Committee on Climate Change

Independent advice to government on building a low-carbon economy and preparing for climate change

The Sixth Carbon Budget and Welsh emissions targets – Call for Evidence

Background to the UK's sixth carbon budget

The UK Government and Parliament have adopted the Committee on Climate Change's (CCC) recommendation to target net-zero emissions of greenhouse gases (GHGs) in the UK by 2050 (i.e. at least a 100% reduction in emissions from 1990).

The Climate Change Act (2008, 'the Act') requires the Committee to provide advice to the Government about the appropriate level for each carbon budget (sequential five-year caps on GHGs) on the path to the long-term target. To date, in line with advice from the Committee, five carbon budgets have been legislated covering the period out to 2032.

The Committee must provide advice on the level of the sixth carbon budget (covering the period from 2033-37) before the end of 2020. The Committee intends to publish its advice early, in September 2020. This advice will set the path to net-zero GHG emissions for the UK, as the first time a carbon budget is set in law following that commitment.

Both the 2050 target and the carbon budgets guide the setting of policies to cut emissions across the economy (for example, as set out most recently in the 2017 Clean Growth Strategy).

The Act also specifies other factors the Committee must consider in our advice on carbon budgets – the advice should be based on the path to the UK's long-term target objective, consistent with international commitments and take into account considerations such as social circumstances (including fuel poverty), competitiveness, energy security and the Government's fiscal position.

The CCC will advise based on these considerations and a thorough assessment of the relevant evidence. This Call for Evidence will contribute to that advice.

Background to the Welsh third carbon budget and interim targets

Under the Environment (Wales) Act 2016, there is a duty on Welsh Ministers to set a maximum total amount for net Welsh greenhouse gas emissions (Welsh carbon budgets). The first budgetary period is 2016-20, and the remaining budgetary periods are each succeeding period of five years, ending with 2046-50.

The Committee is due to provide advice to the Welsh Government on the level of the third Welsh carbon budget (covering 2026-30) in 2020, and to provide updated advice on the levels of the second carbon budget (2021-25) and the interim targets for 2030 and 2040. Section D of this Call for Evidence (covering questions on Scotland, Wales and Northern Ireland) includes a set of questions to inform the Committee's advice to the Welsh Government.

Question and answer form

When responding, please provide answers that are as specific and evidence-based as possible, providing data and references to the extent possible.

Please limit your answers to <u>400 words</u> per question and provide supporting evidence (e.g. academic literature, market assessments, policy reports, etc.) along with your responses.

A. Climate science and international circumstances

Question 1: The climate science considered in the CCC's 2019 Net Zero report, based on the IPCC Special Report on Global Warming of 1.5°C, will form the basis of this advice. What additional evidence on climate science, aside from the most recent IPCC Special Reports on Land and the Oceans and Cryosphere, should the CCC consider in setting the level of the sixth carbon budget?

There is mounting evidence that temperature increase will result in high impact events interconnected across different biophysical systems, potentially committing the world to long-term irreversible changes. The possibility of breaching such "tipping points" in the near future is discussed by Lenton *et al*. (2019), including the potential for "cascading effects" and regime shifts. Spratt and Dunlop (2018) meanwhile present evidence of the value of a risk-based framework to possible catastrophic impacts, and the possibility that the IPCC may have underestimated such risks.

The seriousness of such possibilities is underlined by recent research on the Greenland Ice Sheet (Shepherd *et al*., 2019), which shows that Greenland's ice losses are tracking the IPCC's high-end climate warming scenario, leading to a forecast of an additional 50 to 120 millimetres of global sea-level rise by 2100 when compared to the central estimate.

Emerging evidence on how permafrost thaw (a non-linear and tipping process of the Earth system) reduces the available carbon budget should also be taken into account (Gasser *et al*., 2018; Turetsky *et al*., 2020). Permafrost thaw adds to the uncertainties involved in making climate policy decisions including setting carbon budgets, but efforts geared towards meeting Paris goals should not ignore this or other tipping points or irreversible feedbacks in the Earth system (see also Q2).

New evidence on overshoot, where a temperature limit is first exceeded and later returned to through large-scale CO_2 removal from the atmosphere, should also be considered. Whilst this may result in a reversal of global mean temperature once a temperature limit has been breached, there may be implications for Earth system parameters sensitive to the carbon cycle, even when temperatures have returned to pre-overshoot levels (Tokarska *et al*., 2019).

Key findings regarding the carbon balance of tropical forests meanwhile include the size of the long-term tropical carbon sink (>1 Pg C per year), as well as its recent decline and climatic controls (Brienen *et al*. 2015; Hubau *et al*. 2020), and the discovery of major carbon pools in tropical peatlands (Draper *et al*. 2014, Dargie *et al*. 2018) also now under threat from climate change and direct human impacts.

The climate threat to the tropical C sink shows that modelled expectations of long-term sinks in the tropics may be too optimistic, whilst the pathway to limiting anthropogenic

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global warming to 1.5°C (or 2°C) will be considerably harder without the 1 Pg C sink into tropical intact forests.

References

Lenton *et al*. (2019) Climate tipping points: too risky to bet against, Nature doi:10.1038/d41586-019-03595-0

Spratt and Dunlop (2018) What lies beneath: the understatement of climate risk https://climateextremes.org.au/wp-content/uploads/2018/08/What-Lies-Beneath-V3-LR-Blank5b15d.pdf

Shepherd *et al*. (2019) Mass balance of the Greenland Ice Sheet from 1992 to 2018, Nature doi:10.1038/s41586-019-1855-2

Gasser *et al*. (2018) Path-dependent reductions in CO_2 emission budgets caused by permafrost carbon release, Nature Geoscience doi:10.1038/s41561-018-0227

Turetsky *et al*. (2020) Carbon release through abrupt permafrost thaw, Nature doi:10.1038/s41561-019-0526-0

Tokarska *et al*. (2019) Limiting overshoot: Path independence of carbon budgets when meeting a stringent global mean temperature target after an overshoot, Earth's Future doi:10.1029/2019ef001312

Brienen *et al*. (2015) Long-term decline of the Amazon carbon sink, Nature doi:10.1038/nature14283

Hubau *et al*. (2020) Asynchronous Carbon Sink Saturation in African and Amazonian Tropical Forests, Nature (in press)

Draper *et al*. (2014) The distribution and amount of carbon in the largest peatland complex in Amazonia, Environmental Research Letters doi:10.1088/1748-9326/9/12/12401

Dargie *et al*. (2018) Congo Basin peatlands: threats and conservation priorities, in Mitigation and Adaptation Strategies for Global Change doi:10.1007/s11027-017-9774-8

Question 2: How relevant are estimates of the remaining global cumulative CO_2 budgets (consistent with the Paris Agreement long-term temperature goal) for constraining UK cumulative emissions on the pathway to reaching net-zero GHGs by 2050?

