicles and heat pumps). It is essential to ensure that price incentives are fair and help support this transition away from relying on fossil fuel prices.

89. It will remain the case that households and businesses who install energy saving measures will reap significant savings.

90. As we progress towards net zero, the Government is committed to ensuring the costs of decarbonising the energy system are fair and affordable for all energy users. We are considering both the benefits and the costs of different pathways holistically across the economy and will work with industry and consumers to keep costs down.

91. The impact of decarbonisation on progress in tackling fuel poverty will be determined by changes in electricity and fuel prices, and higher energy efficiency in the housing stock. In particular, policies to improve energy efficiency in homes - such as the Social Housing Decarbonisation Fund, Home Upgrade Grant, Energy Company Obligation and proposals on Minimum Energy Efficiency Standards - will help to improve the building performance for the homes of those in or at risk of fuel poverty. The Warm Homes Discount will support fuel poor homes through reduced bill costs. Fuel poverty is a devolved matter. In England we are committed to our target for fuel poor households, as far as reasonably practicable, to be living in a home rated EPC Band C or better by 2030. Scotland, Wales and Northern Ireland have their own fuel poverty targets and are also working to improve the energy efficiency of their building stock.

Evidence base

Sectoral evidence

Power

BEIS' Dynamic Dispatch Model (DDM) has been used to generate technically feasible pathways that are consistent with achieving the NDC in 2030, the sixth carbon budget in 2033-37 and net zero in 2050.[55] This model was developed by BEIS and is used for all power sector analysis within the department. This includes the Modelling 2050 – Electricity System Analysis report that was published with the *Energy White Paper* and the Energy and Emissions projections.[56] It was also used for the power sector analysis in the CCC's *Sixth Carbon Budget* report although the CCC used their own assumptions and off-model adjustments for this.[57] Assumptions for the Northern Ireland power sector demand and emission pathway are based on the CCC's Sixth Carbon Budget advice.

The DDM relies on many exogenous assumptions and inputs, and results can be sensitive to changes in these assumptions. This includes using electricity demand from UKTM and other sectors analysis and evidence on different technologies costs and characteristics from BEIS' generation costs report.[58] Both full pathway runs and single year analysis is used to underpin the strategy set out in the power sector chapter.

Distribution Network outcomes are modelled in the Distributions Networks Model (DNM). The DNM conducts electricity power flow analysis across 10 representative regional networks to estimate future distribution network constraints (thermal violations and voltage imbalances). The results of the constraint analysis are then fed into a separate investment model to calculate reinforcement costs up to 2050.

Investment costs for power plant generation capacity and flexible assets are calculated from the DDM based on technological costs assumptions. Transmission and Distribution Network costs have been calculated separately. The costs for networks provided are in Allowed Revenues terms. Allowed Revenue estimates are the costs that network operators will be allowed to recover annually – as decided by Ofgem as part of their RIIO price control process. These are therefore the network costs that will be passed through each year. They do not represent the total value of investment in assets.

The 2050 illustrative scenarios represent the power sector at a less granular level than DDM. Supplementary adjustments and results were validated by DDM but should not be read as predictive of the optimal technology mix in 2050. For a detailed assessment of potential scenarios for the 2050 electricity system please consult the *Modelling 2050: electricity system analysis* published alongside the *Energy White Paper*.[59] The high electrification scenario assumes no hydrogen availability for power to illustrate an alternative power sector trajectory.

Fuel Supply and Hydrogen

Hydrogen: The hydrogen demand needed to meet the sixth carbon budget in industry, power, buildings and transport was estimated as set out in the evidence base sections for those sectors. The hydrogen production capacity needed to meet this demand has been calculated assuming hydrogen production plants run at a 95% load factor. Evidence on hydrogen supply and demand has also been drawn from the *Hydrogen Strategy*: further detail can be found in the *Hydrogen Strategy* analytical annex.[60, 61] Estimates of hydrogen production costs are based on the evidence set out in the hydrogen production cost report.[62]

Upstream Oil and Gas: The pathway for upstream oil and gas was developed using the OGA's projected abatement from offshore electrification and flaring.

Estimates of potential abatement from offshore electrification (scope 1 emissions only) were developed using the best available data provided to the OGA by industry as of August 2021, and assumes that there will be a mixture of some installations being partially electrified and some being fully electrified (the list of these installations was provided by industry). Fully electrified installations were estimated, in line with industry representatives' assessment, to have 70% of power demand provided by electrification, while partially electrified ones have 43%. Additionally, it is assumed that project phasing is one year and that electrification of the installation would not affect previously reported economic cessation of production dates.

The estimate of GHG emissions abatement via flaring reduction from offshore oil and gas infrastructure was developed assuming that zero routine flaring will be in place across all UKCS assets in 2030. Routine flaring is assumed to be broadly consistent with category 1 flaring (now defined by the OGA as category A flaring). Future expected flare volumes were calculated by subtracting the routine element of flaring from total anticipated flaring per facility after 2030, with data taken from the *UK Stewardship Survey*. Flared gas values, in both mass and volume units, have been converted to CO2 emissions using emission factors observed in published datasets (e.g. EEMS).[63]

Capex assumptions for Upstream Oil and Gas abatement measures have been sourced from the CCC's *Sixth Carbon Budget advice*. The overall cost profile has been calculated by BEIS and is aligned to the deployment trajectory underpinning the sector's illustrative emissions pathway. This is an early analysis with significant uncertainties. Through discussion with the OGA BEIS is confident that these estimates are in the right order of magnitude, however actual costs might end up being higher.

Hydrogen and other fuel supply assumptions for 2050 are aligned with those used in the *Sixth Carbon Budget Impact Assessment*. The level of curtailment available for electrolysis was taken directly from the power sector modelling.

Industry

A model of the UK industrial sector called Net Zero Industrial Pathways (NZIP) has been used to generate a technically feasible pathway to achieve a net zero industry sector by 2050. The model was developed by Element Energy for BEIS and the Climate Change Committee (CCC)[64] and was used to underpin the manufacturing and construction sector analysis in the CCC's *Sixth Carbon Budget report*[65] and the Government's *Industrial Decarbonisation Strategy* (IDS),[66] published in March 2021. The industry pathway required to reach net zero is based on the IDS National Networks scenario but achieves a faster trajectory through earlier decarbonisation of the Iron and Steel sector and increased CCS ambition by 2030. The model calculates the least cost pathway for a range of technologies, assessed on their capital and operating costs, along with cost reductions over time due to technology learning, and a number of key constraints impacting their deployment (e.g. technology readiness level, hydrogen and CO_2 transport and storage availability, supply chain capacity).

The 2050 scenario analysis includes supplementary adjustments to align the UKTM emissions, energy demands and CCS requirements with the evidence base in NZIP IDS 2050 scenarios. In the high electrification and high resource scenarios these align with the National Networks scenario, whilst the high innovation scenario is more representative of the Cluster Networks scenario.

Heat and Buildings

Both heat and buildings scenarios are developed to be consistent with completely decarbonising buildings by 2050 to meet a net zero target. With the assumption that a typical heating appliance has a lifetime of 15 years, this implies that no new fossil fuel heating systems can be installed after 2035. The high electrification scenario assumes that hydrogen is not available as an option for heating buildings, so the level of heat pump deployment grows from its current level of around 35,000 in 2020 to be able to meet the turnover of fossil fuel systems in 2035. In scenarios involving hydrogen, heat pump deployment meets the common ambition of 600,000 heat pumps by 2028, and further growth is dependent on the level of hydrogen deployment to generate the same level of carbon savings between scenarios. Installation of energy efficiency measures and deployment of low carbon heat networks is assumed to be same in all scenarios.

Domestic Energy Efficiency: The domestic energy efficiency modelling was carried out using the National Household Model.[67] This model estimates the impact of installing different measures in different properties by applying the Standard Assessment Procedure[68] to a representative sample of the housing stock based on the English Housing Survey.[69] Further adjustments are made to modelled savings to account for factors such as the real-life performance of measures and people heating their homes to a more comfortable temperature when their energy bills are reduced. Cost data for different measures comes from a variety of published sources, as well as some internal data.[70, 71, 72] The deployment profile for measures was estimated based on current and planned policies and proposals.

