BAAN/W1/2

TOWN AND COUNTRY PLANNING ACT 1990

Appeal by Bristol Airport Limited concerning land at North Side Road, Felton, Bristol, BS48 3DY

DEVELOPMENT OF BRISTOL AIRPORT TO ACCOMMODATE 12 MILLION PASSENGERS PER ANNUM

Appeal Reference APP/D0121/W/20/3259234

APPENDIX TO

PROOF OF EVIDENCE

of

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Tyndall Centre for Climate Change Research

15 June 2021

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G7 United Kingdom 2021

G7 Climate and Environment Ministers' Meeting Communiqué

London, United Kingdom
20 – 21 May 2021

Joint Commitments

1. We, the G7 Ministers responsible for Climate and Environment, met virtually on 20 - 21 May 2021.

2. As we continue to address the ongoing pandemic, we acknowledge with grave concern that the unprecedented and interdependent crises of climate change and biodiversity loss pose an existential threat to nature, people, prosperity and security. We recognise that some of the key drivers of global biodiversity loss and climate change are the same as those that increase the risk of zoonoses, which can lead to pandemics. We highlight that urgent and concrete action is needed to move towards global sustainability, further mitigate and adapt to climate change, as well as halt and reverse biodiversity loss and environmental degradation. We recognise that climate change and the health of the natural environment are intrinsically linked and will ensure that the actions we take maximise the opportunities to solve these crises in parallel.

3. We will do this by building back better from the pandemic, and we stress our determination to put climate, biodiversity, and the environment at the heart of our COVID-19 recovery strategies and investments. In doing so, we will transform our economies to promote sustainable development, deliver decent green jobs and build resilience. We will also accelerate the clean energy transition, improve resource efficiency, including by reducing food loss and waste and promoting a circular economic approach, transition to sustainable supply chains and mainstream nature, including biodiversity, and climate into economic decision-making. We will help set the world on a nature positive and climate-resilient pathway to bend the curve of biodiversity loss by 2030 and to keep a limit of 1.5°C temperature rise within reach by making our 2030 ambitions consistent with the aim of achieving net zero emissions as soon as possible and by 2050 at the latest.

4. We recognise these are global challenges which require urgent and ambitious global action at all levels. We reaffirm our commitment to international cooperation and multilateralism, and will work collectively to implement fully our national and international commitments. In this critical year of action we recognise the need to

increase global ambition and enhance collaboration, underpinned by the most ambitious sub-national, national and international action. We call on all countries to join us in action.

5. The COVID-19 crisis has reinforced the importance of science and evidence in government policies and decision-making. Recent assessments by the Intergovernmental Panel on Climate Change (IPCC), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), the International Resource Panel (IRP), and the UN Environment Programme (UNEP) have documented that rapid and far-reaching transformations across all sectors of society and the economy are necessary to tackle climate change, environmental degradation and biodiversity loss. Recalling the outcomes of previous G7 meetings on Earth observation systems, we recognise the important role of research and systematic observation to provide information on the state of the planet and support and guide action to address climate change and conserve, protect and restore essential and biodiverse ecosystems. We will ensure our domestic action and international commitments are informed by the best available science and will support others wishing to enhance their evidence-based policy-making processes by sharing our experiences and best practices.

Tackling the twin crises of Climate Change and Biodiversity Loss

6. We recognise the critical role the ocean and seas play for biodiversity and in regulating the Earth's climate, absorbing over 90 percent of all excess heat in the Earth's system and between 20-30 percent of all anthropogenic carbon dioxide emissions since the 1980s, providing a home to up to 80 percent of all life on Earth, and a healthy ocean is central to the livelihoods of more than three billion people. We therefore commit to increase efforts at international, regional and national level, to conserve and sustainably use the ocean, thus increasing its resilience.

7. We recognise the critical role of our world's forests as home to most of the world's terrestrial biodiversity, reducing our vulnerability to climate change impacts, improving our adaptability and resilience, and acting as key carbon sinks with tropical forests capturing and storing up to 1.8 GtCO_2 from the atmosphere every year. We recognise deforestation and forest degradation as a significant cause of climate change. We commit to urgent action to conserve, protect and restore natural ecosystems including forests and habitat connectivity and promote sustainable forest management. We also commit to implement decarbonisation pathways that do not cause further biodiversity loss or deforestation.

8. We recognise the crucial role of Nature-based Solutions in delivering significant multiple benefits for climate mitigation and adaptation, biodiversity, and people and thereby contributing to the achievement of various Sustainable Development Goals (SDGs). Such benefits include, among others, improving air quality, water quality and

availability, soil health, storm and flood protection, disaster risk reduction, and alleviating and preventing land degradation. Nature-based Solutions can also provide sustainable livelihoods through protecting and supporting a wide range of ecosystem services on which the world's most vulnerable and poorest people disproportionately rely. We therefore commit to strengthen their deployment and implementation. We stress that Nature-based Solutions do not replace the necessity for urgent decarbonisation and reduction of emissions, but are needed alongside these efforts. In addition to action on the ocean and forests, we commit to take urgent action across ecosystems, including soils, grasslands, savannah, drylands, wetlands, coral reefs, rivers, lakes, coastal dunes, peatland, seagrass beds, mangroves and saltmarshes, whilst ensuring that relevant safeguards are in place.

9. We reiterate that achieving our collective ambitions will require all sources of finance: public and private, domestic and international, including innovative sources. We commit to using all relevant sources, tools and approaches, including Official Development Assistance and other sources of finance, to support and accelerate global action to tackle climate change and conserve, protect, restore and sustainably manage nature and the environment. We underscore the importance of a predictable investment environment and clear public policies and strategies in facilitating the alignment of global and national financial flows with these objectives, and as such, welcome the UK's incoming United Nations Framework Convention on Climate Change (UNFCCC) COP26 Presidency's ambitious efforts as they relate to mobilising private and public finance. We are each working intensively to increase the quantity of finance for climate mitigation and adaptation actions, including for Nature-based Solutions, and are committed to increasing its effectiveness, accessibility, and where possible its predictability, and call on others to join us in these efforts. In conjunction with these efforts, we are working intensively towards increasing the quantity of finance to nature and Nature-based Solutions. We reaffirm our commitment to the collective developed country climate finance goal to jointly mobilise US$100 billion annually by 2020 through to 2025 from a wide variety of sources, and welcome the commitments already made by some of the G7 to increase climate finance and look forward to new commitments from others well ahead of COP26 in Glasgow. We will promote enabling environments to mobilise private finance towards these efforts while also enhancing action from the international community to support the poorest and those most vulnerable to climate change, biodiversity loss, and environmental degradation. We are committed to further enhance synergies between finance for climate and biodiversity and to promote funding that has co-benefits for climate and nature.

10. We call upon Multilateral Development Banks (MDBs), bilateral Development Finance Institutions (DFIs), multilateral funds, public banks, and export credit agencies to ensure that financial flows from these institutions are aligned with the goals of the Paris Agreement and support the objectives of international biodiversity conventions

including the Convention on Biological Diversity (CBD) and the post-2020 global biodiversity framework, by increasing finance for nature and climate, and leveraging further private capital, in particular for developing countries and emerging markets. We call on MDBs, bilateral DFIs and other support providers to mobilise finance at scale by delivering on their climate finance objectives and targets, and nature finance objectives, making them more ambitious, and mainstreaming climate and nature into their analysis, policy advice, decision-making and financing. We further call on all MDBs to publish, before the UNFCCC COP26, a plan and date by which their operations will be aligned with and support the goals of the Paris Agreement, and encourage them to sign a joint statement committing them to mainstream nature across their operations as appropriate. We also urge the MDBs to commit their private sector arms to pilot and scale up private finance programmes for nature and climate, in particular in under-funded sectors like adaptation and resilience and Nature-based Solutions.

11. In the context of building back better and achieving a global green recovery from COVID-19, we acknowledge the particularly significant impacts faced by developing countries and that increasing debt burdens can constrain fiscal space and the ability to provide stimulus for a green recovery alongside other development objectives, including access to clean and sustainable energy for all. We recognise that macro and fiscal policies, a free, fair and rules-based multilateral trading system, international initiatives and domestic efforts to create an enabling environment to mobilise private finance, offer a powerful tool to both transforming and revitalising economies. We thank Professor Lord Stern for his work and note with interest his paper on "G7 Leadership for Sustainable, Resilient and Inclusive Growth and Recovery" as commissioned by the UK G7 Presidency. We welcome the discussions of Finance Ministers on supporting a global recovery and their role in enabling a smooth transition to net zero, addressing biodiversity loss, and mobilising the private sector.