Global carbon budgets will be continually refined as temperature observations and emissions fluxes are assimilated (e.g. Friedlingstein *et al*., 2019). A new framework for estimating the global carbon budget (Rogelj *et al.,* 2019), based on the methodology used in the IPCC's SR1.5, includes provision for Earth system feedbacks such as permafrost

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thaw (Q1), and allows a consistent approach to improving budget estimates over time as scientific knowledge advances (Q6).

CONSTRAIN (2019) applies the Rogelj *et al.* (2019) framework to estimate a global remaining carbon budget from the start of 2020 of 235 Gt CO_2, for a likely (66%) probability of staying below 1.5°C. This is broadly consistent with the IPCC SR1.5 budget (420Gt) when accounting for emissions since 2018 alongside 100 Gt CO_2 for Earth system feedbacks such as permafrost, which SR1.5 reports separately. Given the global remaining carbon budget is currently reducing by around 43 Gt CO_2 per year, and may reduce further as we gain better understanding of key processes and feedbacks (Q6), this highlights just how small the remaining global budget is.

Translating global carbon budgets to the national level however depends on decisions around fairness and equity as well as methodological choices, national inventories and the inclusion of international offsetting and emissions trading. There is no globally agreed methodology for translating from the global to national level, but questions around equity and justice continue to feature strongly (Alcaraz *et* al, 2018; Rogelj and Schleussner, 2019; Schleussner *et al*., 2019, van den Berg *et al.*, 2019) and should be considered in UK policy. In addition, debate is needed around whether emissions from outside, but generated to satisfy demand within, the UK should be considered in addition to territorial emissions (i.e. through consumption based accounting, e.g. Barrett *et al.*, 2013).

However, regardless of value judgements and political decisions, the key point is that there is less than 0.5°C additional warming before 1.5°C is reached. Combined with uncertainties around near-term warming rates, and the benefits of strong mitigation choices, the focus should remain on creating a roadmap to Net Zero by mid-century at latest.

The global carbon budget will help keep the Paris goals in mind on this pathway: every tonne of CO_2 emitted by the UK will eat into the remaining global budget and our chances of limiting temperature increase; and the more we emit near-term, the faster emissions will have to decline thereafter.

References

Friedlingstein *et al.* (2019) Global Carbon Budget 2019, Earth System Science Data doi:10.5194/essd-11-1783-2019

Rogelj *et al.* (2019) Estimating and tracking the remaining carbon budget for stringent climate targets, Nature doi:10.1038/s41586-019-1368-z

CONSTRAIN (2019) ZERO IN ON the remaining carbon budget and decadal warming rates. The CONSTRAIN Project Annual Report 2019 doi:10.5518/100/20

Alcaraz *et al*. (2018) Distributing the Global Carbon Budget with climate justice criteria, Climatic Change doi:10.1007/s10584-018-2224-0

Rogelj and Schleussner (2019) Unintentional unfairness when applying new greenhouse gas emissions metrics at country level, Environmental Research Letters, doi:1088/1748-9326/ab4928

Question 2: How relevant are estimates of the remaining global cumulative CO_2 budgets (consistent with the Paris Agreement long-term temperature goal) for constraining UK cumulative emissions on the pathway to reaching net-zero GHGs by 2050?

Schleussner *et al*. (2019) Inconsistencies when applying novel metrics for emissions accounting to the Paris Agreement, Environmental Research Letters doi:10.1088/1748-9326/ab56e7

van den Berg *et al.* (2019) Implications of various effort-sharing approaches for national carbon budgets and emission pathways, Climatic Change doi:10.1007/s10584-019-02368-y

Barrett *et al.* (2013) Consumption-based GHG emission accounting: a UK case study, Climate Policy doi:10.1080/14693062.2013.788858

Question 3: How should emerging updated international commitments to reduce emissions by 2030 impact on the level of the sixth carbon budget for the UK? Are there other actions the UK should be taking alongside setting the sixth carbon budget, and taking the actions necessary to meet it, to support the global effort to implement the Paris Agreement?

UK Government investment in overseas oil and gas should be halted, since planned expansion is incompatible with the Paris Agreement (Global Witness, 2019); whilst planned airport growth should be halted or reduced as it is incompatible with Net Zero targets (Finney and Mattioli, 2019). The only proven way for the aviation industry to cut emissions is by managing demand.

The UK should also support new ‘global Britain’ partners in the tropics to effectively monitor their forests. It was global collaborative networks that discovered the tropical carbon sink, quantified its sensitivity to carbon dioxide, heat, and drought, and now predict where and when it will decline (Q1). These include RAINFOR (Red Amazónica de Inventarios Forestales http://www.rainfor.org/en) across tropical South America; AfriTRON (http://www.afritron.org/) in tropical Africa; and MonANPe in Peru, with more than 150 institutional partners in total.

The sink provides major opportunities for tropical countries to protect their forests, and also contribute to their NDCs - in many Amazon countries, the intact forest sink still exceeds their carbon emissions (Phillips and Brienen 2017). No matter what pathway to Net Zero it is taken within the UK, we need to track the behaviour of tropical forests through continued high-quality on-the-ground monitoring of their climate response, an area which the UK has led for the past 20 years.

References

Global Witness (2019) Overexposed: How the IPCC’s 1.5°C report demonstrates the risks of overinvestment in oil and gas https://www.globalwitness.org/en/campaigns/oil-gas-and-mining/overexposed/

Finney and Mattioli (2019) Planned growth of UK airports not consistent with Net Zero climate goal, Carbon Brief Guest Post https://www.carbonbrief.org/guest-post-planned-growth-of-uk-airports-not-consistent-with-net-zero-climate-goal

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Phillips and Brienen (2017) Carbon uptake by mature Amazon forests has mitigated Amazon nations' carbon emission, Carbon Balance and Management doi:10.1186/s13021-016-0069-2

Question 4: What is the international signalling value of a revised and strengthened UK NDC (for the period around 2030) as part of a package of action which includes setting the level of the sixth carbon budget?

A strengthened NDC will obviously signal ambition and serious commitment. However, with recent reports indicating that the UK is not on track to reach Net Zero, (https://www.netzeropolicytracker.co.uk/), Government must not only rapidly bring forward new policies but also facilitate action, or risk undermining diplomatic influence and credibility in the run up to COP26.