Non-Domestic Buildings - Commercial and public: The sixth carbon budget pathway for commercial and public sector buildings was created using BEIS Non-Domestic Buildings Model (NDBM). This models the deployment of low carbon heating and energy efficiency measures in non-domestic buildings. The NDBM uses building stock characteristics and potential energy efficiency information from the Building Energy Efficiency Survey (BEES) dataset.[73] Data on energy consumption and emissions come from the Digest of UK Energy Statistics, Energy and Emissions Projections, and ECUK.[74, 75, 76] The model has been supplemented with updated information on off-gas grid buildings from the Non-domestic National Energy Efficiency Data-Framework (ND-NEED); and updated cost and efficiency assumptions for Heating Ventilation and Cooling (HVAC) technologies in non-domestic buildings.[77] Modelling assumptions for public sector buildings have been further refined through monitoring the on-going rollout of phase 1 and 2 of the Public Sector Decarbonisation Scheme.

Products Policy: For products policies, as well as the sources listed above, additional data is taken from the ONS, consultation with trade associations and research provided by external contractors to develop the evidence base. The average energy consumption of products in the pathway are compared to the market average to calculate energy savings, taking into account product lifetime, usage and different technology types. Costs associated with products price increases, staff labour and training and installation costs are also taken into account, as well as interaction with EU and international trade and product regulations.

Domestic Heat Pumps: Deployment of domestic heat pumps is based on simple analysis of the residential stock, segmenting homes by heating fuel, and considering natural replacement cycles. The trajectory of heat pumps is based on estimates of deployment from current and planned policies, supply chain growth required to meet phasing out of new fossil fuel heating systems, and use of the natural replacement cycle to remove all fossil fuel heating in homes by 2050. Assumptions on appliance costs and performance, and on potential supply chain growth, are based on published research.[78, 79, 80] Assumptions on the current building stock and heat demand are from the NHM and domestic NEED.[81, 82] Assumptions on new build homes are based on DHLUC's 2019 FHS Consultation stage Impact Assessment - these were produced externally by consultants and an independent consortium.[83] These are for appraisal purposes only, and are not an official forecast of housing supply.

Hydrogen: Deployment of hydrogen for heat in buildings up to the sixth carbon budget has been modelled using a spatial analysis approach considering the metered gas demand from residential, commercial and public buildings within an expanding radius around potential industrial cluster sites producing hydrogen. Spatial gas demand has been derived from NEED data and assumptions on rollout rate have been taken from the CCC's residential heat decarbonisation scenarios from their Sixth Carbon Budget advice.[84, 85, 86] Additional assumptions on overall demand for scaling are from DUKES.[87]

Heat Networks: Deployment of heat networks has been derived from the expected impact of capital support and regulation, informed by the heat network opportunity areas.[88] The analysis appraises the impact of low-carbon heat network policies, and on fuel demand relative to a predominately gas-fired counterfactual, to estimate carbon savings. The costs technical assumption come from a AECOM report, but a number of assumptions have been updated since using learning from the Heat Network Investment Projects (HNIP).[89, 90]

Biomethane: Plant deployment scenarios are based on a combination of historic deployment under the Renewable Heat Incentive (RHI), and commercial intelligence. Heat generated is estimated from plant deployment scenarios and using estimates for biomethane injection as proportion of capacity.[91] The internal BEIS Biomass Heat Pathways Tool provides assumptions on biogeneration emissions, feedstock costs, capex and opex costs.[92] These capex and opex costs have also been verified against cost information collected through market intelligence, the Non-Domestic RHI Evaluation, and a review of AD plant costs commissioned by BEIS and awarded to the National Non-Food Crops Centre (NNFCC). Rothamsted Research has provided assumptions on upstream carbon savings, linked to diverting feedstocks from counterfactual uses to AD, and ammonia impacts.[93] Downstream carbon savings, linked to the displacement of natural gas with biomethane, are estimated using emissions factors provided in the HMT Green Book supplementary guidance.[94] Fertiliser savings are valued using the average of fertiliser prices published by the Agriculture and Horticulture Development Board across multiple years.[95] Full methodology and assumptions can be found in the final stage impact assessment for the Green Gas Support Scheme.[96]

The 2050 UKTM scenarios represent the housing stock at a less granular level but have been calibrated to the sectoral evidence base. The high electrification scenario assumes no availability of hydrogen for heating, the high resource scenario limits the deployment of electric heating, whilst the high innovation scenario is left to optimise outcomes.

Transport

Domestic Transport: The pathway for domestic transport covers road transport, rail, domestic shipping and domestic aviation. The *Net Zero Strategy* pathway for road transport, rail and domestic aviation was developed using projections from the recently published *Transport Decarbonisation Plan* (TDP).[97] These projections were produced using a range of models and analysis, including the National Transport Model (road transport), Traction Decarbonisation Network Strategy (rail), and the Aviation model, adjusted for decarbonising transport measures.[98] The forecasts presented in the TDP considered a number of scenarios. The *Net Zero Strategy* pathway for road transport, rail and domestic aviation assumes an ambitious policy package within the range of policy outcomes explored in the TDP. These emissions savings are applied to a central demand scenario. The Net Zero Strategy pathway for domestic shipping is based on research commissioned by the Department for Transport (DfT) – see below for further details.

International Aviation and Shipping: The *Net Zero Strategy* pathway for international aviation was developed using projections from the TDP and the *Jet Zero Consultation*.[99] This uses the same Aviation model and assumptions as used for the domestic aviation projections. The DfT's Aviation model is an established suite of interrelated components used to produce forecasts for aviation demand at the national level, and the associated passenger numbers, aircrafts and CO_2 emissions from flights departing from UK airports.[100] Three abatement measures are considered within the modelling; system efficiencies, sustainable aviation fuels (SAF), and zero emission aircraft.

As with the *Net Zero Strategy* pathway for domestic shipping, the pathway for international shipping is based on research commissioned by the Department for Transport (DfT).[101] For both pathways, the estimates from this research have been adjusted to align them with the latest UK greenhouse gas emissions national statistics.[102] Therefore, the pathways for domestic shipping and international shipping are consistent with the definitions of domestic shipping and international shipping used in these national statistics.[103] Given the emerging nature of zero emission shipping fuels, the NZS pathways for domestic shipping and international shipping should be interpreted as a possible scenario for meeting the government's commitment to achieving net zero in maritime rather than estimates of the impact of specific policies.

The illustrative 2050 scenarios rely on the same evidence base for transport as the Sixth Carbon Budget Impact Assessment with the exception of the high innovation scenarios, where modelling updates on aviation to reflect DfT's Jet Zero consultation high ambition scenario, and the scenarios for shipping which have been aligned with the NZS pathways described above. To support the sustainable fuel production requirements additional assumptions have been taken from the Advanced Gasification Technology review.[104]

Natural Resources and Waste

Agriculture: The agriculture emissions trajectory is based on estimates of maximum technical GHG mitigation potential (MTP) for each technology from the Clean Growth through Sustainable Intensification (CGSI) Project and building upon previous work by the CCC. MTP quantifies the impact if all farms which could technically adopt a measure do so, whilst considering any current uptake to avoid double counting.[105] MTP was derived from expert review of published literature and modelling to scale experimental data to national level. These estimates have been independently peer reviewed. CGSI used the MTP values to derive the trajectory based on ambitious but feasible deployment rates. The trajectory was informed by academic, industry and policy experts to reflect barriers, technology readiness and R&D lead in times.

Additional stretch options were modelled through Defra analysis using CGSI and CCC data, generally through adjustments to implementation rates. Additional modelling addressing agricultural mobile machinery aligned to CCC analysis in its *Sixth Carbon Budget* Report. England only data was scaled to a UK basis using the relative emission share between England and the Devolved Administrations as an estimator of Devolved Administration potential, pending publication of the Devolved Administrations pathways.

The UKTM modelling for the 2050 scenarios uses the same evidence base as the agriculture emissions trajectory. A set of crop and livestock measures are characterised by their cost and maximum technical potential to reduce emissions, and these assumptions are the same across the three scenarios.