Leaving no-one behind

12. We recognise the disproportionate impacts of climate change, biodiversity loss, and environmental degradation on the most vulnerable communities, people living in poverty and those already facing intersecting inequalities and discrimination, including women and girls, Indigenous Peoples, people with disabilities and other marginalised groups. We will increase our efforts to address environmental justice issues in order to make their voices heard and support their full, equal and meaningful participation in decision-making, recognising their critical role as leaders and agents of change, and adapting new and existing policies to support social justice, economic empowerment and achieving gender equality. We further recognise the need to protect the rights of Indigenous Peoples, as acknowledged in national law and international instruments, and respect and value their knowledge and leadership in tackling climate change and biodiversity loss. We are steadfastly committed to addressing barriers to accessing finance for climate and nature faced by women, marginalised people, and underrepresented groups and increasing the gender-

responsiveness and inclusivity of finance. We reaffirm our commitment to implementing the 2030 agenda for sustainable development and its associated SDGs and taking action in support of the UNFCCC, CBD and the UN Convention to Combat Desertification (UNCCD) Gender Action Plans.

13. We will ensure that the transition to a net zero emissions and nature positive economy happens in a fair and inclusive way. This transition must go hand in hand with policies and support for a just transition for affected workers, and sectors so that no person, group or geographic region is left behind.

Climate Change

A G7 committed to accelerating progress under the Paris Agreement

14. We reaffirm our strong and steadfast commitment to strengthening implementation of the Paris Agreement and to unleashing its full potential. To this end we will make ambitious and accelerated efforts to reduce emissions to keep a limit of 1.5°C temperature rise within reach, strengthen adaptation to the impacts of climate change, scale-up finance and support, protect, restore and sustainably manage nature, and enhance inclusive and gender-responsive action. We affirm our commitment to work with these objectives in mind towards a successful COP26 in Glasgow and beyond.

A net zero G7 leading a step change in mitigation

15. There is a global imperative to pursue efforts to limit the increase in the global average temperature to 1.5°C above pre-industrial levels, recognising that the avoided climate impacts are greater at 1.5°C than 2°C, as stated in the IPCC's 2018 Special Report on Global Warming of 1.5°C. This will require meaningful action by all countries, in particular the major emitting economies, pursuant to continuous improvement in climate and environmental action to align with a pathway that keeps 1.5°C within reach. We, G7 members, will lead by example and each commit to achieve net zero greenhouse gas (GHG) emissions as soon as possible and by 2050 at the latest.

16. We affirm the importance of taking domestic action to phase down hydrofluorocarbons (HFCs) and of pursuing further actions to enhance the benefits of the Montreal Protocol in ozone layer protection and tackling climate change, and call upon all countries who have not already done so to ratify the Kigali Amendment to the Montreal Protocol.

Short-term action – building back better and more resilient through a net zero pathway

17. Accelerating the transformation of the global economy towards a net zero pathway will depend upon securing a green, sustainable, resilient, inclusive and gender-responsive recovery from COVID-19 in a manner consistent with the 2030 Agenda for Sustainable Development, leaving no one behind. To accelerate progress towards achieving our Paris Agreement goals, we need to harness the significant opportunities for sustainable development – including green jobs and sustainable, resilient growth – by making investments in the recovery from COVID-19 that are aligned with pathways towards our respective enhanced Nationally Determined Contributions (NDCs) and 2050 net zero commitments, recognising the risk of stranded assets associated with high carbon investments.

Medium and long-term action – guided by net zero aligned NDCs and LTSs

18. We highlight with deep concern the findings from the IPCC Special Report 2018, and recognise the need to reduce the global level of annual GHG emissions to 25-30 Gt of carbon dioxide equivalent or lower by 2030 to put the world on track to limit global warming to 1.5°C above pre-industrial levels, in order to reduce the risk of catastrophic consequences of climate change. We commit to submitting long-term strategies (LTSs) that set out concrete pathways to net zero GHG emissions by 2050 as soon as possible, making utmost efforts to do so by COP26. We commit to updating them regularly, including to reflect on the latest science, as well as technological and market developments. We also note with concern the initial version of the NDC Synthesis Report prepared by the UNFCCC Secretariat which highlights that many parties are yet to submit new and updated NDCs. NDCs communicated by 2020 collectively fall far short of the ranges found in pathways identified by the IPCC, which limit global warming to 1.5°C or well below 2°C. We welcome the significantly enhanced ambition reflected in 2030 targets announced by all G7 members, which put us on clear and credible pathways towards our respective 2050 net zero GHG emission reduction targets. We note the important contribution these commitments make towards keeping 1.5°C within reach and in providing an unequivocal direction of travel for business, investors and society at large. Those of us who have not already done so commit to submitting our enhanced NDCs to the UNFCCC as soon as possible ahead of COP26.

19. The G7 members cannot tackle climate change alone. The G7 calls on all countries, in particular other major emitting economies, to join the growing numbers that have made 2050 net zero commitments, to present specific and credible strategies for achieving them – including LTSs – and to enhance their NDCs accordingly to keep 1.5°C within reach, highlighting the importance of parties who have not already done so submitting their increased ambition NDCs to the UNFCCC as soon as possible ahead of COP26.

20. We reaffirm our commitment that our successive NDCs will represent a progression and reflect the highest possible level of ambition, in alignment with the Paris Agreement. Both our NDCs and LTSs will remain informed by the global stocktake outcomes and the best available science – particularly IPCC reports (including the forthcoming 6th Assessment Report), as well as IPBES reports. In preparing and implementing our NDCs, we reaffirm our commitment to public participation. We highlight the important and active role of all levels of government as well as businesses, workers, local communities, non-governmental organisations (NGOs), academia, Indigenous Peoples, youth and other non-state actors in driving ambitious climate action, including in a gender-responsive manner. We call for an enhanced Marrakech Partnership for Global Climate Action (MPGCA) to accelerate and broaden climate ambition and action in this regard, with improved tracking of its initiatives. We recognise the benefits of enhanced international collaboration in driving action in all sectors as part of an economy-wide effort.

More people protected from climate impacts

21. We acknowledge with grave concern the impacts of climate change already being experienced worldwide, particularly by those most vulnerable to them. We commit to enhance, accelerate and scale up adaptation actions, including Nature-based Solutions, and to support the most vulnerable to adapt to and cope with the impacts of climate change and biodiversity loss, identified by plans at local, national and sub-national levels, including ambitious National Adaptation Plans (NAPs). We reaffirm our commitment to Article 9.4 of the Paris Agreement, which calls for the provision of scaled-up financial resources to aim to achieve a balance between adaptation and mitigation, taking into account country-driven strategies. This includes continuing to scale-up finance contributing to adaptation action. We highlight the important role of businesses, workers, investors, cities, women, Indigenous Peoples and civil society in mobilising action to support vulnerable communities. Finally, we call on all states and non-state actors to cooperate to enhance adaptation and resilience, including through the Adaptation Action Coalition, InsuResilience Global Partnership, and National Adaptation Plans Global Network, and for non-state actors to join the Race to Resilience Campaign to strengthen the resilience of 4 billion people in vulnerable communities by 2030, and to participate in the adaptation activities undertaken within the Marrakech Partnership for Global Climate Action. Recognising the importance of adaptation in our own national planning, we G7 members commit to submitting Adaptation Communications as soon as possible, and if feasible by COP26. We further affirm our commitment to a diverse and inclusive, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems in the delivery of adaptation policies, plans, strategies and actions. As Climate and Environment Ministers, we acknowledge and fully support the work of the Foreign and Development Ministers' track to increase

action on adaptation and protect more people from climate impacts, including the commitment to continue scaling up finance contributing to adaptation action.

Mobilising and aligning finance to support the green recovery

22. We, the G7, reaffirm our commitment to the collective developed country goal of jointly mobilising US$100 billion annually through to 2025, from a wide variety of sources, public and private, bilateral and multilateral and in the context of meaningful mitigation actions and transparency on implementation. We welcome the commitments already made by some of the G7 to increase climate finance and look forward to new commitments from others well ahead of COP26 in Glasgow. We underline G7 commitments to further strengthen the Green Climate Fund (GCF) as an effective tool in implementing the Paris Agreement. Further, we highlight the Paris Agreement's recognition that mobilising finance requires a global effort. In this context, we encourage all potential contributors of official finance, including emerging economies, to join existing providers in supporting climate action in developing countries. We underline the urgent need to scale up efforts to mobilise the private sector if we are to achieve a global green recovery and net zero emissions by 2050, recognising the critical role that innovative financing vehicles, bilateral and multilateral finance institutions, blended finance, policies, risk pools and enabling environments play in this regard.