One of the major causes of uncertainty in NDCs is meanwhile the practice of expressing emissions levels as a single number for all greenhouse gases combined (tonnes of carbon dioxide equivalent). Although the uncertainty in temperature increase of using this approach, due to for example including the contribution of short-lived gases, has been calculated as less than 0.17°C using the GWP100 metric (Denison *et al*., 2019), this is still a significant fraction of the 0.5°C difference between the warming limits specified in the Paris Agreement, and is likely to be material in the future.

As gaining international agreement on using a different metric will require time and effort when action and ambition are priority, we recommend that supplementary information is included within the UK NDC on emissions levels of the most significant greenhouse gases, particularly CO_2 and methane, and that other countries are encouraged to do the same. This would help to reduce uncertainties without impairing the setting of NDCs or mitigating action at this crucial time.

References

Denison *et al.* (2019) Guidance on emissions metrics for nationally determined contributions under the Paris Agreement, Environmental Research Letters doi:10.1088/1748-9326/ab4df4

B. The path to the 2050 target

Question 5: How big a role can consumer, individual or household behaviour play in delivering emissions reductions? How can this be credibly assessed and incentivised?

ANSWER:

Question 6: What are the most important uncertainties that policy needs to take into account in thinking about achieving Net Zero? How can government develop a strategy that helps to retain robustness to those uncertainties, for example low-regrets options and approaches that maintain optionality?

Setting a carbon budget assumes a roughly linear relationship between CO_2 emissions and temperature increase. This relationship is however still subject to considerable uncertainties from, for example, cloud feedbacks and the nature of Effective Radiative Forcing (ERF) (CONSTRAIN, 2019).

Narrowing these uncertainties, through insights into driving mechanisms behind various climate forcers, is key to improved carbon budget estimates. Summaries of the latest knowledge on ERF, based on peer-reviewed publications submitted to IPCC AR6, and their policy implications will be available on the CONSTRAIN website (www.constrain-eu.org) in March 2020.

Meanwhile, no obvious mitigation options have been identified that can completely eliminate several important sources of non-CO_2 emissions whilst the climate may not respond in the same way to CO_2 as it does to methane or aerosol changes (Richardson *et al*., 2019). Uncertainties in reducing non-CO_2 emissions are estimated as ±250Gt for the 1.5°C limit (CONSTRAIN, 2019) highlighting the scale of uncertainties still present in the carbon budget, and further emphasising the need to cut emissions.

Variations in near-term warming rates due to anthropogenic (rather than natural) factors will also affect the carbon budget. Some recent models show warming of greater than 0.5°C per decade over the near-term, which would suggest smaller remaining carbon budgets or a need to reach Net Zero emissions sooner. Forster *et al.* (2020) show that many of these high warming rates are low probability, but are still a possibility – again emphasising the need for urgent mitigation and minimising risks through adaptation choices. Very high near-term warming rates are however unlikely if we follow a sustainable growth (below 1.5°C) pathway, and there is potential to cut the maximum historical warming rate by half if we are ambitious (CONSTRAIN 2019).

As new evidence comes to light it will be incorporated into estimates of the remaining global carbon budget, to be set out in future CONSTRAIN reports, but such factors should also be discussed widely across the policy arena to improve awareness of key uncertainties affecting the concepts of carbon budgets and Net Zero.

It should also be recognised that uncertainties cannot always be reduced and decisions may need to be made in the face of deep uncertainties. Tools to support this kind of decision making have been applied effectively both in the UK (e.g. Dessai and Hulme, 2007; Ranger *et al.*, 2013; Roelich and Giesekam 2019) and in Europe (e.g. Haasnoot *et al.,* 2013).

References

CONSTRAIN (2019) ZERO IN ON the remaining carbon budget and decadal warming rates. The CONSTRAIN Project Annual Report 2019 doi:10.5518/100/20

Forster *et al.* (2020) Latest climate models confirm need for urgent mitigation, Nature Climate Change doi:10.1038/s41558-019-0660-0

Richardson *et al.* (2019) Efficacy of Climate Forcings in PDRMIP Models, JGR Atmospheres doi:10.1029/2019JD030581

Question 6: What are the most important uncertainties that policy needs to take into account in thinking about achieving Net Zero? How can government develop a strategy that helps to retain robustness to those uncertainties, for example low-regrets options and approaches that maintain optionality?

Dessai and Hulme (2007) Assessing the robustness of adaptation decisions to climate change uncertainties: A case study on water resources management in the East of England, Global Environmental Change doi:10.1016/j.gloenvcha.2006.11.005

Ranger *et al.* (2013) Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project, EURO J Decis Process doi:10.1007/s40070-013-0014-5

Roelich and Giesekam (2019) Decision making under uncertainty in climate change mitigation: introducing multiple actor motivations, agency and influence, Climate Policy doi:10.1080/14693062.2018.1479238

Haasnoot *et al*. (2013) Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, Global Environmental Change doi:10.1016/j.gloenvcha.2012.12.006

Question 7: The fourth and fifth carbon budgets (covering the periods of 2023-27 and 2028-32 respectively) have been set on the basis of the previous long-term target (at least 80% reduction in GHGs by 2050, relative to 1990 levels). Should the CCC revisit the level of these budgets in light of the net-zero target?

ANSWER:

Question 8: What evidence do you have of the co-benefits of acting on climate change compatible with achieving Net Zero by 2050? What do these co-benefits mean for which emissions abatement should be prioritised and why?

Reducing fossil fuel consumption leads to lower air pollution and better public health outcomes (Lelieveld *et al*., 2019) whilst not significantly increasing the rate of global temperature change in 1.5°C-consistent pathways through reducing the formation of atmosphere-cooling aerosols (Shindell and Smith, 2019).

In the UK, air pollution is responsible for 28,000-36,000 premature deaths per year (COEMAP 2018), disproportionally affecting children, young adults and poorer households in urban areas (Barnes *et al*., 2019), whilst the transport sector is responsible for 33% of national CO_2 emissions and is the only key sector in which emissions have not declined substantially since 1990 (BEIS 2019). Policies to incentivise a reduction in private car use, particularly in urban areas, would therefore have climate and air quality co-benefits, whilst also improving transit efficiency and health outcomes (e.g. Khreis *et al*., 2019).

References

Lelieveld *et al.* (2019) Effects of fossil fuel and total anthropogenic emission removal on public health and climate, PNAS doi:10.1073/pnas.1819989116

Question 8: What evidence do you have of the co-benefits of acting on climate change compatible with achieving Net Zero by 2050? What do these co-benefits mean for which emissions abatement should be prioritised and why?