Biomass: The biomass analysis is an indicative technical assessment of potential carbon abatement assuming optimal species/site/climate matching and a relatively simplistic approach to modelling carbon removals. Five biomass crop categories were modelled, deployed in fixed proportions: exotic SRF (14%); conifer SRF (23%); broadleaf SRF (poplar, aspen) (12%); SRC willow (27%); miscanthus (25%). A high-level analysis of land availability has been undertaken, indicating that the *Net Zero Strategy* pathway deployment profile is feasible. To calculate carbon stocks, a simple linear approach to yield modelling has been adopted which could overestimate initial growth and thus abatement. For all crops, appropriate biomass expansion coefficients were applied to account for branches and/or roots, as appropriate. All biomass was converted to carbon, assuming carbon comprises 50% of biomass. Emissions savings are modelled as the time-averaged increase in biomass carbon stocks resulting from planting of the crop, assuming the land use change is permanent.

In addition, the 2050 scenarios assume a maximum technical potential of 53 kha domestic bioenergy crop planting rate by 2050. Bioresource import assumptions in 2050 do not exceed current levels of imports.

Forestry: Emissions/removals are estimated using output from Forest Research's CSORT model, an off-line version of Carbine, the greenhouse gas accounting model used to calculate the forestry contribution to the UK LULUCF GHG inventory.[106, 107] Three indicative woodland types are represented in the model: productive conifer, productive broadleaf, and unmanaged. The modelled abatement is for England only and adjusted to a UK basis to be broadly aligned to the CCC share of afforestation by country in the "Balanced Net Zero pathway" scenario.[108] Linear expansion of deployment is assumed between 2025 and 2035. Non-market benefits are calculated using various research, compatible with the Enabling a Natural Capital Approach services data book.[109]

The 2050 scenarios vary the maximum afforestation/tree planting rate assumptions between 30 kha (in the high electrification/innovation scenario) and 50 kha pa (in the high resource scenario).

Peatland: The peatland trajectory covers restoration as well as technical potential modelling covering abatement from responsible management and the ending of peat extraction. Emissions savings from peatland restoration are based on upland, lowland cropland and lowland grassland emissions factors, which are applied to the peatland restoration deployment profile, delivered via the Nature for Climate Fund and Blended finance up to 2050.[110] The technical potential modelling covering responsible management measures (management activity that does not seek to re-establish peat habitats, but which significantly reduces the impact of using peatland for its current purpose) assumes abatement to be 1/3 of respective cropland/grassland restoration abatement. Biodiversity and water quality benefits are monetized using central values, whilst upfront restoration costs are estimated using 2017 Defra grant scheme data.[111, 112] The peatland modelling from Defra is England only, including an early stage assessment of how emissions factors from wasted peat may be revised in future inventories. Abatement potential in DAs is assumed to be in line with CCC analysis.

Peatland assumptions are the same across the three 2050 scenarios and there are two separate evidence bases – one that covers England, and one that covers Scotland. Both evidence bases consist of a set of restoration measures characterised by cost and maximum technical potential to reduce emissions. Assumptions for England come from Defra but for Scotland, data comes from the Scottish TIMES model and are uplifted to account for Wales and Northern Ireland.

Resources and Waste: For municipal wastewater, water companies use the Carbon Accounting Workbook developed by UK Water Industry Research to estimate operational GHG emissions across the industry. The workbook has been in place since 2004 and is updated annually to reflect the needs of the industry, including changes in carbon accounting practices with updated emission factors to align with the latest UK and international data. There are no internal models for private or industrial emissions and there are still significant gaps in our understanding of the magnitude and main sources of these. The Water UK Routemap to 2030 sets out industry plans to achieve net zero by 2030.[113] This routemap has been used as the basis for Defra to develop net zero consistent policies, for example, using assumptions from industry on cost and feasibility of policy deployment.

For landfill emissions estimation, the Landfill Environmental and Financial (LEAF) model has been used. This was developed by Resource and Waste Solutions, and more detail can be found in their report.[114] This is a high-level and strategic model of non-hazardous waste flows in England. LEAF allows the different scenarios to be described numerically and their effects on landfill emissions and costs of landfill to be calculated. The model considers the impacts of changes on landfill gas, leachate and void space consumption. The model is England only, but to provide an indication of Devolved Administration potential, emission savings are scaled to a UK level using relative emissions shares between England and the Devolved Administrations. It is assumed that there is a linear increase in diversion from landfill after 2021.

F-Gases: The *Net Zero Strategy* pathway for F-gas Emissions was estimated primarily using the UK-Level HFC Outlook Model developed by Gluckman Consulting. Non-HFC F-gas emissions are estimated using the BEIS Energy and Emissions Projections. The level of ambition for metered dose inhalers is derived from the ambition within the NHS report 'Delivering a 'Net Zero' National Health Service'.[115] Costs were developed using the CCC report 'Assessment of the potential to reduce UK F-gas emissions beyond the ambition of the F-gas Regulation and Kigali Amendment'.[116] Uplift of HFC GWPs to AR5 with Carbon Cycle Feedback values was taken from BEIS Methodology.

Assumptions on maximum technical potential for resources, waste, and F-gases in the 2050 scenarios are aligned with the sectoral evidence base for the pathway analysis.

Greenhouse Gas Removals

The engineered removals include the following technologies: Power Bionenergy with Carbon Capture and Storage (Power BECCS), Industry BECCS, Direct Air Carbon Capture and Storage (DACCS), and BECCS applications based on advanced gasification technologies (Hydrogen generation with waste, Hydrogen generation with biomass, Biofuels, Biogas, and Biomethane generation with CCS). Other engineered removals solutions, such as enhanced weathering, carbon-negative cements, ocean carbon sequestration and biochar have not been included in the modelling at this stage given the underlying uncertainty and need for further development.

The pathway was developed through a combination of bottom-up sectoral modelling, as well as UKTM whole-system modelling. The pathway analysis (including build rates, energy demand, and costs) relied on assumptions from published sources on BECCS and DACCS, alongside a benchmarking study commissioned by BEIS.[117, 118, 119, 120, 121] The study presented evidence based on an original review of the published literature, feedback received through the GGR Call for Evidence and additional stakeholder engagement.[122]

An investment lead-in time of four years is assumed for power BECCS, and five years for hydrogen BECCS and DACCS. Costs for power BECCS and hydrogen BECCS represent both the cost of generation (electricity/hydrogen) and of CO_2 removal. Power and hydrogen generation with BECCS are assumed to operate at baseload. DACCS is assumed to rely on low carbon energy inputs.

UKTM modelling for the 2050 scenarios uses the same technology assumptions as the pathway analysis where possible. In addition to the benchmarking study, assumptions on maximum technical potential and technology performance have been sourced from the sectoral models such as NZIP and from the Advanced Gasification Technology review.

Supporting the transition across the economy

Green Jobs, Skills and Industries

Skills evidence presented in the *Net Zero Strategy* is largely drawn from the work carried out by the Green Jobs Taskforce and found in the published Green Jobs Taskforce report.[123] The joint BEIS and DfE Ministerially led independent Taskforce included representatives from across business, trade unions and the skills/education sector and it was supported by a secretariat comprised of civil servants from BEIS and the DfE. The secretariat facilitated the drawing together of its evidence review and supported the Green Jobs Taskforce reviewing over 200 reports published by industry, academia, and government to form a robust evidence base upon which to build recommendations. The Annex published alongside the Green Jobs Taskforce brings together a wide range of information about how certain sectors, occupations, skills requirements and qualification levels (L)1 will change as the UK transitions to a net zero economy gathered by the secretariat.

Green Investment

Research referenced in the Green Investment chapter is drawn from external sources. This includes the Climate Change Committee's *The Road to Net Zero Finance*, which was a report prepared by the Advisory Group on Finance to critically assess the UK financial systems ability to deliver net zero.[124] This report provides an estimate for the total amount of capital investment needed in technologies to achieve net zero and therefore does not deliver a full picture of investment needs given the exclusion of operational costs.