23. We affirm the crucial importance of making finance flows consistent with a pathway towards low GHG emissions and climate-resilient development, as reflected in Article 2.1.c of the Paris Agreement and in line with the SDGs. As part of our efforts towards this objective, we commit to making official finance flows consistent with the goals of the Paris Agreement and call on all countries, as well as MDBs, DFIs, multilateral funds, public banks and export credit agencies to join us in this effort. We emphasise the transformative role of the policies and actions of all governments, but also public and private stakeholders in creating the right enabling environments to support climate action and in integrating climate change into economic and financial decision-making processes. We also urge businesses and investors to join the Race to Zero, align their portfolios with the goals of the Paris Agreement and set science-based net zero targets of 2050 at the latest.

24. We recognise the potential of carbon markets and carbon pricing to foster cost-efficient reductions in emission levels, drive innovation and boost the breakthrough of technologies that enable a transformation to net zero. We affirm the fundamental importance of environmental integrity and sustainable development in the design of high integrity carbon market mechanisms, including those used for voluntary purposes, which should be based on robust rules and accounting that ensure avoidance of all forms of double counting. They should require the use of conservative emissions and emissions reductions estimations and assumptions, as well as

safeguards to mitigate carbon leakage risks, avoid negative social and biodiversity impacts, and to address potential reversals. We further note that such mechanisms can mobilise private finance and help to close the ambition gap for limiting global warming to 1.5°C.

Unleashing the full potential of the Paris Agreement

25. We are steadfast in our commitment to achieving an ambitious set of outcomes from COP26 in line with the objectives set out above. We emphasise the importance of finalising the outstanding mandates relating to the Paris Rulebook – including the adoption of common tables and formats for the enhanced transparency framework, decisions on cooperative approaches (Article 6), and common time frames for NDCs – in a manner that promotes transparency and accountability and ensures environmental integrity. We will address mandates and deliver on our commitments across the three pillars of the Paris Agreement – on mitigation, adaptation, and support – and enhance international collaboration to accelerate global implementation ahead of COP26 and beyond. We will have a continued focus on supporting those most vulnerable to the impacts of climate change and will continue to support developing country partners as they pursue green, sustainable, resilient, inclusive and gender-responsive recoveries from COVID-19. This includes providing support with the preparation and implementation of national plans and commitments (including NDCs, LTSs, NAPs and Adaptation Communications) bilaterally, through our contributions to multilateral funds and through the NDC Partnership and other such initiatives. We welcome the creation by the OECD of the 'International Programme for Action on Climate' as part of the 'Horizontal Project on Climate and Economic Resilience in the Transition to a Low Carbon Economy', and look forward to its possible contribution to climate action.

Supporting the transition to a net zero economy

26. We recognise that the transition to net zero will depend upon developing the skilled workforce necessary to deliver it, in a way that leaves no one behind, by building on the skills and knowledge in transitioning sectors, developing new labour markets for decent work and quality green jobs, as well as investing in pioneering clean and sustainable industries and technologies. We will address the challenges workers face by ensuring that they have the appropriate skills and training to build back greener, alongside a long-term plan for skills needed for a net zero economy, in a gender-responsive way. This will support the creation of green jobs, a diverse workforce, and will support workers in high carbon sectors to gain skills and knowledge to implement more sustainable practices and green technologies. We reaffirm our commitment under the Equal by 30 Campaign to work towards equal pay, leadership and opportunities for women in the clean energy sector by 2030. We agree to deepen

efforts to advance gender equality and diversity in the energy sector, including under the Equal by 30 Campaign by adopting a set of strengthened commitments. This will support our commitment to make diversity and gender equality central to the global energy sector's recovery efforts and help build a more inclusive and equitable energy future. We acknowledge the need for specific support for all workers as part of a clean energy transition.

27. We recognise that delivering and accelerating the transition to a net zero global economy will require scaled-up international collaboration. The institutional architecture to enable this should be structured and strengthened appropriately where needed, utilising synergies with existing initiatives to ensure net zero emissions are achieved on an economy-wide basis. We will convene to review the pace of the transition required in each sector to meet the Paris Agreement goals, and the international landscape of institutions and sectoral fora to decarbonise major emitting sectors, with a view to strengthening collaboration in key sectors up to COP26 and beyond.

28. We recognise the importance of working closely with city, state and regional governments in driving the transition to a net zero economy, and the vital role of national governments to support such actions. We highlight the role of cities in piloting a future with net zero emissions, through innovative and sustainable energy solutions. Local governments and sub-national actors, including businesses, workers, communities and civil society, are central to taking ambitious action on high-emitting sectors and should implement solutions that curb emissions while ensuring equitable and inclusive development for citizens and communities. We will implement a range of measures to encourage and empower citizens, business, communities and regions to decarbonise, including supporting the development of local strategies and plans, encouraging investments for the implementation of model projects for low carbon urban infrastructure, encouraging behavioural change, utilising information systems to promote the transparency of local actions and achievements, and disseminating good practices of concrete actions.

Net zero energy

29. We recognise the key contribution of energy efficiency as "the first fuel" to emissions reduction, energy security, economic growth, sustainable development, alleviating energy poverty, and job creation. We therefore note with concern the decline in the global rate of energy efficiency improvements and commit to strengthen our efforts to deliver improvements in buildings, industry and transport. We continue to emphasise the need for stronger international exchanges to learn about best practices in this policy space. We stress the importance of strengthening and coordinating international collaboration in developing policy frameworks for new business models

and to ensure the necessary investments in energy efficiency measures in all sectors. We therefore welcome the establishment of the Energy Efficiency Hub, hosted at the International Energy Agency, as a key international forum for global collaboration on energy efficiency. We welcome the Super-Efficient Equipment and Appliance Deployment (SEAD) initiative. We further endorse its goal of doubling the efficiency of four key energy-using products sold globally by 2030: lighting, cooling, refrigeration, and motor systems, and will contribute to that end using the full policy toolkit at our disposal.

30. We affirm the fundamental role of renewable energy sources. We welcome the rapid growth, decreasing cost and increasing value of renewable energy technologies around the world. We stress the need for their further integration in the systems, and we recognise that renewables are a major driver of economic growth, jobs, and increased access to affordable energy. We recognise that the significant progress made in the development and deployment of renewable energy has been driven by a virtuous circle of technological development, a supportive regulatory and policy environment including innovative market designs, and industry-led cost reductions. We affirm our commitment to supporting the development and deployment of renewable energy globally, particularly for developing countries, as well as accelerating the development and deployment of renewable heating and cooling, where a step change in progress is urgently required. We recognise the importance of promoting clean energy transitions in islands, as well as in remote and rural communities, through innovative renewable energy solutions, fostering self-determination and community ownership of resources.

31. We recognise the role of energy storage as an enabling technology to support the transformation of the global economy towards a net zero pathway. We commit to drive energy storage technology innovation and accelerate its commercialisation and deployment by supporting the private sector in reducing the cost and increasing the performance of energy storage technologies, through policies and tools supportive of energy storage market adoption, including regulatory frameworks and market structures.

32. Recognising that coal power generation is the single biggest cause of global temperature increases, we commit now to rapidly scale-up technologies and policies that further accelerate the transition away from unabated coal capacity and to an overwhelmingly decarbonised power system in the 2030s, consistent with our 2030 NDCs and net zero commitments. In doing so, we reaffirm the importance of national energy security and resilience and underscore the importance of providing support for affected workers, regions and communities. We welcome with appreciation the work of the Energy Transition Council in supporting the new economic opportunities and sustained quality job creation offered by a transition to clean energy in developing

countries. We commit to exploring further ways that we can accelerate global progress towards net zero power, including leading by example as the G7, and working with collaborative initiatives and institutions. We note that several G7 members participate in the Powering Past Coal Alliance. We will convene by COP26 to lay the groundwork for further joint action by G7 members.

33. In line with Article 2.1.c of the Paris Agreement, we commit to aligning official international financing with the global achievement of net zero GHG emissions no later than 2050 and deep emissions reductions in the 2020s. We commit to promoting the increased international flow of public and private capital toward Paris Agreement-aligned investments and away from high-carbon power generation to support the clean energy transition in developing countries. In this context, we will phase out new direct government support for carbon intensive international fossil fuel energy, except in limited circumstances at the discretion of each country, in a manner that is consistent with an ambitious, clearly defined pathway towards climate neutrality in order to keep 1.5°C within reach, in line with the long-term objectives of the Paris Agreement and best available science. Consistent with this overall approach and recognising that continued global investment in unabated coal power generation is incompatible with keeping 1.5°C within reach, we stress that international investments in unabated coal must stop now and commit to take concrete steps towards an absolute end to new direct government support for unabated international thermal coal power generation by the end of 2021, including through Official Development Assistance, export finance, investment, and financial and trade promotion support. We commit to reviewing our official trade, export and development finance policies towards these objectives. We further call on other major economies to adopt these commitments. We welcome the support provided and mobilised by DFIs and multilateral funds, including the GCF, to support the energy transition. In particular, we note the recent Climate Investment Funds board decision to launch new sector specific funds, including those to accelerate coal transitions, and support renewable energy deployment in emerging economies.