Shindell and Smith (2019) Climate and air-quality benefits of a realistic phase-out of fossil fuels, Nature doi:10.1038/s41586-019-1554-z

COMEAP (2018) Associations of long-term average concentrations of NO_2 with mortality https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

Barnes *et al*. (2019) Emissions vs exposure: Increasing injustice from road traffic-related air pollution in the United Kingdom, Transportation Research Part D: Transport and Environment doi:10.1016/j.trd.2019.05.012

BEIS (2019) 2018 UK Greenhouse Gas Emissions, Provisional Figures https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/790626/2018-provisional-emissions-statistics-report.pdf

Khreis *et al.* (2019) Transport Policy Measures for Climate Change as Drivers for Health in Cities. In: Nieuwenhuijsen M., Khreis H. (eds) Integrating Human Health into Urban and Transport Planning. Springer, Cham

C. Delivering carbon budgets

Question 9: Carbon targets are only credible if they are accompanied by policy action. We set out a range of delivery challenges/priorities for the 2050 net-zero target in our Net Zero advice. What else is important for the period out to 2030/2035?

Government and scientists need to work together to improve the translation of new climate science into an improved evidence base for policy and action, not only in terms of mitigation but also adaptation and resilience as we prepare for further temperature change in the period before 2050. This will particularly help where policy makers lack expertise, time or resources to fully assess new findings in climate science.

Clear science-into-policy mechanisms should therefore exist for all areas of Government, targeted towards a better understanding not only of carbon budgets and the implications of different emissions pathways, but also global and regional climate projections.

For example, most projections concentrate on the pathway to 2100, whereas policy-relevant timeframes are much nearer-term. Rather than promoting the output of complex climate models, simplified climate emulators are being developed to explore possible emissions pathways and how these can inform policy. One such tool will be available on the CONSTRAIN website (https://constrain-eu.org) by autumn 2020, but routes into policy are needed.

With these clear routes, updated projections and knowledge can be integrated into decision making as scientific understanding develops, and used to inform adaptation and mitigation policy and action. Such an approach could also learn from the experiences of the energy sector in whole systems research and a low carbon transition (Munro and Cairney, 2019). The experiences of other sectors in science-into-policy, such as

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healthcare and medicine (e.g. Cairney and Oliver, 2017; Gentry *et al.*, 2020) may also be useful in supporting co-production of usable scientific knowledge.

References

Munro and Cairney (2019) A systematic review of energy systems: The role of policymaking in sustainable transitions. Renewable and Sustainable Energy Reviews doi:10.1016/j.rser.2019.109598

Cairney and Oliver (2017) Evidence-based policymaking is not like evidence-based medicine, so how far should you go to bridge the divide between evidence and policy? Health Research Policy and Systems doi:10.1186/s12961-017-0192-x

Gentry *et al.* (2020) Why is translating research into policy so hard? Public Health doi:10.1016/j.puhe.2019.09.009

Question 10: How should the Committee take into account targets/ambitions of UK local areas, cities, etc. in its advice on the sixth carbon budget?

Low carbon measures in cities could reduce urban emissions by nearly 90% by 2030, whilst delivering significant benefits in areas such as public health as above, as well as job creation and poverty alleviation from climate-friendly urban development (Coalition for Urban Transitions, 2019).

However, whilst local governments have huge potential to drive climate action, they must be empowered to do so at the national level. The Committee should promote flexible national arrangements that can be tailored to local contexts, as well as the removal of any regulatory barriers to ambitious local action (e.g. Roelich *et al.* 2018, Kuzemko and Britton 2020).

References

Coalition for Urban Transitions (2019) Climate Emergency, Urban Opportunity, World Resources Institute (WRI) Ross Center for Sustainable Cities and C40 Cities Climate Leadership Group. London and Washington, DC. Available from: https://urbantransitions.global/urban-opportunity/

Roelich *et al.* (2018) Institutional pathways to municipal energy companies in the UK: Realising co-benefits to mitigate climate change in cities, Journal of Cleaner Production

Kuzemko C and Britton J (2020) Policy, politics and materiality across scales: A framework for understanding local government sustainable energy capacity applied in England, Energy Research and Social Science doi:10.1016/j.erss.2019.101367

Question 11: Can impacts on competitiveness, the fiscal balance, fuel poverty and security of supply be managed regardless of the level of a budget, depending on how policy is designed and funded? What are the critical elements of policy design (including funding and delivery) which can help to manage these impacts?

The form of finance used to support a low carbon transition can have a significant effect on the just-ness of that transition, affecting the affordability of projects, the transparency of decision making and spatial equality. "Just" energy finance, for example, should fulfil a number of criteria including affordability, good governance, due process, intra-generational equity, spatial equity, and financial resilience (Hall *et al.,* 2018).

References

Hall *et al.* (2018) Finance and justice in low-carbon energy transitions, Applied Energy doi:10.1016/j.apenergy.2018.04.007

Question 12: How can a just transition to Net Zero be delivered that fairly shares the costs and benefits between different income groups, industries and parts of the UK, and protects vulnerable workers and consumers?

As many as one in five workers will be affected by a transition to Net Zero, with effects unevenly distributed across the UK. Large inequality can also be found in not only international but also intranational energy footprints (Robins *et al*., 2019, Oswald *et al*., 2020). At the household level, energy use and carbon emissions are highly unequally distributed across income groups, and income remains one of the most important drivers of emissions. However, this differs across consumption domains.

Energy use in the home is more evenly distributed across income groups than travel related emissions such as from car ownership or air travel. This means that Net Zero policies that increase household energy prices tend to have much more regressive effects (burdening low income households more than other groups) compared to policies leading to price increases in road or air travel.

To ensure fairness and public acceptability, great care would need to be taken to avoid any regressive effects, especially for the home energy domain. This could be done by redistributing revenues from energy or carbon taxes through the tax and benefit system, or by providing a free, equal amount of energy to every household to ensure basic needs are met and fuel poverty avoided. This would also have strongly progressive distributional effects (Buchs and Schnepf, 2013; Buchs *et al*. 2014).

Alternatively, funds raised through general taxation could offer a fair and practical approach, but as with other options would also require leadership and long term commitment to avoid leaving policies vulnerable to short term budgetary or political change (Barrett *et al*., 2018).

While rising costs associated with private vehicle use are, on average, less regressive, poorer groups will still be adversely affected. Car ownership among poorer groups has risen, and they would still be disproportionally affected by higher motoring costs. It is therefore important to expand affordable and reliable mass transit systems to reduce car dependency while ensuring that everyone's mobility needs are being met (Mattioli *et al*. 2018). This would also deliver significant co-benefits (Q8).