Innovation for Net Zero

The published Energy Innovation Needs Assessments (EINAs) are the main source of evidence base underlying the innovation chapter.[125] It is a whole system analysis used in understanding the sectors and innovations of highest potential benefit to the UK energy system. The analysis is based on cost optimisation modelling carried with the Energy System Modelling Environment (ESME), and extensive engagement with industry to shape input assumptions and guide technical specifications. The EINAs are split into twelve reports, each covering a group of similar technologies and exploring their potential impacts and current barriers to their innovation and deployment. Overall, the EINAs aid understanding of where innovation can help achieve the largest energy system cost reductions and business opportunities when on a net zero trajectory.

GVA figures used in this publication have been updated internally by BEIS using the same EINA methodology to reflect increased net zero ambition, as original EINA publications were on the basis of the previous 80% greenhouse gas reduction target.

Local Climate Action

Analysis of local based decarbonisation policies is based on the Local Net Zero Model. The model takes assumptions from the ELENA programme, an EU fund which leverages public money for local based decarbonisation projects.[126] These assumptions include the expected level of private funding leveraged, energy savings of projects and additionality. The model estimates the public costs, private costs, carbon savings and energy savings of expected projects resulting from the programme.

Empowering the Public and Businesses to Make Green Choices

Much of the research contributing towards this chapter was part of BEIS' Net Zero Societal Change Research Programme 2020-21. Components of the research programme that have fed into this chapter include: 'Climate change and net zero: public awareness and perceptions' (an online survey of circa 7,000 members of the UK public on public perceptions of climate change and net zero); 'Net zero public dialogue' (online workshops with the public exploring their understanding and perceptions of net zero); 'Net Zero Societal Change Analysis Project' (analysis carried out by Energy Systems Catapult exploring the potential impact of different societal changes in reaching net zero); and a research note entitled 'Net zero public engagement and participation'.[127, 128, 129, 130]

Within the chapter, the 'Principles underpinning green public and business choices' section is drawn from 'Net zero: principles for successful behaviour change initiatives', a report BEIS commissioned from the Behavioural Insights Team.[131] The chapter also uses findings from BEIS' Public Attitudes Tracker surveys regarding people's concern about climate change.[132]

Cross-cutting assumptions

Fuel prices: Fossil fuel price assumptions are based on the BEIS Fossil Fuel Prices Assumptions 2020, with the exception of UKTIMES analysis which uses the BEIS Fossil Fuel Prices Assumptions 2016.[133]

Carbon values: Carbon values apply a monetary value to emissions in policy appraisal and are based on a target-consistent approach. The latest 2021 HMG carbon values are consistent with the UK's national and international climate commitments and represent an increase on previous values.[134] Where cost benefit analysis of the sixth carbon budget from the Impact Assessment is quoted, the 2018 carbon values were used. These are consistent with the previous 80% emissions reduction target. To compensate for subsequent increased climate ambition, the high rather than central 2018 carbon values were used in the cost benefit analysis.[135]

Economic growth and demography: The baseline for economic growth used for all analysis is consistent with the July 2020 OBR long term projections of economic growth.[136] When calculating the GDP carbon intensity and GDP energy intensity deployment assumptions, projections from the March 2021 Economic and fiscal outlook were used, for both short and long-term GDP forecasts.[137]

Air quality: Where air quality impacts have been quantified, they have been monetised in line with the national values of the most recent air quality damage costs.[138]

Discount rates: Discount rates are used in line with Green Book guidance.[139] For appraisal periods up to 2050 the discount rate is 3.5%. A 2% cumulative annual health uplift is applied to air quality benefits prior to discounting, effectively reducing the discount rate to 1.5%.

Estimating jobs: The estimate of jobs delivered since the *Ten Point Plan* announcement is based on internal HMG analysis of employment impacts across a range of policies and programmes within the 10 Points of the Plan. The method for estimating the number of jobs supported by *Net Zero Strategy* policies and proposals in 2025 and 2030 is as follows. This varies by sector and in some cases by the period of analysis.

Power: Analysis aggregates projected employment across Power Networks, Offshore wind, Onshore wind, Solar, and Storage and demand side flexibility, all based on BEIS analysis using the EINA methodology and the technology deployment levels implied by the indicative delivery pathway (see Table 11). The 2030 figure also includes 10,000 jobs (peak employment) from the construction of a large nuclear plant. These estimates are based on the number employed directly in the power sector technologies, with the exception of offshore wind, which also includes indirect (supply chain) jobs based on a multiplier of 1 direct job to 1 indirect job.

Fuel supply: The 2025 analysis is an estimate of potential employment by that year in a UK industry in Sustainable Aviation Fuels (SAF) (based on DfT analysis). The 2030 figure is an aggregation of anticipated employment by that year in SAF (based on DfT analysis), along with an estimate of potential employment in a UK hydrogen economy as set out in the Hydrogen Strategy.[140] This is based on BEIS analysis of an updated model from the Energy Innovation Needs Assessment.

Industry: Analysis relates to estimated employment in the UK in Carbon Capture Utilisation and Storage (CCUS), calculated using the Energy Innovation Needs Assessments approach and pro-rated for 2025 based on the anticipated trajectory for the level of carbon captured through CCUS over the decade. These are high-level estimates and actual outturn of employment will depend on several factors, although the jobs estimate is considered broadly consistent with stated government policy for the development of the technology. These estimates cover both power CCUS and CCUS for industrial purposes, but are included in the Industry chapter as the estimates do not directly overlap with any estimates included in the Power chapter.

Heat and Buildings: Analysis aggregates anticipated employment impacts from the decarbonisation of heating (calculated using an update of the *Energy Innovation Needs Assessments* applied to the deployment levels set out in Table 11) and total public and private spending on energy efficiency measures (based on BEIS analysis using a jobs/capex multiplier). These estimates are based on broad assumptions of the policy mix driving carbon savings from domestic buildings over the 2020s. As some of these policies are still not confirmed, there is large uncertainty over the exact timing and job numbers supported by them.

Transport: Both numbers are based on an aggregation of anticipated employment impacts from the Automotive Transformation Fund and the Advanced Propulsion Centre, along with anticipated levels of employment in active travel (cycling and walking), and rail decarbonisation. The active travel and rail decarbonisation estimates are based on DfT analysis of what policy ambitions for active travel and rail decarbonisation are likely to imply for employment in their respective sectors in these years.

Natural Resources, Waste and F-gases: These numbers relate exclusively to direct employment in the UK forestry sector and are based on Defra analysis. These estimates exclude indirect jobs, such as those supported in tourism, the wider forestry supply chain or local farming. Employment in forestry will be supported by policies such as the Nature for Climate Fund. This number does not include potential employment in other areas covered in the chapter such as peat restoration, sustainable agriculture or waste recycling.

Public and private investment estimates

Public investment figures in the strategy refer to sums of government spend committed to a relevant Budgets and Spending Reviews, unless otherwise stated. Private investment estimates are derived through analysis of how much private sector spend is likely to be leveraged from this public spend. Further public and private investment will be delivered as proposals are developed into firm policies. Analysis of the potential GVA generated by decarbonisation has been conducted for a subset of sectors: power, renewables, heat and buildings, industry, CCUS, hydrogen, smart systems and road transport. The analysis follows the methodology developed by Vivid Economics for the Energy Innovation Needs Assessment in 2019.[141] Where possible, it uses whole energy systems modelling to estimate domestic economic opportunities from achieving net zero in the UK in 2050 and, while export opportunities rely on a global scenario limiting global warming to two degrees Celsius above pre-industrial levels.