34. We reaffirm the need to take into account the imperative of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities, as reflected in the Paris Agreement. Recalling the SDGs, we commit ourselves to a people-centred transition, that will work to create decent employment in the low carbon economy while making energy more accessible, affordable, and cleaner for all communities. We support reskilling workers across industries and communities and developing the industries of the future, as the clean energy transition continues to gather momentum. We welcome the substantial economic opportunities inherent in a people-centred transition, including alleviating energy poverty for people and communities, removing barriers to employment,

especially for marginalised populations, which will in turn lead to substantial and equitable economic growth and prosperity for all.

35. We recognise that inefficient fossil fuel subsidies encourage wasteful consumption, reduce energy security, impede investment in clean energy sources, and undermine efforts to deal with the threat of climate change. We reaffirm our commitment to the elimination of inefficient fossil fuel subsidies by 2025 and encourage all countries to adopt this commitment. We encourage greater international action to meet this commitment and we support calls for greater transparency.

36. We recognise the importance of ambitious and urgent action to reduce emissions and leakage of methane (fossil and biogenic) from the energy sector, as well as waste and agricultural sectors, and of other potent warming substances, such as black carbon, in order to slow global warming. This will require improved measurement and reporting to better locate and quantify these emissions.

37. We recognise the importance of maintaining energy security as we transform our energy systems and the need for energy markets that are open, flexible, transparent, competitive, stable, sustainable, reliable and resilient. We reaffirm the need for investment to ensure energy supply and demand remain balanced throughout energy transitions, recognising the need for energy demand to be met by sources that align with our Paris Agreement and net zero objectives. We commit to developing strategies and actions that enhance our focus on the security of innovative, clean, safe, and sustainable energy technologies. This includes resilience in the face of cyber security threats, the system integration of variable renewable energy, energy storage, flexible power plants, hydrogen, as well as demand side management, smart grids, and related infrastructure including the accommodation of sustainable biofuels and hydrogen. We recognise the important role of electricity interconnection in market integration, flexibility and promoting decarbonisation, alongside supporting security of supply and system security. We recognise that natural gas may still be needed during the clean energy transition on a time-limited basis and we will work to abate related emissions towards overwhelmingly decarbonised power systems in the 2030s. We also note the importance of ensuring secure, safe and sustainable clean energy supply chains, including with regards to critical minerals and critical renewables components.

38. We affirm that access to secure affordable, reliable, sustainable, clean and modern energy is a key enabler of the SDGs. We welcome progress made to increase energy access and eradicate energy poverty worldwide, while noting that the world remains off-track to meet our SDG for access to energy. We note the essential role of gender equality in achieving sustainable energy access and welcome synergies with the work of the G7 Gender Equality Advisory Council. We stress the importance of achieving universal, equitable and sustainable access in driving forward a global and inclusive

clean energy transition that addresses the disproportionate impact of energy poverty on vulnerable and marginalised populations, both in developing countries and in more mature economies. We welcome the UN commitment to address progress on SDG7 within the High-Level Energy Dialogue.

39. Those countries that opt to use it reaffirmed the role of nuclear energy in their energy mix. Those countries recognise its potential to provide affordable low carbon energy and contribute to the security of energy supply as a baseload energy source.

Net zero mobility

40. We stress the urgent need to promote sustainable mobility and reduce GHG emissions from the transport sector to help achieve net zero emissions by 2050. We recognise that this will require dramatically increasing the pace of the global decarbonisation of the road transport sector throughout the 2020s and beyond, consistent with the goals of the Paris Agreement and our respective 2030 NDCs and net zero commitments. In this regard, and as part of this effort, we welcome and support the Zero Emission Vehicle Transition Council and will work with other global partners to accelerate the deployment of zero emission vehicles for passengers and freight, including exploring ways to support developing countries in making the transition. We further recognise the commitments of some states to the target of sales of passenger cars being zero emission by 2040 or earlier. Furthermore, we also need to promote decarbonising the entire life cycle of vehicles. We commit to support transitioning our industrial bases and providing ambitious investment to research, further develop, and scale up the technologies needed to support a rapidly growing global market for sustainable mobility. We will intensify our efforts in enhancing the offer of more sustainable transport modes in urban and rural areas, including public transport, shared mobility, cycling and walking, and supporting inter-modal transport with investment in rail and waterborne infrastructure.

41. We further recognise the urgent need for effective efforts to reduce emissions from the international aviation and maritime sectors to put both sectors on a pathway of emissions reduction consistent with the mitigation goals of the Paris Agreement. We commit to supporting the development and adoption of ambitious mid- and long-term measures at the International Maritime Organization (IMO) and to building a global consensus on strengthening the levels of ambition in the initial IMO strategy on reduction of GHG emissions from ships in the context of its forthcoming revision, with the aim of contributing to the Paris Agreement temperature goal. We will also support the development and adoption of an ambitious long-term global goal at the International Civil Aviation Organization in line with our vision for decarbonising the aviation sector.

Net zero innovation

42. We recognise clean energy innovation as a driver of sustainable and inclusive growth to create jobs, an enabler of a resilient economic recovery. We also recognise the need to accelerate innovation this decade to meet our net zero goal by 2050 or sooner. This includes scaling up demonstrations and the early deployment of zero and negative carbon technologies while ensuring negative impacts on the environment and human wellbeing are avoided. This must be enabled by mechanisms and clear signals, including an increased focus on ESG (environmental, social and governance) performance, that incentivise private sector investment to fast-track innovations to the market. To accelerate the pace of industry decarbonisation, we commit to launch the G7 Industrial Decarbonisation Agenda to complement and support the activities of existing key initiatives and amplify ambition, while plugging critical gaps in the landscape wherever they exist.

43. For the G7, we commit to increasing clean energy innovation investments to a level in line with our net zero ambition. We support the launch of a second phase of Mission Innovation as a global platform to strengthen international cooperation that will continually promote increased clean energy innovation ambition and concrete actions for clean energy technical innovation. We support the commencement of Clean Energy Ministerial's third phase as a global platform to share experience, raise ambition, and implement cooperative action for clean energy deployment, including innovative policy, regulatory and market measures. We encourage closer alignment between Mission Innovation and the Clean Energy Ministerial to better coordinate efforts from innovation all the way through to the deployment of clean and sustainable energy technologies including through energy efficiency and from renewable energy sources. We will design appropriate pull mechanisms to accelerate the innovation and scaling up of clean energy and net zero technologies across G7 members and to support the green transition in developing countries. We also acknowledge that the successful deployment of clean energy technologies requires further investment in a skilled, technologically advanced and diverse workforce.

44. Innovation that supports net zero industries can help existing sectors through the transition, as well as creating additional value with the birth of new industries. We will work together in the lead up to COP26, building on existing initiatives to coordinate action on standards and public procurement in order to create globally competitive markets for green industrial products. In parallel, we will also work to reduce emissions from key industrial processes through enhanced energy efficiency, the development of circular economy and resource efficiency principles, electrification, comprehensive industrial heat utilisation and reduced waste in industry, fuel switching and carbon capture, usage and storage (CCUS). We recognise the importance of early action to decarbonise hard-to-abate industrial sectors such as iron and steel, cement, chemicals, and petrochemicals, to ensure that emissions across the

entire economy reach net zero by 2050. For these hard to abate sectors to achieve this, we commit to targeting greater levels of innovation funding to lower the costs of industrial decarbonisation technologies, including the use of hydrogen, electrification, sustainable biomass, CCUS and synthetic fuels (including ammonia and fuels made from hydrogen). Acknowledging that achieving net zero industry will require enhanced global efforts, we will support low and middle-income countries through financial and technical cooperation, as well as in multilateral fora. We will work together to accelerate the decarbonisation of industry, and welcome the development of the new Industrial Decarbonisation Innovation Mission and the launch of the Clean Energy Ministerial's Industrial Deep Decarbonisation Initiative, while supporting ongoing activities in the Leadership Group for Industry Transition.

45. We recognise the importance of renewable and low carbon hydrogen on the pathway to net zero. We will step up efforts to advance commercial scale hydrogen from low carbon and renewable sources across our economies, including support for fuel cell deployment globally. This will help realise the development of a future international hydrogen market that creates new jobs for current and future workers in the energy sector.

46. While the focus must remain on protecting and expanding our natural carbon sinks, we recognise that negative emissions technologies, such as Direct Air Capture, can also play a role in reaching net zero GHG emissions. Negative emissions will be required to offset residual emissions in sectors that are difficult to decarbonise completely. Technical solutions such as CCUS, and carbon recycling where appropriate, will also be important for some countries in meeting our goal of a net zero economy.