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Justice should also be considered in a broader sense than simply impacts on jobs or cost distribution. The effect of the transition on citizens' ability to achieve wellbeing should be considered, possibly using a framework such as the capabilities approach (e.g. Wood and Roelich, 2019) or Human Needs (e.g. Brand-Correa *et al,* 2018).

References

Robins *et al.* (2019) Investing in a just transition in the UK: How investors can integrate social impact and place-based financing into climate strategies. London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science

Oswald *et al.* (2020) Large inequality in international and intranational energy footprints between income groups and across consumption categories, Nature Energy, in press

Büchs and Schnepf (2013) Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO_2 emissions. Ecological Economics doi:10.1016/j.ecolecon.2013.03.007

Büchs *et al.* (2014) Unequal emissions – unequal policy impacts: how do different areas of CO_2 emissions compare? In T. Fitzpatrick (Ed.), International Handbook on Social Policy and the Environment (pp. 62-92). Cheltenham, UK: Edward Elgar http://eprints.whiterose.ac.uk/146443/

Barrett *et al.* (2018) Funding a low carbon energy system: A fairer approach? UKERC Policy Briefing UKERC/EES/2018/BN/01 http://www.ukerc.ac.uk/publications/funding-a-low-carbon-energy-system.html

Mattioli *et al.* (2018) Vulnerability to fuel price increases in the UK: A household level analysis. Transportation Research Part A: Policy and Practice doi:10.1016/j.tra.2018.04.002

Wood and Roelich (2019) Tensions, capabilities, and justice in climate change mitigation of fossil fuels, Energy Research and Social Science doi:10.1016/j.erss.2019.02.014

Brand-Correa *et al.* (2018) Human Scale Energy Services: Untangling a 'golden thread', Energy Research & Social Science doi:10.1016/j.erss.2018.01.008

D. Scotland, Wales and Northern Ireland

Question 13: What specific circumstances need to be considered when recommending an emissions pathway or emissions reduction targets for Scotland, Wales and/or Northern Ireland, and how could these be reflected in our advice on the UK-wide sixth carbon budget?

ANSWER:

Question 14: The Environment (Wales) Act 2016 includes a requirement that its targets and carbon budgets are set with regard to:

- The most recent report under section 8 on the State of Natural Resources in relation to Wales;
- The most recent Future Trends report under section 11 of the Well-Being of Future Generations (Wales) Act 2015;
- The most recent report (if any) under section 23 of that Act (Future Generations report).

a) What evidence should the Committee draw on in assessing impacts on sustainable management of natural resources, as assessed in the state of natural resources report?

b) What evidence do you have of the impact of acting on climate change on well-being? What are the opportunities to improve people's well-being, or potential risks, associated with activities to reduce emissions in Wales?

c) What evidence regarding future trends as identified and analysed in the future trends report should the Committee draw on in assessing the impacts of the targets?

d) Question 12 asks how a just transition to Net Zero can be achieved across the UK. Do you have any evidence on how delivery mechanisms to help meet the UK and Welsh targets may affect workers and consumers in Wales, and how to ensure the costs and benefits of this transition are fairly distributed?

ANSWER:

Question 15: Do you have any further evidence on the appropriate level of Wales' third carbon budget (2026-30) and interim targets for 2030 and 2040, on the path to a reduction of at least 95% by 2050?

ANSWER:

Question 16: Do you have any evidence on the appropriate level of Scotland's interim emissions reduction targets in 2030 and 2040?

ANSWER:

Question 17: In what particular respects do devolved and UK decision making need to be coordinated? How can devolved and UK decision making be coordinated effectively to achieve the best outcomes for the UK as a whole?

ANSWER:

E. Sector-specific questions

Question 18 (Surface transport): As laid out in Chapter 5 of the Net Zero Technical Report (see page 149), the CCC's Further Ambition scenario for transport assumed 10% of car miles could be shifted to walking, cycling and public transport by 2050 (corresponding to over 30% of trips in total):

a) What percentage of trips nationwide could be avoided (e.g. through car sharing, working from home etc.) or shifted to walking, cycling (including e-bikes) and public transport by 2030/35 and by 2050? What proportion of total UK car mileage does this correspond to?

b) What policies, measures or investment could incentivise this transition?

For questions 18-20 please see the response from the Centre for Research into Energy Demand Solutions (CREDS).

Question 19 (Surface transport): What could the potential impact of autonomous vehicles be on transport demand?

ANSWER:

Question 20 (Surface transport): The CCC recommended in our Net Zero advice that the phase out of conventional car sales should occur by 2035 at the latest. What are the barriers to phasing out sales of conventional vehicles by 2030? How could these be addressed? Are the supply chains well placed to scale up? What might be the adverse consequences of a phase-out of conventional vehicles by 2030 and how could these be mitigated?

ANSWER:

Question 21 (Surface transport): In our Net Zero advice, the CCC identified three potential options to switch to zero emission HGVs – hydrogen, electrification with very fast chargers and electrification with overhead wires on motorways. What evidence and steps would be required to enable an operator to switch their fleets to one of these options? How could this transition be facilitated?

Since the increasing electrification of passenger car and vans is already imposing significant strains on the global lithium supply, further mass electrification in the heavy-duty vehicle sector, expected to increase the accumulated net demand by 29% to 53%, would come with risks.

Even if electric HDVs gain a technoeconomic advantage over other powertrain technologies and achieve market success in the short term, their long-term development is likely to face resource constraints with a reflected surge in lithium prices. It is therefore proposed that fuel cell vehicles should be prioritized for decarbonizing the HDV segment.

This supports the CCC conclusion and targeted investment is urgently needed in assessing the feasibility of a de-carbonised hydrogen infrastructure and heavy-duty vehicle technology.

Question 21 (Surface transport): In our Net Zero advice, the CCC identified three potential options to switch to zero emission HGVs – hydrogen, electrification with very fast chargers and electrification with overhead wires on motorways. What evidence and steps would be required to enable an operator to switch their fleets to one of these options? How could this transition be facilitated?

Hao, H., Geng, Y., Tate, J.E. *et al.* (2019) Impact of transport electrification on critical metal sustainability with a focus on the heavy-duty segment, Nature Communications doi:10.1038/s41467-019-13400-1

Question 22 (Industry): What policy mechanisms should be implemented to support decarbonisation of the sectors below? Please provide evidence to support this over alternative mechanisms.

a) Manufacturing sectors at risk of carbon leakage
b) Manufacturing sectors not at risk of carbon leakage
c) Fossil fuel production sectors
d) Off-road mobile machinery

ANSWER:

Question 23 (Industry): What would you highlight as international examples of good policy/practice on decarbonisation of manufacturing and fossil fuel supply emissions? Is there evidence to suggest that these policies or practices created economic opportunities (e.g. increased market shares, job creation) for the manufacturing and fossil fuel supply sectors?