Endnotes

1 UK Legislation (2008), 'Climate Change Act 2008', https://www.legislation.gov.uk/ukpga/2008/27/contents

2 CCC (2019), 'Net Zero – The UK's contribution to stopping global warming', https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

3 See in particular sections 13, 14 and 15 of the Act.

4 BEIS (2021), '2019 UK greenhouse gas emissions: final figures - statistical release', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/957887/2019_Final_greenhouse_gas_emissions_statistical_release.pdf

5 UNFCCC (2015), 'Paris Agreement', https://unfccc.int/sites/default/files/english_paris_agreement.pdf

6 Excluding international aviation and shipping emissions.

7 BEIS (2021), 'Annual statements of emissions', https://www.gov.uk/government/collections/annual-statements-of-emissions

8 BEIS (2021), UK Greenhouse Gas Inventory, 1990-2019, https://uk-air.defra.gov.uk/reports/cat09/2105061125_ukghgi-90-19_Main_Issue_1.pdf

9 UK Legislation (2021), 'The Carbon Accounting (Provision for 2019) Regulations 2021', https://www.legislation.gov.uk/uksi/2021/189/made?view=plain

10 BEIS (2021), 'UK Greenhouse Gas Inventory', 1990-2019, https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2019

11 IPCC (2013), 'Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands', https://www.ipcc.ch/site/assets/uploads/2018/03/Wetlands_Supplement_Entire_Report.pdf

12 IPCC (2007), 'Assessment Report 4' WGI Chapter 2, table 2.14, https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

13 IPCC (2013), 'Assessment Report 5' WGI Chapter 8, table 8.A.1 and 8.SM.16, https://www.ipcc.ch/report/ar5/syr/

14 UNFCCC (2018), 'Modalities, procedures and guidelines', Annex II, Metrics https://ledslac.org/wp-content/uploads/2020/09/e.-Decision-18-cma.1.pdf

15 IPCC (2021), 'Assessment report 6' WGI table 7.15, https://www.ipcc.ch/report/ar6/wg1/

16 UK Legislation (2016), 'Carbon Budget Order 2016 impact assessment', https://www.legislation.gov.uk/en/ukdsi/2016/9780111147825/impacts

17 The UK may also purchase international credits to contribute to its carbon budgets. We assume that no such credits are purchased for the purposes of this analysis.

18 BEIS (2020), 'Updated energy and emissions projections: 2019', 2020, https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019

19 BEIS (2020), 'Updated energy and emissions projections: 2019', Annex A: Greenhouse gas emissions by source, 2020, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/931200/Annex-A-greenhouse-gas-emissions-by-source__EEP2019_.ods

20 OBR (2020), 'Fiscal sustainability report', Chapter 2, July 2020, https://obr.uk/download/fiscal-sustainability-report-july-2020/

21 Figure 1 shows EEP 2019 which for comparability has been adjusted for accounting changes, namely including Wetlands brought in under the 2019 inventory (c.15 mt per year) and converting the projections into AR5 with Feedback

22 EEP19 has been adjusted for accounting changes, namely including Wetlands brought in under the 2019 inventory, including IAS emissions, and converting the projections into AR5 with feedback.

23 BEIS (2021), '2020 UK greenhouse gas emissions', provisional figures, 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/972583/2020_Provisional_emissions_statistics_report.pdf

24 OBR (2020), 'Fiscal sustainability report, July 2020', https://obr.uk/download/fiscal-sustainability-report-july-2020/

25 BEIS (2019), 'Energy Innovation Needs Assessment', https://www.gov.uk/government/publications/energy-innovation-needs-assessments

26 BEIS (2019), 'Energy Innovation Needs Assessment', https://www.gov.uk/government/publications/energy-innovation-needs-assessments

27 UCL, 'UK TIMES', https://www.ucl.ac.uk/energy-models/models/uk-times

28 The model takes account of the direct cost of purchasing, installing, running and maintaining the abatement technologies. The cost of purchasing and installing includes assumed capital costs and the cost of borrowing to pay for the capital. Running costs include the cost of energy supplies, both domestic and any imports.

29 UK Legislation (2021), 'Carbon Budget Order 2021 impact assessment', https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf

30 UK Legislation (2021), 'Carbon Budget Order 2021 impact assessment', https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf

31 BEIS (2020), 'Updated energy and emissions projections: 2019' Annex D: Policy savings in the projections (revised December 2020), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/947604/Annex-D-policy-savings_revised_Dec2020__EEP2019_.ods

32 This range is provisional. The Secretary of State will lay before Parliament a report setting out a finalised indicative annual range as soon as is reasonably practicable.

[33] BEIS (2019), 'Updated energy and emissions projections 2018', Chapter 6 Uncertainty in emissions projections, 2019, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794590/updated-energy-and-emissions-projections-2018.pdf

[34] IAS emissions increase the width of the range by 7.1mt on average over CB6, and the additional LULUCF emissions increase the width by 11.8 mt. Both ranges are symmetrical.

[35] Whilst sectors are characterised by different sources and magnitudes of uncertainty, we have made the simplifying assumption that uncertainty in 2020 is +3.7%/-3.5% in each sector, broadly in line with the economy wide average. The proportional up-/down-lift applied to produce the rage increases by +0.35%/-0.17% in each subsequent year, again in line with the economy wide average.

[36] AR5 without feedback modelling undertaken for Agriculture, F-gases, Fuel Supply, LULUCF and Waste. Heat & Buildings, International Aviation and Shipping, Industry, Power, Removals and Transport all contain very small amounts of non-CO2 gases and pathways are assumed invariant to GWP.

[37] For the Natural Resources, Waste and F-gases sector, illustrative costs for Forestry, Peat and Wastewater in the Devolved Nations have been included by assuming they are line with those set out in CCC estimates. BEIS Analysis, CCC 6th Carbon Budget Report https://www.theccc.org.uk/publication/sixth-carbon-budget/

[38] UK Legislation (2021), 'Carbon Budget Order 2021 impact assessment', https://www.legislation.gov.uk/ukia/2021/18/pdfs/ukia_20210018_en.pdf

[39] This figure was based on outdated 2018 carbon values, with the 'high' series used to compensated for anticipated increases in new carbon values: https://www.gov.uk/government/publications/updated-short-term-traded-carbon-values-used-for-uk-policy-appraisal-2018

[40] OBR (2021), 'Fiscal risks report', https://obr.uk/frr/fiscal-risks-report-july-2021/

[41] HMT (2021), 'Net Zero Review'

[42] BEIS (2019), 'Energy Innovation Needs Assessment', https://www.gov.uk/government/publications/energy-innovation-needs-assessments

[43] European Commission Free allocation of allowances in the EU ETS, https://ec.europa.eu/clima/policies/ets/allowances_en

[44] BEIS, Free allocation of allowances in the UK ETS, https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets#free-allocation

[45] HMT (2021), 'Net Zero Review'

[46] OBR (2021), 'Fiscal risks report, July 2021', Chapter 3, https://obr.uk/download/fiscal-risks-report-july-2021/

[47] BEIS , Prime Minister's office, 10 Downing Street, The Rt Hon Alok Sharma MP & The Rt Hon Boris Johnson MP (2020), 'The Ten Point Plan for a Green Industrial Revolution', https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

[48] Natural Capital Committee (2020), 'The Green Book guidance: embedding natural capital into public policy appraisal – November 2020 Update, 2020', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/937652/ncc-green-book-advice.pdf

[49] HMT (2013), 'The Green Book: appraisal and evaluation of central government', paragraph 6.50, https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent

[50] Defra (2021), 'Enabling a Natural Capital Approach (ENCA)', https://www.gov.uk/guidance/enabling-a-natural-capital-approach-enca

[51] See https://www.gov.uk/government/groups/natural-capital-committee The Natural Capital Committee is an independent advisory body, set up in 2012. It provides advice to the government on the state of England's natural capital; our natural assets include forests, rivers, land, minerals and ocean

[52] Cambridge Conservation Initiative, 'Natural Capital Coalition' (2016), https://naturalcapitalcoalition.org/wp-content/uploads/2016/07/CCI-Natural-Capital-Paper-July-2016-low-res.pdf

[53] ONS (2020), 'UK natural capital accounts 2020', https://www.ons.gov.uk/economy/environmentalaccounts/datasets/uknaturalcapitalaccounts2020

[54] International Resource Panel (2020), 'Global Resources Outlook 2019: Natural Resources for the Future We Want', https://www.resourcepanel.org/reports/global-resources-outlook

[55] For further background on the DDM, please see https://www.gov.uk/government/publications/dynamic-dispatch-model-ddm

[56] BEIS (2020), 'Modelling 2050: electricity system analysis, 2020', https://www.gov.uk/government/publications/modelling-2050-electricity-system-analysis