Environment

Resetting our relationship with nature

47. A healthy natural environment is critical to human health, wellbeing and prosperity globally and underpins sustainable development. Despite existing global agreements for the protection, conservation, sustainable use and restoration of biodiversity, global negative trends in biodiversity and ecosystem functions are projected to continue or worsen. We therefore confirm our strong determination to halt and reverse biodiversity loss by 2030, building on the G7 Metz Charter on Biodiversity and the Leaders' Pledge for Nature as appropriate.

48. We recall with deep concern the 2019 IPBES Global Assessment Report on Biodiversity and Ecosystem Services and the 2021 UNEP Making Peace with Nature report. We commit to take urgent action to address the five direct drivers of biodiversity loss, all

a result of human activity: changes in land and sea use, direct exploitation of organisms, climate change, pollution and invasive alien species. We will also address overexploitation and illegal exploitation of resources as well as the indirect drivers identified, including those caused by unsustainable methods and patterns of consumption and production. We stress that concerted and collaborative action is needed by all partners and stakeholders including governments, businesses, farmers, academia and scientists, NGOs, citizens, Indigenous Peoples, and local communities, and underline the importance of including these groups in co-design, decision-making and implementation.

49. We commit to raise ambition and accelerate and intensify action, including at CBD COP 15, UNFCCC COP 26, Ramsar COP 14, UNCCD COP 15, UN Environment Assembly (UNEA) 5, UN Food Systems Summit and the UN Ocean Conference, and in support of the UN Decades on Ecosystem Restoration and Ocean Science for Sustainable Development. We will also build on existing synergies, break down silos and support linkages at the domestic and institutional level across relevant Multilateral Environmental Agreements, as appropriate, including Regional Seas Conventions.

50. Highlighting the urgent need for transformative action, we will champion the agreement and successful implementation of an ambitious and effective post 2020 global biodiversity framework to be adopted by parties at CBD COP15 to protect, conserve and restore ecosystems, halt and reverse biodiversity loss, ensure the conservation and sustainable use of biodiversity, increase resilience to climate change and sustain healthy ecosystems on which our lives, well-being and economies depend. We commit to champion ambitious and effective global biodiversity targets, including conserving or protecting at least 30 percent of global land and at least 30 percent of the global ocean by 2030 to halt and reverse biodiversity loss by 2030 and address climate change, including through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures (OECMs) by 2030 (30by30), recognising that Indigenous Peoples, and local communities, are full partners in the implementation of this target. We will strive to ensure the effective and equitable management of protected areas and OECMs, and strive to improve their ecological connectivity, with a focus on areas that deliver the greatest benefits for global biodiversity, ecosystem services and climate protection. We underline the importance of a strong accountability framework that strengthens implementation and increases transparency of our actions to meet these targets, and will actively support the development of robust implementation, monitoring and review frameworks. We will enhance or put in place robust, science-based domestic implementation plans, strategies and policies to conserve, protect and restore terrestrial, freshwater, marine and coastal ecosystems and play our part in successfully delivering these global goals and targets. We will work with the competent international and regional organisations, including Regional Seas programmes, Regional Seas

Conventions and Regional Fisheries Management Organisations (RFMOs). We will contribute to 30by30 by conserving or protecting at least 30 percent of our own land, including terrestrial and inland waters, and coastal and marine areas by 2030 according to national circumstances and approaches.

Mainstreaming nature

51. According to the WEF "New Nature Economy Report 2020", over half the world's GDP in 2019, almost US$44 trillion, was generated from industries that depend on nature. Waldron et al in their report "Protecting 30% of the planet for nature: costs, benefits and economic implications" suggest that achieving 30 percent protection in two biomes alone could result in gross economic benefits of US$170 billion to US$530 billion per annum by 2050. The report also states that the global financial cost of adequately protecting 30 percent of all the earth's land and ocean has been estimated to be between US$103 billion and US$177.5 billion per annum. It is clear therefore that the economic benefits of protecting and conserving the land and ocean far outweigh the financial costs of doing so.

52. We welcome the contribution of the Dasgupta Review on the Economics of Biodiversity, which builds on The Economics of Ecosystems and Biodiversity (TEEB) process among other initiatives. Its conclusion that a fundamental change is needed in how we think about and approach economics if we are to reverse biodiversity loss and protect and enhance our prosperity will inform our work. We will work collaboratively to build on the Dasgupta Review insights and those of other such reports, as appropriate, to support efforts for economic and financial decision-making to account for the goods and services we derive from, and the intrinsic value attributed to nature. We commit to take the urgent and transformative action required to ensure that a deep understanding of ecosystem processes, their interlinkages, and how they are affected by economic activity, is incorporated as part of economic and financial decision-making. To ensure appropriate management of environmental risks and reduce related transaction costs, we will also work with businesses and other stakeholders in developing standardised natural capital accounting practices. We welcome the work being done by the UN Statistical Commission to continue updating the SEEA ecosystem accounting system.

53. We commit to mainstream nature into all sectors and policies. We recognise the urgency and call for the integration of both climate and nature-related risks into organisational risk management architecture, and of investing in natural capital, which will enable finance to play a greater role by pivoting towards nature positive projects and investments. We recognise the importance of work on nature-related financial disclosure and note with interest the establishment of the Taskforce on Nature-related Financial Disclosures and its aims.

54. We note the analysis from the OECD, which provides policy recommendations based on the findings of the Dasgupta Review, among other reports. The G7 commits to review these recommendations in order to identify actions to mainstream nature into financial and economic decision-making. In particular we note the OECD's analysis and recognise the harmful effect of some subsidies on the environment and people's livelihoods. We therefore commit to lead by example by reviewing relevant policies with recognised harmful impacts on nature and will take action, as appropriate, to deliver nature positive outcomes.

Preventing and combatting zoonoses and antimicrobial resistance (AMR) using a One Health approach

55. The COVID-19 pandemic reminds us that human, plant, animal and environmental health are interdependent and we therefore stress the importance of a strengthened One Health approach. We welcome the contribution of the IPBES Workshop Report on Biodiversity and Pandemics to the debate and recognise with concern that increased contact between humans, wildlife and livestock, as a result of human activities including habitat loss, human encroachment into natural areas, land use change such as agricultural expansion, unsustainable food production systems, deforestation, climate change, the legal and illegal wildlife trade, unsustainable international trade and unsustainable consumption is increasing the risk of zoonotic disease emergence and spread. The COVID-19 pandemic has reinforced the importance of close international collaboration in preventing and combatting existing and emerging zoonotic threats. We call for further cross sector research and scientific analysis and evidence on the interactions between humans, wildlife, domesticated animals and the environment, the pathogens which exist in these populations, the risks arising from these interactions and the control and prevention of zoonoses. We call on all governments to ensure transparency and swift sharing of data and information on zoonoses.

56. As the G7, we will continue to strengthen global collaboration and work towards improving the resilience of our surveillance systems through sharing relevant information in a timely manner, implementing best practice, building capability and improving technology domestically and internationally, particularly with developing countries and countries with economies in transition.

57. We endorse the work of the One Health Working Group and will join, on a voluntary basis, the International Zoonoses Community of Experts (IZCE) established under the UK Presidency. The IZCE will bring together national points of contact with expertise and interest in zoonoses, their drivers, prevention and monitoring. Through sharing best practice and methodologies, knowledge will be increased across the community and will contribute to improve risk assessment, risk management and early warning capabilities at a global level. We recognise the need to ensure complementarity with

such initiatives as the Tripartite Plus and the One Health High Level Expert Panel to avoid duplication. The IZCE will liaise with other relevant G7 working groups, for example the G7 Chief Veterinary Officers Group.

58. We recognise that better understanding and enhanced visibility, accessibility and interoperability of data is a crucial first step in delivering improved global surveillance and response to One Health threats and issues. We encourage climate, environment and health stakeholders to consider how best they can work together to support the Tripartite Plus in this crucial work.

59. We recognise that the release of antimicrobials into the environment can select for antimicrobial resistance (AMR) and have an impact on human, animal and environmental health. We also note that heavy metals and biocides potentially have an impact on AMR and human, animal and environmental health. We underline the importance of a One Health approach in tackling AMR and call on all governments to promptly implement measures for the sound management and reduction of inappropriate use of antimicrobials. In this context, we note the potential role that soil microorganisms may play in the fight against AMR. We call on UNEP, in collaboration with the Tripartite organisations, to strengthen the evidence base on the contamination, mechanisms, causes and impacts of AMR emerging and spreading in the environment as mandated at UNEA 3. We commit to work in close collaboration with governments and relevant parties such as, medicines regulators where independent of government agriculture, academia, industry, the Tripartite on AMR and UNEP to develop and implement long-term, sustainable solutions to this issue. We note with concern that there are currently no international standards on safe concentrations of antimicrobials released into the environment from, *inter alia,* pharmaceutical manufacturing, healthcare facility effluent, agriculture and aquaculture. We also acknowledge the work of the AMR Industry Alliance in this regard. We commit to accumulate knowledge on AMR in the environment. We will work with our ministerial colleagues with responsibility for health, food, farming and medicines regulators where independent of government, as appropriate to develop and agree such standards.