ANSWER:

Question 24 (Industry): How can the UK achieve a just transition in the fossil fuel supply sectors?

ANSWER:

Question 25 (Industry): In our Net Zero advice, the CCC identified a range of resource efficiency measures that can reduce emissions (see Chapter 4 of the Net Zero Technical Report, page 115), but found little evidence relating to the costs/savings of these measures. What evidence is there on the costs/savings of these and other resource efficiency measures (ideally on a £/tCO2e basis)?

ANSWER:

Question 26 (Buildings): For the majority of the housing stock in the CCC's Net Zero Further Ambition scenario, 2050 is assumed to be a realistic timeframe for full roll-out of energy efficiency and low-carbon heating.

a) What evidence can you point to about the potential for decarbonising heat in buildings more quickly?

b) What evidence do you have about the role behaviour change could play in driving forward more extensive decarbonisation of the building stock more quickly? What are the costs/levels of abatement that might be associated with a behaviour-led transition?

The Sustainability Research Institute at the University of Leeds has produced two recent papers on UK housing stock, which are relevant to part a):

1) Nieto, J., Brockway, P. and Barrett, J. (2020) *Socio-macroeconomic impacts of meeting new build and retrofit UK building energy targets to 2030: a MARCO-UK modelling study*. Sustainability Research Institute (SRI) Working Paper No. 121. (https://sri-working-papers.leeds.ac.uk/wp-content/uploads/sites/67/2020/01/SRIPs-121.pdf)

2) Nieto, J., Brockway, P. and Barrett, J. (2019) *Report on the socio-macroeconomic impacts of the UK Labour Party's renewable and low carbon energy targets in the '30 by 2030' UK Energy Plan*. Sustainability Research Institute (SRI) Working Paper No. 120 (https://sri-working-papers.leeds.ac.uk/wp-content/uploads/sites/67/2019/12/SRIPs-120.pdf)

Both use the MARCO-UK model to look at the wider socio-macroeconomic benefits of rapid retrofitting and new build energy targets, to 2030, via a range of scenarios. 1) looks at existing BEIS targets, whilst 2) considers the UK Labour Party's Energy Plan produced for the 2019 election.

For 1), the findings included that building retrofit was more significant in socioeconomic terms (e.g. larger GDP growth, more jobs, higher wages) than new build, but that a combination of all policies yielded more economic and energy benefits than their sum due to multiplier effects. All policies also acted as a source of employment creation, whilst accounting for the labour skills upgrade also had overall positive effects at the macroeconomic level.

Overall, both analyses show widespread socioeconomic benefits (as well as energy reduction of the scale required for Net Zero) of deep, rapid retrofit and new build energy targets, including GDP growth, gains to employment, skills and wages (both analyses assume retrofit in 12 years). The broader benefits highlighted by these studies also relate to Q8 in terms of welfare gains and health improvements via better homes.

Question 27 (Buildings): Do we currently have the right skills in place to enable widespread retrofit and build of low-carbon buildings? If not, where are skills lacking and what are the gaps in the current training framework? To what extent are existing skill sets readily transferable to low-carbon skills requirements?

ANSWER:

Question 28 (Buildings): How can local/regional and national decision making be coordinated effectively to achieve the best outcomes for the UK as a whole? Can you point to any case studies which illustrate successful local or regional governance models for decision making in heat decarbonisation?

The area based, city wide approaches to retrofit being developed via the UK Green Building Council Accelerator Cities Retrofit Programme highlight the need for an ambitious home retrofit programme if the UK is to realise its Net Zero target by 2050.

This initiative is currently developing comprehensive proposals for a city-led retrofit programme, and an action plan for how it might be taken forward, based on workshops which took place at the end of 2019. This should be considered by the CCC as soon as available (https://www.ukgbc.org/ukgbc-work/accelerator-cities-pathfinder/).

Question 29 (Power): Think of a possible future power system without Government backed Contracts-for-Difference. What business models and/or policy instruments could be used to continue to decarbonise UK power emissions to close to zero by 2050, whilst minimising costs?

Local supply business models can offer significant benefits to the electricity system, but also generate economic, social, and environmental values that are not well accounted for in current policy or regulation (Hall and Roelich, 2016). The energy sector will meanwhile have to adapt its business models in order to capture new markets and accelerate low carbon transitions. Research shows that new business models are technologically feasible, but there is still a need for system integration, as well as comprehensive demonstration trials which can combine and test information and communications technology (ICT) solutions (Mazur *et al*., 2019).

Prosumers (who both produce and consume renewable energy) are meanwhile key actors in energy transitions. Traditional prosumer business models are increasingly unviable without subsidies, and so new business models should play an increasing role in a post subsidy environment, for example through microgrids, local energy companies, P2P, aggregators, ESCOs and V2G models (Brown *et al.*, 2019).

References

Hall and Roelich (2016) Business model innovation in electricity supply markets: The role of complex value in the United Kingdom, Energy Policy doi:10.1016/j.enpol.2016.02.019

Mazur *et al.* (2019) Technology is not a Barrier: A Survey of Energy System Technologies Required for Innovative Electricity Business Models Driving the Low Carbon Energy Revolution. Energies doi:10.3390/en12030428

Brown *et al*. (2019) Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK, Energy Policy doi:10.1016/j.enpol.2019.110984

Question 30 (Power): In Chapter 2 of the Net Zero Technical Report we presented an illustrative power scenario for 2050 (see pages 40-41 in particular):

a) Which low-carbon technologies could play a greater/lesser role in the 2050 generation mix? What about in a generation mix in 2030/35?

b) Power from weather-dependent renewables is highly variable on both daily and seasonal scales. Modelling by Imperial College which informed the illustrative 2050 scenario suggested an important role for interconnection, battery storage and flexible demand in a future low-carbon power system:

i. What other technologies could play a role here?

ii. What evidence do you have for how much demand side flexibility might be realised?

i. The UK would still need large scale biomass power by 2030/35, with a transition to biomass-CCS (BECCS) and renewables with energy storage by 2050. Some nuclear power may also still be needed.

Question 31 (Hydrogen): The Committee has recommended the Government support the delivery of at least one large-scale low-carbon hydrogen production facility in the 2020s. Beyond this initial facility, what mechanisms can be used to efficiently incentivise the production and use of low-carbon hydrogen? What are the most likely early applications for hydrogen?