[57] CCC (2020), 'The Sixth Carbon Budget: Electricity generation', https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Electricity-generation.pdf

[58] BEIS (2020), Electricity Generation Costs, 2020, https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020

[59] BEIS (2020), 'Modelling 2050: electricity system analysis', https://www.gov.uk/government/publications/modelling-2050-electricity-system-analysis

[60] BEIS (2021), 'UK Hydrogen Strategy, 2021', https://www.gov.uk/government/publications/uk-hydrogen-strategy

[61] BEIS (2021), 'Hydrogen analytical annex, 2021', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011499/Hydrogen_Analytical_Annex.pdf

[62] BEIS (2021), Hydrogen analytical annex, 2021, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011499/Hydrogen_Analytical_Annex.pdf

[63] BEIS (2019), 'Oil and gas: Environmental and Emissions Monitoring System database', https://www.gov.uk/guidance/oil-and-gas-eems-database

[64] Element Energy (2020), 'Deep-Decarbonisation Pathways for UK Industry, Element Energy, 2020', https://www.theccc.org.uk/publication/deep-decarbonisation-pathways-for-uk-industry-element-energy/

[65] CCC (2020), 'Sixth Carbon Budget report', https://www.theccc.org.uk/publication/sixth-carbon-budget/

[66] BEIS (2021), 'Industrial decarbonisation strategy', https://www.gov.uk/government/publications/industrial-decarbonisation-strategy

[67] BEIS (2017), 'National Household Model, 2017', https://data.gov.uk/dataset/957eadbe-43b6-4d8d-b931-8594cb346ecd/national-household-model

[68] BRE Group (2012), 'Standard Assessment Procedure', https://www.bregroup.com/sap/standard-assessment-procedure-sap-2012/

[69] MHCLG (2021), 'English Housing Survey': https://www.gov.uk/government/collections/english-housing-survey

[70] BEIS (2017), 'Domestic cost assumptions – what does it cost to retrofit homes': https://www.gov.uk/government/publications/domestic-cost-assumptions-what-does-it-cost-to-retrofit-homes

[71] (BEIS 2019), 'Determining the costs of insulating non-standard cavity walls and lofts': https://www.gov.uk/government/publications/determining-the-costs-of-insulating-non-standard-cavity-walls-and-lofts

[72] BEIS (2016),'Building Energy Efficiency Survey', https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees

[73] BEIS (2016), 'Building Energy Efficiency Survey', https://www.gov.uk/government/publications/building-energy-efficiency-survey-bees

[74] BEIS (2021), 'Digest of UK Energy Statistics', https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

[75] BEIS (2020), 'Energy and Emissions Projections', https://www.gov.uk/government/collections/energy-and-emissions-projections

[76] BEIS (2020), 'Energy Consumption in the UK', https://www.gov.uk/government/statistics/energy-consumption-in-the-uk

[77] BEIS (2021),'Non-domestic National Energy Efficiency Data Framework', https://www.gov.uk/government/statistics/non-domestic-national-energy-efficiency-data-framework-nd-need-2020

[78] BEIS (2020), 'Cost of installing heating measures in domestic properties', https://www.gov.uk/government/publications/cost-of-installing-heating-measures-in-domestic-properties

[79] BEIS (2017), 'Detailed analysis of data from heat pumps installed via the Renewable Heat Premium Payment Scheme (RHPP)', https://www.gov.uk/government/publications/detailed-analysis-of-data-from-heat-pumps-installed-via-the-renewable-heat-premium-payment-scheme-rhpp

[80] BEIS (2020), 'Heat pump manufacturing supply chain research project', https://www.gov.uk/government/publications/heat-pump-manufacturing-supply-chain-research-project

[81] BEIS (2017), 'National Household Model', https://data.gov.uk/dataset/957eadbe-43b6-4d8d-b931-8594cb346ecd/national-household-model

[82] BEIS (2021), 'National Energy Efficiency Data-Framework (NEED)', https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework

[83] MHCLG (2019), 'The Future Homes Standard consultation impact assessment', https://www.gov.uk/government/publications/the-future-homes-standard-consultation-impact-assessment

[84] BEIS (2021), 'National Energy Efficiency Data-Framework (NEED)', https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework

[85] BEIS (2021), 'Non-domestic National Energy Efficiency Data-Framework (ND-NEED)', https://www.gov.uk/government/collections/non-domestic-national-energy-efficiency-data-framework-nd-need

[86] Element Energy (2021), 'Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget (Element Energy)', https://www.theccc.org.uk/publication/development-of-trajectories-for-residential-heat-decarbonisation-to-inform-the-sixth-carbon-budget-element-energy/

[87] BEIS (2021), 'Digest of UK Energy Statistics (DUKES)', https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

[88] BEIS (2021), 'Opportunity areas for district heating networks in the UK: second National Comprehensive Assessment, 2021', https://www.gov.uk/government/publications/opportunity-areas-for-district-heating-networks-in-the-uk-second-national-comprehensive-assessment

[89] BEIS (2015), 'Assessment of the Costs, Performance and Characteristics of UK Heat Networks, 2015', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/424254/heat_networks.pdf

[90] BEIS (2019), 'Heat Networks Investment Project (HNIP) pilot scheme, 2019', https://www.gov.uk/government/publications/heat-networks-investment-project-hnip

[91] This model is based on historic RHI data.

[92] Assumptions for this model drawn from Bioenergy Heat Pathways to 2050 Rapid Evidence Assessment, Ecofys & E4Tech (for BEIS) 2018, unpublished.

[93] These are consistent with those used to compile the 1990-2019 National Atmospheric Emissions Inventory (NAEI).

[94] BEIS (2021), 'Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal', https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[95] AHDB (2021), 'Great Britain fertiliser prices', https://ahdb.org.uk/GB-fertiliser-prices

[96] BEIS (2020), 'Future support for low carbon heat, 2021', https://www.gov.uk/government/consultations/future-support-for-low-carbon-heat

[97] DFT (2021), 'Decarbonising transport: a better, greener Britain', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009448/decarbonising-transport-a-better-greener-britain.pdf

[98] DFT (2020), 'Transport appraisal and modelling tools', https://www.gov.uk/government/collections/transport-appraisal-and-modelling-tools

[99] DfT (2020), 'Jet Zero consultation: Evidence and analysis', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002163/jet-zero-consultation-evidence-and-analysis.pdf

[100] DfT (2017), 'UK Aviation Forecasts', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878705/uk-aviation-forecasts-2017.pdf

[101] UMAS, E4Tech, Frontier Economics, CE Delft (2019), 'Reducing the Maritime Sector's Contribution to Climate Change and Air Pollution. Scenario Analysis: Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs. A Report for the Department for Transport'
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

[102] BEIS (2021), 'Final UK greenhouse gas emissions national statistics 1990 to 2019', https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2019

[103] For example, the estimates of the greenhouse gas emissions from international shipping represent estimates of the greenhouse gas emissions from fuel sold in the UK for use in international shipping.

[104] BEIS (2021), 'Advanced Gasification Technologies Review and Benchmarking: summary report', https://www.gov.uk/government/publications/advanced-gasification-technologies-review-and-benchmarking

[105] Defra (2021), 'Delivering Clean Growth Througfh Sustainable Intensification Project'. To be published in 2021.

[106] Morison et al. (2012), 'Understanding the carbon and greenhouse gas balance of forests in Britain', https://www.forestresearch.gov.uk/research/understanding-the-carbon-and-greenhouse-gas-balance-of-forests-in-britain/.