Transition to sustainable and legal use of natural resources

Resource efficiency

60. Recalling the findings of the Global Resources Outlook 2019 of the International Resource Panel, we recognise that the continued degradation and loss of natural resources threatens our ability to meet our shared commitments to sustainable development, conservation and restoration, food security and combatting climate change. We underline the importance of increasing the resource efficiency and reducing the global environmental footprint of products and moving to more globally sustainable methods and patterns of consumption and production. We reaffirm our

commitment to progress actions to increase resource efficiency and transition to a more circular economy, in line with the Bologna Roadmap, to reduce the pressure and adverse impacts on our natural environment, reduce resource use, maximise the value of materials through a life-cycle approach, curb biodiversity loss, and support climate mitigation and adaptation action and in doing so are determined to reduce pollution from all sources. We ask the G7 Alliance for Resource Efficiency to continue technical work on all aspects of the Bologna Roadmap and invite the next G7 Presidency to take stock of its implementation.

Deforestation

61. We recognise that deforestation, forest degradation and ecosystem conversion are global threats to our climate, biodiversity, food security and livelihoods and are driven by the expansion of agriculture, mining, logging and infrastructure projects. Agricultural expansion is the driver of around 80 percent of global deforestation. A significant proportion of this expansion is linked to the production of agricultural commodities, including particularly those traded internationally. We will increase our support for sustainable supply chains that decouple agricultural production from deforestation and forest degradation, including production stemming from illegal land conversion, and other negative impacts on nature, in accordance with our national legislation, and commit to conserve, sustainably manage, restore and protect forests and other ecosystems. We will do this while promoting development and trade, including through participating in the dialogue between consumer and producer countries under the Forest, Agriculture and Commodity Trade (FACT) dialogue hosted by the UK as UNFCCC COP26 President, and through work by the International Tropical Timber Organisation. We will work with partners, including the private sector and producer countries, NGOs, as well as Indigenous Peoples, and local communities, to incentivise consumption of commodities that are not associated with deforestation and forest degradation. We will therefore enhance supply chain transparency and traceability, and if appropriate, develop regulatory frameworks or policies, which may include the introduction of due diligence requirements, to bring about trade that is environmentally, socially, and economically sustainable, and resilient, in order to achieve a successful green recovery. We look forward to discussions by G7 Trade Ministers on facilitating sustainable supply chains.

62. We reaffirm our commitment to the New York Declaration on Forests to end natural forest loss and, building on the Bonn Challenge, restore 350 million hectares of forest by 2030. We commit to support measures to strengthen forest governance, transparency, and the rule of law, while also empowering Indigenous Peoples as partners in decision-making as well as local communities. We also support measures that promote sustainable finance and tackle the drivers of forest loss and degradation, including efforts to enhance sustainable production and increasing the incentives for preventing deforestation, protecting intact forests and restoring degraded forests and

lands. We recognise the need for enhanced monitoring of deforestation globally, regionally and nationally.

Illicit threats to nature

63. We recognise that the illegal wildlife trade (IWT), trafficking in timber and timber products, hazardous and other wastes, and precious metals, gemstones and other minerals, illegal logging and illegal, unreported and unregulated (IUU) fishing have a devastating impact on our natural environment and livelihoods, with an estimated full global economic value of over US$1 trillion to US$2 trillion per year. These activities drive biodiversity loss, corruption, money laundering, insecurity and other forms of organised criminal activities as well as undermining our efforts to tackle climate change and its impacts. We commit to continue our efforts to strengthen international and transboundary cooperation to tackle these crimes and harmful activities.

64. We acknowledge that wildlife trafficking is a serious crime, often carried out by transnational organised criminal networks linked to other forms of organised crimes and commit to take urgent and collective action to address this criminal activity in a way that reflects and acknowledges the serious nature of this crime. We remain robustly committed to delivering on our commitments within the 2018 London Declaration and will work to strengthen the capacity of law enforcement authorities and judiciaries in investigating, prosecuting and adjudicating wildlife-related offences where needed. We note proposals to discuss options *inter alia* to strengthen the international criminal legal framework to effectively combat such offences including prevention, while maintaining our focus on making the best possible use of existing international mechanisms, strengthening legislation, international cooperation, capacity building, criminal justice responses, and law enforcement efforts to strengthen our response. We commit to increase our efforts to reduce the demand for IWT products by developing targeted and evidence-based interventions in order to inform consumer behaviour and close markets where these illegal products are trafficked and sold. We will review our administrative, preventative and criminal justice responses to wildlife and forest crime using the International Consortium on Combatting Wildlife Crime's (ICCWC) Wildlife and Forest Crime Analytic Toolkit. We welcome the discussions by Finance Ministers on strengthening beneficial ownership transparency to better tackle the illicit financial flows stemming from IWT and other illicit threats to nature and welcome the work of the Financial Action Task Force and its recommended actions in this area.

65. We recognise that IUU fishing remains one of the most serious threats to a healthy ocean, depleting fish stocks, distorting competition, destroying marine habitats and jeopardising international efforts to promote better ocean governance and effectively and sustainably manage fisheries. We recognise the importance of concerted international action to deter IUU fishing, including through support for developing

countries. Urgent efforts are needed to prohibit harmful fisheries subsidies that contribute to overfishing, overcapacity and IUU fishing. We commit to concluding the ongoing WTO negotiations as swiftly as possible in order to ensure that a meaningful agreement is reached that delivers effective disciplines.

66. Building on the outcomes of the Canadian G7 Presidency, we commit to ending IUU fishing by ensuring strong measures are effectively implemented and enforced, such as the Catch Documentation Schemes (CDS) to increase traceability, including those used by RFMOs and other relevant bodies for certain species; a commitment to develop and enforce more robust Port State measures including by effectively implementing the UN Food and Agriculture Organization (FAO) Port State Measures Agreement (PSMA) and other relevant initiatives, as well as increasing Monitoring, Control and Surveillance (MCS) activities to help tackle IUU fishing. We highlight the importance of bilateral agreements that include mechanisms that effectively address IUU fishing, in particular through effective regulation and enhanced monitoring of fisheries activities, transhipments, landings, and trade in fish and fish products. We also commit to the enhanced sharing of information, intelligence, and best practice and expertise in tackling IUU fishing, acknowledging that international cooperation is the most effective way to tackle this issue.

67. Recognising that illicit threats to nature deprive some of the world's poorest communities of sustainable forms of living income, we commit to mobilise public and private support for sustainable livelihoods as an alternative to these activities. We recognise the importance of Indigenous Peoples, and local communities, in protecting forests and natural habitats and supporting sustainable land use. We further recognise the importance of securing the legal recognition of the right of Indigenous Peoples to the lands, territories and resources which they owned, occupied, or otherwise used or acquired as acknowledged in national law and international instruments. We also recognise the importance of securing applicable resource and legitimate tenure rights of persons belonging to local (or other) communities, women, and persons in marginalised groups as acknowledged in national law and international instruments. We underline the importance of engagement with these groups to co-develop solutions to these issues, including land tenure rights.

Ocean Action

68. We recognise that the health of our seas and ocean is critical to the economic, social and environmental well-being of people and the planet, and has a vital role in supporting biodiversity, providing ecosystem services including regulating our climate. Yet the ocean and seas are under significant threat from human actions. Overfishing, IUU fishing, overexploitation of marine habitats and resources, the introduction of invasive alien species, pollution, including marine litter, other anthropogenic pressures on ocean habitats, microplastics, underwater noise are major drivers of

marine biodiversity loss. At the same time, climate change is leading to sea level rise, extreme weather events, ocean warming and influences stratification, reduced oxygen levels and shifts in marine resources, which also impact marine biodiversity. Increased carbon dioxide absorption is also leading to increased ocean acidification. We acknowledge with concern the recent high-level findings from the IPCC Report on Climate Change on the Ocean and Cryosphere. Building on the outcomes of the Canadian and other G7 Presidencies, including the Charlevoix Blueprint for Healthy Oceans, Seas and Resilient Coastal Communities, we commit to support the UN Decade of Ocean Science for Sustainable Development (2021-2030) and work towards its goals, which include the global ocean being clean, healthy and resilient, productive, safe, predicted, accessible and inspiring and engaging. We recognise the value of robust and continuous scientific observation and cooperation to ensure a sustainable ocean for all and to support the science-based implementation of commitments under the 2030 Agenda, SDGs, the CBD, the Paris Agreement and within UNEA resolutions. We will continue our efforts to strengthen the conservation, protection and restoration of coral reefs, mangroves, seagrass beds, salt marshes, polar regions and other ecosystems and we recognise the value of blue carbon ecosystems, which can provide climate resilience benefits while also sequestering carbon. We recognise the importance of sustainable resilience for coastal communities and marine ecosystems and will strengthen our support for the Ocean Risk and Resilience Action Alliance (ORRAA).