ANSWER:

Question 32 (Aviation and Shipping): In September 2019 the Committee published advice to Government on international aviation and shipping and Net Zero. The Committee recognises that the primary policy approach for reducing emissions in these sectors should be set at the international level (e.g. through the International Civil Aviation Organisation and International Maritime Organisation). However, there is still a role for supplementary domestic policies to complement the international approach, provided these do not lead to concerns about competitiveness or carbon leakage. What are the domestic measures the UK could take to reduce aviation and shipping emissions over the period to 2030/35 and longer-term to 2050, which would not create significant competitiveness or carbon leakage risks? How much could these reduce emissions?

The Committee's letter to Government states that "up to a 49% increase in demand" is projected for aviation. The conservative estimate of Finney and Mattioli (2019) suggests airports are aiming for growth in UK airport capacity of 59% at least. Since increasing supply can drive down prices and generate demand, this is very worrying indeed, especially as the Committee's plans themselves rest on an assumption of a 25% increase in demand.

Finney and Mattioli (2019) show that, with projects already underway and projects approved, capacity for a 25% increase in passenger numbers would likely already be surpassed. Since the article was written, Bristol has also been given approval for expansion. This is a rapidly changing picture and it is imperative that the Committee make clear that a national strategy is required so that capacity is not increased by more than reasonable increases in demand in line with the Net Zero target. This should be done fairly, so that poorer regions of the country are not disadvantaged.

Question 32 (Aviation and Shipping): In September 2019 the Committee published advice to Government on international aviation and shipping and Net Zero. The Committee recognises that the primary policy approach for reducing emissions in these sectors should be set at the international level (e.g. through the International Civil Aviation Organisation and International Maritime Organisation). However, there is still a role for supplementary domestic policies to complement the international approach, provided these do not lead to concerns about competitiveness or carbon leakage. What are the domestic measures the UK could take to reduce aviation and shipping emissions over the period to 2030/35 and longer-term to 2050, which would not create significant competitiveness or carbon leakage risks? How much could these reduce emissions?

Finney and Mattioli (2019) also estimate that, if demand follows the current plans for increased airport capacity, an extra 8 $MtCO_2e$ of speculative emissions reductions will be needed, at the same time as ruling out the speculative option of maintaining aviation demand at current levels. This means that airport expansion is likely one of the key infrastructure decisions being taken now that will significant damage the chances of achieving Net Zero.

The Committee is not making this explicit enough in its communications. This is not even about finding demand-side options to help reduce emissions further, it is about the vital need for demand-side options to avoid ruining the chance of achieving the Net Zero target.

With regard to leakage, the majority of flights are made by UK citizens going on holiday (ONS, 2018). These are not essential flights, and in most cases it will not make sense for people to leave the country by car, boat or train solely to take the flight from elsewhere. There is much scope for demand-side options such as a frequent flyer levy without resulting in carbon leakage.

References

Finney and Mattioli (2019) Planned growth of UK airports not consistent with net-zero climate goal, Carbon Brief Guest Post https://www.carbonbrief.org/guest-post-planned-growth-of-uk-airports-not-consistent-with-net-zero-climate-goal

ONS (2018) Travel trends: 2018 https://www.ons.gov.uk/peoplepopulationandcommunity/leisureandtourism/articles/traveltrends/2018

Question 33 (Agriculture and Land use): In Chapter 7 of the Net Zero Technical Report we presented our Further Ambition scenario for agriculture and land use (see page 199). The scenario requires measures to release land currently used for food production for other uses, whilst maintaining current per-capita food production. This is achieved through:

- A 20% reduction in consumption of red meat and dairy
- A 20% reduction in food waste by 2025
- Moving 10% of horticulture indoors
- An increase in agriculture productivity:
  - Crop yields rising from the current average of 8 tonnes/hectare for wheat (and equivalent rates for other crops) to 10 tonnes/hectare
  - Livestock stocking density increasing from just over 1 livestock unit (LU)/hectare to 1.5 LU/hectare

Can this increase in productivity be delivered in a sustainable manner?

Do you agree that these are the right measures and with the broad level of ambition indicated? Are there additional measures you would suggest?

ANSWER:

Question 34 (Agriculture and Land use): Land spared through the measures set out in question 33 is used in our Further Ambition scenario for: afforestation (30,000 hectares/year), bioenergy crops (23,000 hectares/year), agro-forestry and hedgerows (~10% of agricultural land) and peatland restoration (50% of upland peat, 25% lowland peat). We also assume the take-up of low-carbon farming practices for soils and livestock. Do you agree that these are the key measures and with the broad level of ambition of each? Are there additional measures you would suggest?

Agricultural management of lowland peatlands is a key contributor to UK land-use related carbon release each year (DEFRA report SP1210). A key hotspot for such release is East Anglia. Most UK lowland peatland has been destroyed or is highly degraded, and to suggest that 25% lowland peat should be restored will not sufficiently address the large annual carbon releases from the other 75% of lowland peatlands, which are predominant sources. Wholesale change is therefore needed in the management of lowland peatlands as a UK priority.

UK upland peatlands meanwhile provide a huge potential for net carbon gain if appropriately managed. The 50% target here is good, but we could proactively harness almost all of our upland peatlands for further storage and sequestration, while at the same time reducing flood risk (e.g. Gao *et al.* 2016), enhancing water quality (particularly important as the UK is unique in a global context in the very high proportion of drinking water sourced from peatlands (Xu *et al*., 2018), biodiversity (e.g. Ramchunder *et al.,* 2012), and public access to tackle health and wellbeing.

Acceleration of peatland restoration and carbon sequestration in upland peatlands should be a UK priority. Further research is required to study how to maximise carbon storage across these landscapes through nuanced types of intervention (rather than relying solely on traditional restoration methods) and to mitigate the effects of future climate change which will degrade these systems further unless we intervene more radically now (Li *et al.,* 2015, 2017; Xu *et al.,* 2020).

Question 34 (Agriculture and Land use): Land spared through the measures set out in question 33 is used in our Further Ambition scenario for: afforestation (30,000 hectares/year), bioenergy crops (23,000 hectares/year), agro-forestry and hedgerows (~10% of agricultural land) and peatland restoration (50% of upland peat, 25% lowland peat). We also assume the take-up of low-carbon farming practices for soils and livestock. Do you agree that these are the key measures and with the broad level of ambition of each? Are there additional measures you would suggest?