[107] Matthews, Broadmeadow (2009), 'The potential of UK forestry to contribute to government's emissions reduction commitments', https://www.cabdirect.org/cabdirect/abstract/20103082977

[108] CCC (2020),'Sixth carbon budget: Agriculture & land use, land-use change & forestry (LULUCF)', https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Agriculture-land-use-land-use-change-forestry.pdf

[109] Defra (2021), 'ENCA services databook', https://www.gov.uk/guidance/enabling-a-natural-capital-approach-enca#enca-services-databook

[110] Evans et al. (2017), 'Implementation of an Emissions Inventory for UK Peatlands', https://uk-air.defra.gov.uk/library/reports?report_id=980

[111] Christie et al. (2011), 'An economic assessment of the ecosystem service benefits derived from the SSSI biodiversity conservation policy in England and Wales', https://www.sciencedirect.com/science/article/pii/S2212041612000095

[112] Morris, Camino (2011), 'Economic Assessment of Freshwater, Wetland and Floodplain (FWF) Ecosystem Services', http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=lVLEq%2BxAI%2BQ%3D&tabid

[113] Water UK (2020), 'Net Zero 2030 Routemap', https://www.water.org.uk/routemap2030/

[114] Resources and Waste Solutions (2019), 'Financial Costs of Current and Future Landfill Operations', http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20309

[115] NHS England (2020), 'Delivery a Net Zero National Health Service', https://www.england.nhs.uk/greenernhs/wp-content/uploads/sites/51/2020/10/delivering-a-net-zero-national-health-service.pdf

[116] Ricardo and Gluckman Consulting (2019), 'Assessment of potential to reduce UK F-gas emissions', https://www.theccc.org.uk/publication/assessment-of-potential-to-reduce-uk-f-gas-emissions-ricardo-and-gluckman-consulting/

[117] Gas Turbine World (2015), GTW 2014-2015 Handbook, Volume 31, https://gasturbineworld.com/shop/annual-handbook/2014-15-handbook-volume-31/

[118] Ricardo (2019), 'Analysing the potential of bioenergy with carbon capture in the UK to 2050', https://www.gov.uk/government/publications/the-potential-of-bioenergy-with-carbon-capture

[119] BEIS & Wood Plc (2018), 'Assessing the Cost Reduction Potential and Competitiveness of Novel (Next Generation) UK Carbon Capture Technology, Benchmarking State-of-the-art and Next Generation Technologies, Revision 4A', https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/864688/BEIS_Final_Benchmarks_Report_Rev_4A.pdf

[120] NAS (2018), 'Negative Emission Technologies and Reliable Sequestration: A Research Agenda', https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda

[121] Element Energy and UK Centre for Ecology & Hydrology (2021), 'Greenhouse Gas Removal Methods and Their Potential UK Deployment', https://www.gov.uk/government/publications/greenhouse-gas-removal-methods-technology-assessment-report

[122] BEIS (2020), 'Greenhouse gas removals: call for evidence', https://www.gov.uk/government/consultations/greenhouse-gas-removals-call-for-evidence

[123] Green Jobs Taskforce (2021), 'Report to the Government, Industry and Skills Sectors', https://www.gov.uk/government/publications/green-jobs-taskforce-report

[124] CCC (2020), 'The Road to Net-Zero Finance', https://www.theccc.org.uk/publication/the-road-to-net-zero-finance-sixth-carbon-budget-advisory-group/

[125] BEIS (2019), 'Energy Innovation Needs Assessment', https://www.gov.uk/government/publications/energy-innovation-needs-assessments

[126] European Investment Bank (2021), 'ELENA – Completed Project Factsheets', https://www.eib.org/en/products/advising/elena/completed-projects/index.htm

[127] BEIS (2021), 'Climate change and net zero: public awareness and perceptions', https://www.gov.uk/government/publications/climate-change-and-net-zero-public-awareness-and-perceptions

[128] BEIS (2021), 'Net zero public dialogue', https://www.gov.uk/government/publications/net-zero-public-dialogue

[129] BEIS, Defra (2021), 'Net Zero Societal Change Analysis Project', https://www.gov.uk/government/publications/net-zero-societal-change-analysis-project

[130] BEIS (2021), 'Net zero public engagement and participation', https://www.gov.uk/government/publications/net-zero-public-engagement-and-participation

[131] Behavioural Insights Team (2021), 'Net zero: principles for successful behaviour change initiatives', https://www.gov.uk/government/publications/net-zero-principles-for-successful-behaviour-change-initiatives

[132] BEIS (2021), 'BEIS Public Attitudes Tracker', https://www.gov.uk/government/collections/public-attitudes-tracking-survey

[133] BEIS (2020), 'Fossil fuel price assumptions', https://www.gov.uk/government/collections/fossil-fuel-price-assumptions

[134] BEIS (2021), 'Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal', https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[135] BEIS (2018), 'Update to traded carbon values: 2018', https://www.gov.uk/government/collections/carbon-valuation--2#update-to-traded-carbon-values:-2018

[136] OBR (2020), 'Fiscal sustainability report – July 2020', https://obr.uk/fsr/fiscal-sustainability-report-july-2020/

[137] OBR (2021), 'Economic and fiscal outlook report – March 2021', https://obr.uk/efo/economic-and-fiscal-outlook-march-2021/

[138] Defra (2021), 'Air quality appraisal: damage cost guidance', https://www.gov.uk/government/publications/assess-the-impact-of-air-quality

[139] HMT (2013), 'Green Book supplementary guidance: discounting', https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting

[140] BEIS (2021), 'UK Hydrogen Strategy', https://www.gov.uk/government/publications/uk-hydrogen-strategy

[141] BEIS (2019), 'Energy Innovation Needs Assessments', https://www.gov.uk/government/publications/energy-innovation-needs-assessments

Net Zero Strategy: Build Back Greener

Climate Science Annex

Climate Science Annex

Why we must act

Science is clear that the world is warming, that this is occurring because of human activity, and that left unchecked, continued warming would be deeply harmful, not just to the natural world, but also to human security and wellbeing. Global average temperatures have already risen by around 1.1°C[1] and 2020 concluded the earth's warmest 10-year period on record.[2] Without action to reduce the level of greenhouse gas (GHG) emissions emitted globally down to net zero, climate change is set to continue with increasing temperatures across the world.[3]

We are already seeing the impacts of climate change across all parts of the world, with many types of extreme weather becoming more frequent and more intense – causing droughts, wildfires and flooding.[4] The North American heatwave in June 2021, which broke temperature records by over 4°C and reached 49.6°C in Canada, would have been virtually impossible without climate change.[5] The melting of glaciers and ice sheets is accelerating, with sea levels currently rising at 3.7mm annually.[6] In the UK we can see a trend towards warmer and wetter winters, along with hotter summers.[7]

These changes are damaging the land and oceans that support human society and the natural environment. As a result, many species are being driven closer to extinction,[8] food supplies are being disrupted,[9] and the health and livelihood of people across the world are being affected.[10] Climate change disproportionally affects poor and disadvantaged people, with rural, coastal, and indigenous communities facing greater risks from impacts such as rising sea levels, drought, and food shortages.[11]

There is still uncertainty over the responsiveness of global temperatures to GHG emissions; the Intergovernmental Panel on Climate Change (IPCC) estimate that a doubling of pre-industrial CO_2 levels would result in warming in a range of 2.5°C – 4°C.[12] The higher that temperatures rise, the greater the risk of seeing dangerous low-likelihood, high-impact outcomes. These could include abrupt responses and tipping points such as dieback of the Amazon Rainforest, melting of the polar ice sheets, and the collapse of key ocean currents controlling global weather, which cannot be ruled out.[13, 14] To avoid these risks, strong and decisive action is needed to reduce GHG emissions. Limiting further warming decreases the likelihood of more severe and potentially irreversible impacts on people and ecosystems. Action would also provide other co-benefits, such as limiting the rate of ocean acidification and improving air quality. Every additional fraction of a degree of global warming counts – with every 0.5°C of warming there are clearly discernible increases in the intensity of and frequency of impacts.[15] This is why we should aim to reduce global emissions to net zero as quickly as is practically possible.[16]

Global temperature goals and emissions pathways

Rapid and deep cuts to emissions are essential to avoid the most dangerous impacts of climate change.[17] Greenhouse gas concentrations and global temperatures will continue to rise until we reduce GHG emissions to net zero.[18] In 2015 the Paris Agreement was signed, where 196 parties committed to hold "the increase in the global average temperature to well below two degrees above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change". The Agreement recognised that, to achieve this goal, global emissions of greenhouse gases would need to peak as soon as possible, reduce rapidly thereafter, and reach a net zero level in the second half of this century.

As part of the Paris Agreement, countries also committed to reduce or limit their greenhouse gas emissions. These commitments are contained in their Nationally Determined Contributions (NDCs). A number of studies have assessed how close these commitments bring us to staying below two degrees.