69. We commit to upholding the UN Convention on the Law of the Sea (UNCLOS) which sets out the legal framework within which all activities in the ocean and seas must be carried out, including for the conservation and sustainable use of the ocean and seas. We will work to expeditiously conclude, if possible by the end of 2021, the negotiation of a new and ambitious international legally binding instrument under UNCLOS on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction which will include a clear obligation to conserve and sustainably use marine biodiversity and include a mechanism to establish Area-Based Management Tools (AMBTs), including Marine Protected Areas (MPAs) and will aid the implementation of intended new marine targets, recognising our commitment to support global 30by30 for the ocean.

70. As an example of the kind of action that needs to be taken to protect and conserve the ocean, we fully support the commitment by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to develop a representative system of MPAs in the Convention Area. This should be based on the best available scientific evidence, the proposals to establish MPAs in East Antarctica, in the Weddell Sea and in the Antarctic Peninsula, and taking full consideration of the CCAMLR Convention.

71. Recognising that marine litter continues to pollute the ocean worldwide, has adverse impacts on marine life through ingestion and entanglement, as well as damaging

habitats and people's livelihoods, and with possible impacts on food safety and human health, we are determined to accelerate action to tackle sources of marine litter, building on national, regional and global efforts, noting the example of the G7 Action Plan to Combat Marine Litter, the Osaka Blue Ocean Vision, and the G20 Implementation Framework for Actions on Marine Plastic Litter and the Ocean Plastics Charter as appropriate. We acknowledge that there are a number of key contributors to marine litter, including inadequate management of land-based sources, and abandoned, lost and otherwise discarded fishing gear, also known as Ghost Gear, which has a significant direct impact on marine life. Effective policies, practices and management measures to address these issues need to be taken nationally, regionally and internationally by all countries, in partnership with relevant stakeholders, including industry and NGOs. Concerning fishing gear loss and its retrieval, we commit to working through relevant international and regional frameworks to address Ghost Gear including by the FAO, IMO, RFMOs and the Regional Seas Conventions and will work with or support other initiatives such as the Global Ghost Gear Initiative (GGGI). We will collaborate through concrete actions such as gear marking and retrieval and will support and expand existing efforts to address ghost gear as appropriate, including through the implementation of the UN FAO voluntary guidelines on the marking of fishing gear. We note with interest the contribution to the debate of the OECD report Towards G7 Action to Combat Ghost Fishing Gear, and will carefully consider its recommendations.

72. Recognising the scale, urgency and transboundary nature of the global action needed to tackle marine plastic litter and microplastics, including by considering a life-cycle approach, we welcome the work of the ad hoc open-ended expert group (AHEG) established by UNEA resolution 3/7 and extended by UNEA resolution 4/6 towards UNEA 5.2, and will fully engage in discussions or negotiations on the options identified, with the aim of taking a step forward on that occasion on suggested options which include strengthening existing instruments, a potential new global instrument, and multi-stakeholder engagement. We look forward to the forthcoming OECD study on existing MDB resources that address marine litter, prepared in cooperation with the G7 Alliance for Resource Efficiency.

73. We welcome the discussions of the Expanded Future of the Seas and Oceans Working Group and endorse the G7 Ocean Decade Navigation Plan establishing a framework for ambitious and collaborative action under the UN Ocean Decade. This framework will advance the ocean science needed to underpin ocean action, with direct reference to the UN Ocean Decade, its societal outcomes and other international agreements. We commit to work closely with international and regional partners and organisations, including the Intergovernmental Oceanographic Commission (IOC) of UNESCO, to support the UN Ocean Decade and its societal outcomes. We welcome the ongoing work of the G7 Future of the Seas and Oceans Initiative and will continue to support its programme of activities, including to share best practice, and advance

scoping activities such as to develop a digital twin ocean, work towards net zero oceanographic capability, and evaluate global ocean indicator frameworks.

Food Loss and Waste

74. We recognise that one third of food produced for human consumption is lost or wasted globally, and that food grown but never eaten consumes an estimated 250 km^3 of fresh water per year and requires an estimated 1.4 billion hectares land area. Furthermore, food loss and waste produces an estimated 8 percent of global GHGs. We note with concern the recent estimate within UNEP's Food Waste Index Report 2021 that 931 million tonnes of food waste was generated globally in 2019 at the level of retail, food service and households, which represents 17percent of food available for consumption. We acknowledge the importance of reducing food loss and waste in improving food security, particularly in the most vulnerable communities, mitigating climate change and land degradation and protecting biodiversity. We welcome the upcoming UN Food Systems Summit which will highlight the need to put sustainable food systems at the centre of efforts to meet the 2030 Agenda and its SDGs. We reaffirm our commitment to achieve SDG 12.3 and commit to utilise a "Target, Measure, Act" approach and establish national targets to reach that goal.

75. We further commit to measure food loss and waste in accordance with the transparent methodologies outlined in the Food Loss and Waste Accounting and Reporting Standard and consistent with the requirements of international reporting under SDG 12.3. We will establish national baselines and goals against which progress can be measured. We will implement actions to support food supply chains and households to reduce food loss and waste and promote the adoption of sustainable food consumption and production through circular economy and resource efficiency approaches. Our actions will include encouraging collaboration and cooperation between public, private and civil society actors, the adoption of innovative business models and technologies, redistribution of surplus food, the promotion of youth and wider public education and behaviour change programmes across all sectors on food loss and waste prevention. Food no longer intended for human consumption should be prevented from becoming waste through use as animal feed or reprocessing into new products, whilst ensuring that all safety and related requirements are met. Recalling our commitments under the Bologna Roadmap, and recognising that approximately 60 percent of global food waste occurs in households, we welcome the discussions of the G7 Alliance for Resource Efficiency on key components that support action to reduce food waste at the household level, and the Presidency Summary of the discussion. We further welcome the G7 Alliance for Resource Efficiency document highlighting examples of best practice across the G7 to address this issue.

Conclusion

76. We express our appreciation to the Formal G7 Engagement Groups and other partners for their important contributions to the UK's G7 Presidency. We look forward to continuing our collaborative efforts on these and other issues under the German G7 Presidency in 2022.

The houses slipping into the sea: Dozens of home-owners will lose their properties on the fastest eroding coastline in northwest Europe - where 10 yards of land has disappeared in less than a year

- **A report found 24 homes are at risk along the 80km Holderness Coast in east Yorkshire which is fast erodi**
- **Members of East Riding of Yorkshire Council are set to meet in Beverley to discuss the severe coastal eros**
- **Report predicts that the erosion, which is likely to increase further, will put 24 Skipsea homes at risk by 20**
- **Jimmy Mac, 28, who lives in Skipsea, said the 'erosion's doing to this country what the Germans couldn't d**

By JAMES WOOD FOR MAILONLINE

PUBLISHED: 09:48, 22 January 2020 | **UPDATED:** 18:38, 22 January 2020

Monitoring of the soft clay cliffs on the 80km Holderness Coast, east Yorkshire has found that the coastline is eroding at a rate of between 0.5m and 4m each year (pictured, houses on the coastline in Skipsea)

Members of East Riding of Yorkshire Council are to meet after a report found 24 homes are at risk on the coast, which has seen losses of up to 10 metres since March (pictured, deterioration of a cliff road in Skipsea)

The report predicts that this erosion, which is likely to increase in future due to climate change, will put 24 homes in Skipsea at risk by 2025.

But it says that a 'single erosion event' could put a large number of properties at imminent risk within the next year and more than 200 residential properties will be lost within the next 100 years.

Jimmy Mac, 28, who lives with his partner Megan Shaw in a chalet home in the village has been told his rented home needs to be demolished as soon as possible after the cliff at the bottom of the garden eroded past the nine-metre mark deemed safe by East Riding of Yorkshire Council.

The couple said the cliff edge is now 8.2 metres away from the back of their property. They fear they will find it hard to find alternative rented accommodation because they own four dogs.

Looking out over the crumbling cliffs and the calm North Sea, Mr Mac said: 'It's not just that, though. Look what we're losing. It's beautiful, isn't it? It's a dream home. It's just a shame. I don't want to move from this house.'

He added: 'Everyone loses out at this end. They could block that, they could put barriers up there but they won't.'

Mr Mac said he put a golf tee in the cliff top to see how fast the cliff was eroding.

He said: 'It was sad to see how much we are losing. It was quite a short time. Obviously the sea's crashing against it, it just needs a sea barrier, doesn't it?

'On a stormy night when the waves are crashing, it keeps you awake. I don't know if I'm going to wake up with the sea in my bed.'