References

Gao *et al.* (2016) The impact of land-cover change on flood peaks in peatland basins, Water Resources Research doi:10.1002/2015WR017667

Li *et al.* (2015) Prediction of blanket peat erosion across Great Britain under environmental change, Climatic Change doi:10.1007%2Fs10584-015-1532-x

Li *et al.* (2017) Spatial variability of fluvial blanket peat erosion rates for the 21st Century modelled using PESERA-PEAT, Catena doi:10.1016/j.catena.2016.11.025

Ramchunder *et al.* (2012) Catchment-scale peatland restoration benefits stream ecosystem biodiversity, Journal of Applied Ecology, doi:10.1111/j.1365-2664.2011.02075.x

Xu *et al.* (2018) Hotspots of peatland-derived potable water use identified by global analysis, Nature Sustainability doi:10.1038/s41893-018-0064-6

Xu *et al.* (2020) Increased dissolved organic carbon concentrations in peat-fed UK water supplies under future climate and sulfate deposition scenarios, Water Resources research doi:10.1029/2019WR025592

Question 35 (Greenhouse gas removals): What relevant evidence exists regarding constraints on the rate at which the deployment of engineered GHG removals in the UK (such as bioenergy with carbon capture and storage or direct air capture) could scale-up by 2035?

Biomass-based power generation combined with CO_2 capture and storage (Biopower CCS) currently represents one of the few practical and economic means of removing large quantities of CO_2 from the atmosphere, and the only approach that involves the generation of electricity at the same time.

The Techno-Economic Study of Biomass to Power with CO_2 capture (TESBiC) (Bhave *et al*., 2017) identified and assessed twenty-eight Biopower CCS technology combinations involving combustion or gasification of biomass (either dedicated or co-fired with coal) together with pre-, oxy- or post-combustion CO_2 capture from the perspective of being able to deploy Biopower CCS by 2050 (rather than 2035).

In addition to the capital and operating costs, techno-economic characteristics such as electrical efficiencies (LHV% basis), Levelised Cost of Electricity (LCOE), costs of CO_2 captured and CO_2 avoided were modelled over time assuming technology improvements from today to 2050.

Many of the Biopower CCS technologies gave relatively similar techno-economic results when analysed at the same scale, with the plant scale (MWe) observed to be the principal

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driver of CAPEX (£/MWe) and the cofiring % (i.e. the weighted feedstock cost) a key driver of LCOE. However, the TESBiC project also highlighted the lack of financial incentives for generation of electricity with negative CO_2 emissions: current policies either only penalise positive emissions, or incentivise zero emissions, and the data collected indicates that the most significant barriers to the deployment of Biopower CCS technologies will be economic and regulatory in nature, rather than technical, assuming fossil CCS technologies are successfully proven at scale.

Furthermore, establishing sustainable biomass supply chains with low upstream emissions and availability and suitability of CO_2 sequestration sites are important issues that would need to be considered for the development and deployment of Biopower CCS. More detailed engineering studies are recommended to help reduce the uncertainties in the cost estimates, followed by pilot and demonstration activities.

References

Bhave *et al.* (2017) Screening and techno-economic assessment of biomass-based power generation with CCS technologies to meet 2050 CO_2 targets, Applied Energy doi:10.1016/j.apenergy.2016.12.120

Question 36 (Greenhouse gas removals): Is there evidence regarding near-term expected learning curves for the cost of engineered GHG removal through technologies such as bioenergy with carbon capture and storage or direct air capture of CO_2?

BECCS is one of the most promising NETs suggested by many and involves utilising biomass to produce energy. However, due to the lack of BECCS installations internationally, learning curve analysis has not been conducted on BECCS. Nonetheless, learning curve analysis has been conducted on the components (bioenergy and carbon capture and storage) separately. This shows that the cost reduction of the technology is dependent upon several factors including: investment, location, technology chosen, and the capacity installed, and that cost reductions are highly likely where there is a significant amount of learning from the technology (e.g. Junginger *et al*, 2006; Wu *et al.* 2016; Van den Broek *et al*., 2009; Riahi *et al*., 2004).

Conversely, although there is very little literature available, based on existing learning rates, without substantial investment and development in the early stages of BECCS, the costs would soon become increasingly expensive.

References

Junginger *et al.* (2006) Technological learning in bioenergy systems, Energy Policy
Wu *et al.* (2016) Progress and prospect of CCS in China: Using learning curve to assess the cost-viability of a 2 x 600 MW retrofitted oxyfuel power plant as a case study, Renewable & Sustainable Energy Reviews

van den Broek *et al.* (2009) Effects of technological learning on future cost and performance of power plants with CO_2 capture, Progress in Energy and Combustion Science doi:10.1016/j.pecs.2009.05.002

Question 36 (Greenhouse gas removals): Is there evidence regarding near-term expected learning curves for the cost of engineered GHG removal through technologies such as bioenergy with carbon capture and storage or direct air capture of CO_2?

Riahi, K. *et al*. (2004) Technological learning for carbon capture and sequestration technologies, Energy Economics doi:10.1016/j.eneco.2004.04.024

Question 37 (Infrastructure): What will be the key factors that will determine whether decarbonisation of heat in a particular area will require investment in the electricity distribution network, the gas distribution network or a heat network?

ANSWER:

Question 38 (Infrastructure): What scale of carbon capture and storage development is needed and what does that mean for development of CO_2 transport and storage infrastructure over the period to 2030?

IIASA has conducted climate modelling on several negative emissions technologies s. The results, published on their public database, is a conglomeration of integrated assessment modelling (IAM) and impact, adaptation and vulnerability (IAV) analysis (Riahi *et al,* 2007).

This investigates how BECCS should contribute to the future energy mix, finding that BECCS is a key technology and favorable for achieving negative emissions because of its ability to produce energy vectors (van Vuuren *et al*., 2013).

Recent research has also quantified the prospects and costs of the ten most important applications of atmospheric CO_2, which include chemical production, building materials, fuels, and fertilizer in algae farming, up to 2050. In the long term, each option would make it possible to bind at least half a gigatonne of atmospheric CO_2 per year (Hepburn *et al.* (2019). Although the potential uses of atmospheric CO_2 still need to be systematically analysed, CO_2 utilisation could play an important role on the path to Net Zero, for example by accelerating the development and reducing costs of removal technologies through new business models and niche markets. Mitigation through reducing emissions should nonetheless remain the priority.

References

Riahi *et al.* (2007) Scenarios of long-term socio-economic and environmental development under climate stabilization, Technological Forecasting and Social Change doi:10.1016/j.techfore.2006.05.026

van Vuuren *et al.* (2013) The role of negative CO_2 emissions for reaching 2 °C - insights from integrated assessment modelling, Climatic Change doi:10.1007/s10584-012-0680-5

Hepburn *et al.* (2019) The technological and economic prospects for CO_2 utilisation and removal, Nature doi:10.1038/s41586-019-1681-6