It is worth noting that these assessments use different assumptions regarding both the extent to which countries will meet their NDCs and, crucially, the actions that will be taken by countries to reduce their emissions after 2030. The latter will be a key determinant of whether the world will meet the long-term global temperature goal.

The Climate Action Tracker (CAT)[19] estimates that if there were a continuation of the currently implemented global policies these set us on course for a global average temperature rise of 2.1°C to 3.9°C by the end of the century. But if currently pledged ambitions (i.e. those not yet implemented into tangible policies) are implemented this range decreases to 1.9°C to 3.0°C, with a mid-range estimate of 2.4°C. These estimates are also consistent with projections in the UN Environment Programme's 2020 Emissions Gap Report.[20] Whilst these assessments show that current NDCs can have a significant impact on projected temperature rises, greater action is still needed if we are to limit global temperature increases to well below two degrees.

Adaptation in the UK

Responding to the complexity of climate change demands a multifaceted approach. Regardless of global success in reducing GHG emissions, some future temperature rises are already locked in by historical emissions up to the present day. Even the most optimistic, ambitious emission reduction scenarios suggest approximately 0.5°C of further warming by mid-century compared to the present day.[21] Furthermore, future global emissions pathways are highly uncertain, so it is essential that the UK's adaptive capacity is rapidly developed to prepare for, and bolster our resilience to, the inevitable near-term and potential future impacts of climate change.

To prepare for these eventualities, the UK is already considering climate risks and what actions will be required through its five-yearly policy cycle of a Climate Change Risk Assessment followed by a National Adaptation Programme (NAP). The Government's Third Climate Change Risk Assessment will be published in January 2022 and will outline Government views on the key risks and opportunities the UK will face from climate change. The Climate Change Committee's 2021 Independent Assessment of UK Climate

Risk identified eight risk areas that will require the most urgent attention in the next two years.[22] These are applicable even if global warming is limited to 1.5°C.

- Risks to the viability and diversity of terrestrial and freshwater habitats and species from multiple hazards
- Risks to soil health from increased flooding and drought
- Risks to natural carbon stores and sequestration from multiple hazards leading to increased emissions
- Risks to crops, livestock and commercial trees from multiple hazards
- Risks to supply of food, good and vital services due to climate-related collapse of supply chains and distribution networks
- Risks to people and the economy from climate-related failure of the power system
- Risks to human health, wellbeing and productivity from increased exposure to heat in homes and other buildings
- Multiple risks to the UK from climate change impacts overseas

The NAP is a cross-department collaboration, bringing together government's policies on managing climate risks in one place. The second NAP sets out how we will address climate risks for the period 2018 to 2023, including risks to terrestrial, coastal, marine, and freshwater ecosystems, soils and biodiversity; and flooding and coastal change risks to communities, businesses and infrastructure.

Future developments in climate science

In recent years the debate and focus of scientific research has shifted from whether climate change is happening and/or is being caused by human activity, to the range of the expected impacts and the level of action required to address climate change through a combination of adaptation and mitigation. We need to better understand the nature, magnitude and rate of climate change. Preparing for unavoidable changes to the climate will require more local analysis and more information on how global warming relates to local-scale changes in weather and climate extremes. Further research is also needed around stronger mitigation actions to inform climate policy that can get us to net zero.

Our knowledge has increased significantly but many key research priorities remain, including deepening our understanding around the four questions Government posed to the Met Office this year.[23]

- What current weather and climate risks and impacts are expected globally and in the UK?
- What are the future risks and impacts from weather and climate that we need to avoid or need to adapt to?
- What are the carbon budget and mitigation scenarios that will avoid the most dangerous impacts of global climate change?
- What impacts and opportunities from mitigation and adaptation actions are needed to proceed towards a resilient and net zero future?

The UK has also recently committed £1.2 billion of funding to develop a new state-of-the-art supercomputer for the Met Office. This will help ensure government, industry and communities are better prepared for the impacts from a changing climate through increased amounts of data. Examples include the provision of very detailed localised climate information to improve city planning and public transport infrastructure.

Climate science continues to rapidly improve and develop. This year saw the publication of the Working Group I (WGI) contribution to the IPCC's Sixth Assessment Report (AR6). The report addresses the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science. WGII and WGIII contributions to AR6 will be published in 2022 and respectively cover the impacts of climate change on people and nature, and the options for reducing GHG emissions and removing GHG from the atmosphere.

The main conclusions of WGI are a reinforcement of the consensus on climate science: that there is absolutely no doubt that human activities have warmed the planet and are causing widespread and rapid changes to the climate. Without immediate and drastic action, the impacts will be more severe and frequent. It shows that we are already feeling the effects of climate change and know that some changes to the planet are already irreversible on timescales of centuries to millennia. However, with immediate, concerted action to reduce emissions now, the worst impacts can still be averted. Technologies to remove CO_2 directly from the atmosphere or ocean can also help, but to adhere to the temperature goal of the Paris Agreement ambitious action on emission reductions is still required, and is needed today.

Endnotes

1 IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph A.1.2, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

2 Met Office (2021), '2020 ends earth's warmest 10 years on record', https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2021/2020-ends-earths-warmest-10-years-on-record

3 IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph D.1.1, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

4 PCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph A.3.2 and A.3.5, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

5 Philip, S. Y. et al (2021), 'Rapid attribution analysis of the extraordinary heatwave on the Pacific Coast of the US and Canada', https://www.ecodebate.com.br/wp-content/uploads/2021/07/20210707-rapid-attribution-analysis-of-the-extraordinary-heatwave-on-the-pacific-coast-of-the-us-and-canada-june-2021.pdf

6 IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph A.4.3 and A.1.7, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

7 Kendon, M. et al (2021), 'State of the UK Climate 2020', https://rmets.onlinelibrary.wiley.com/doi/10.1002/joc.7285

8 PCC (2019), Special Report on Climate Change and Land, Section 2.2.4, Chapter 2, Food Security, Land-Climate interactions, https://www.ipcc.ch/srccl/

9 IPCC (2019), Special Report on Climate Change and Land, Chapter 5 Executive Summary, https://www.ipcc.ch/srccl/

10 IPCC (2019), Special Report on Climate Change and Land, Chapter 5 Executive Summary, https://www.ipcc.ch/srccl/

11 IPCC (2018), IPCC Special Report on Global Warming of 1.5°C, Chapter 3 Section 3.5.2.3 and Paragraph B5.1 Summary for Policymakers, https://www.ipcc.ch/sr15/

12 IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph A.4.4 Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

13 IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph C.3.2, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

[14] IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Box TS.9, Technical Summary, https://www.ipcc.ch/report/ar6/wg1/#TS

[15] IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph B.2.2, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

[16] IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph D.1, Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

[17] Lowe, J. et al (2019), 'Links between emissions pathways and time lags in Earth's climate system', https://www.theccc.org.uk/wp-content/uploads/2019/07/Briefing-note-on-time-lags-in-the-climate-system-Met-Office.pdf

[18] PCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Paragraph B.1 and D.1 Summary for Policymakers, https://www.ipcc.ch/report/ar6/wg1/#SPM

[19] Climate Action Tracker (2021), 'Warming Projections Global Update May 2021', https://climateactiontracker.org/documents/853/CAT_2021-05-04_Briefing_Global-Update_Climate-Summit-Momentum.pdf

[20] UNEP (2020), 'Emissions Gap Report 2020', https://www.unep.org/emissions-gap-report-2020

[21] IPCC (2021), 'Working Group I Contribution to the IPCC 6th Assessment Report, Climate Change 2021: The Physical Science Basis', Box TS.1 and Table 1, Technical Summary, https://www.ipcc.ch/report/ar6/wg1/#TS

[22] CCC (2021), 'Independent Assessment of UK Climate Risk', Executive Summary, https://www.theccc.org.uk/publication/independent-assessment-of-uk-climate-risk/

[23] Met Office Hadley Centre Climate Programme, https://www.metoffice.gov.uk/weather/climate/met-office-hadley-centre/climate-programme/index

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