He added: 'Build a barrier. I'll help build a barrier free of charge.'

Councillors have said that residents in areas such as Skipsea are 'appalled' that they are not being protected when they see other areas, such as the more populated Withernsea, receiving funding for coastal defence schemes.

One Green Lane resident, returning home with bags full of shopping, did not want to talk about the situation, but said: 'We've had the council round here for the last seven years. But nothing ever changes.'

Carol Woods, 55, from Goldthorpe in Barnsley, South Yorkshire, said her parents own a caravan on a site near Green Lane.

She said they have had to move the mobile home back from the cliff edge a number of times.

Mrs Woods added: 'They won't defend Skipsea because it's a small village, it's like the land that time forgot.

'I do think people are wanting some kind of defence put up, which is only fair really.'

Mrs Woods's husband Mick, 59, said: 'Erosion's doing to this country what the Germans couldn't do. Because in the war they put all concrete blocks on beaches so the German Luftwaffe couldn't land their aeroplanes, so they didn't land, but nature has landed, hasn't it?'

The road between Ulrome and Skipsea fell into the sea a number of years ago and now the route is blocked by concrete blocks with red 'danger' signs.

On the cliff top, huge cracks in the ground show which sections are likely to go next.

And a walk along the beach reveals pipes and electrical cables in the cliff face, exposed by previous erosion events.

Councillors have said that residents in areas such as Skipsea are 'appalled' that they are not being protected when they see other areas, such as the more populated Withernsea, receiving funding for coastal defence schemes (pictured, erosion of a coastal road in Skipsea)

Standing on the broken road, Mr Woods added: 'If I live another 20 years, we'd be in the sea now. Probably another four or five years, all this will be in the sea.'

Government decisions have been to not defend much of the sparsely populated coastline, with coastal defences not economically, socially or environmentally sustainable for large stretches of the coast.

Councillor David Elvidge, who will chair a meeting on the issue today, said: 'With the amount of funding available, we can only really defend the large areas of population. It's a devastating thing.'

Residents are also left facing a bill of thousands of pounds to demolish their homes and, while the council has historically met these costs, it cannot afford to fund the demolition of all 24 properties at risk.

As a result, councillor Jane Evison is now calling on the Government to provide funding to help cover these costs, which she said can be as much as £20,000.

She said: 'The council is in a position where they're not allowed to defend a coastline and neither are the private householders, clearly there's erosion taking place, one or two homes are at very high risk, yet there's no funding.'

'I don't think it's a fair situation when we're not allowed to provide any protection but we're picking up the bill to keep people safe.'

Mr Elvidge said: 'To lose your home and then the financial cost on top must be traumatic to say the least. If the Government could stump up the cash, that would be fantastic.'

He said people in unprotected places such as Skipsea are 'appalled' when they see coastal defence schemes being planned for other areas.

A £5.5 million scheme, which has received £3 million funding from the European Regional Development Fund, is due to start in Withernsea this year.

He said: 'It shouldn't have to happen like that but unfortunately that's where we are.'

The councillor said he hoped residents might be reassured after the meeting on Wednesday.

He said: 'I want them to take away a reassurance that we're doing everything we can to protect our coastline where we can and, where we can't, we're helping our residents every way we can.'

Simon Barkley, 52, lives in Bradford but stays at the Crossways Caravan Park around 12 times a year and believes the government has 'let the area down'.

He said: 'Over the last two years, it has eroded by about 12 metres. It's a real shame, it's a lovely part of the world and it's nice to come here and get away from everything.

'People will lose their homes within five years, many people in the town have already packed up and left. It's inevitable that this caravan will end up in the sea. People's houses will be gone, it is just a matter of time.

'People here just can't believe it, it's devastating. I'm gutted to see it erode like this.'

He added: 'My friend who owns the land has lost about a third of it. A lot of money has been put into protecting other areas, but nothing in here. The government hasn't done enough. They have let the area down.'

Residents of Green Lane have been told when the coast reaches 9.2m from their houses, they must agree to compulsory evictions - or face paying for the demolition and clean up costs themselves.

Self-employed builder Liam Patrick, 28, lives in a two bedroom bungalow with his girlfriend, Megan Shaw, at the end of Green Lane closest to the cliff.

He has lived at the house, which is owned by Megan's father, for three years and said he will have to be dragged 'kicking and screaming' from his house.

He said: 'This will be the first house to go into the sea. It's heartbreaking, it's a dream home. We love the view we wake up to every morning.

'They say you have to leave when the cliff is nine metres from the house, we're already at that, if not past it slightly. They should definitely build a barrier and a sea defence for the house.

'It's poor from the government. I think it will get to the point where houses will have to come down and the government will be forced to do something. But they should have done something by now.'

Liam added it will be difficult to find a house big enough and with sufficient land for his five pet dogs to roam.

He said: 'I don't know where we'll find somewhere else big enough.

'I put a golf tee on the cliff two metres from the edge a couple of months ago and the tee is now in the sea. That's how quickly the cliff is eroding.When it is stormy it keeps you up at night. It clearly needs a barrier.

'It feels like the government aren't really bothered about us. We are being treated like second class citizens.'

Deborah Hawksley lives in Beverley, but has been visiting her family's home on the sea front in Skipsea since she was a child. Her elderly mother still owns the property, but it is used as a holiday home for the family.

Mrs Hawksley said she spent entire summer holidays in the home as a child and the family would often visit for weekends.

But now she faces the prospect of the house being demolished before it falls into the sea.

She said: 'We are losing our homes. It is inevitable, but it is inevitable because there has been nothing done about it. We never see the council, except for once a month when they come through our gardens measuring how far the cliff edge is from the house.

Deborah Hawksley (pictured above), who owns a property on Green Lane in Skipsea, which is at risk of falling into the sea. Councillors in Yorkshire are to discuss the 'devastating' effect of the coastal erosion

+17

On the cliff top, huge cracks in the ground show which sections are likely to go next. And a walk along the beach reveals pipes and electrical cables in the cliff face, exposed by previous erosion events

'We are currently four metres away from the eviction point. It's devastating. We have lost a great deal of land to the sea. I spent my entire childhood here, we would spend full summers here. I scaled these cliffs as a child and now we are losing our homes to them.'

She added: 'I have seen the cliff just get closer and closer to the house over the years and it is heartbreaking.

'We have boarded the windows up because when the sea is strong, it throws rocks up and we have come to the house to find the front window smashed and rock in the living room.'

Peter and Sheila Garforth have lived in Green Lane for 20 years.

Sheila said: 'We are being treated like second class citizens, there has been no input from the council, they are not interested in us. They've had money from Defra in the past and they have whittled it away on admin and other things.

'We have lived here for 20 years and paid our mortgage off, we don't want to go and pay rent somewhere else now. We don't want to move, but we know we will have to very soon. It's heartbreaking, we're really upset about it.'

Peter said: 'We used to have a 28 metre garden and a 12ft road then 39 metres of cliff. All that has disappeared and we are left now just metres from the edge.

'When we bought this house, we did a lot of work on it, re-wired it, installed central heating. We spent thousands on it, it was our investment for the future and our retirement. We retired here and wanted to spend the rest of our lives here. Now we are being told we will have to leave and we won't get any financial compensation for it. It's really not on.

'We pay our council tax and the level of service we get is shocking. We have no street lights and we have to wheel the bins down to the end of the street ourselves. We are just forgotten about by the council. They are not interested in us at all.'

THE Sun

850 people could be forced to leave their homes

Molly Rose Pike
27 May 2019, 0:44 Updated: 27 May 2019, 12:31

Share

THIS Welsh town is being "abandoned" as rising sea levels could see it vanish in just 25 years.

Fairbourne is tipped to become the first in the UK to be relocated due to the threat of climate change, known as "decommissioning".

This could mean that the 850 people living there could be forced to leave their homes.

Shops would be shut down and the 400 homes would be demolished.

Fairbourne is just a few feet away from the sea of Barmouth Bay, which is getting closer as sea levels continue to rise.

A Shoreline Management Plan for the west of Wales "raises significant concerns over the future sustainability of the defence of Fairbourne".

Gwynedd Council the town needs to be considered for decommission, confirming that relocating residents is a certainty.

Fairbourne in Wales could be abandoned as rising sea levels could see it vanish in just 25 years Credit: Alamy

400 HOMES COULD BE DEMOLISHED

Estimates predict that this could happen as early as 2042.

The council is planning to move locals before 2054, when they say “sea level rises and changing weather patterns will mean that it will not be possible to further bolster the village’s sea defences”.

After this there will be no more money spent on defending the town.

Natural Resources Wales has already spent more than £6million on a flood risk management scheme in the area in the last four years

There are currently no plans in place for homeowners to receive compensation if they have to move.

Scientists think that sea levels are now rising at the extreme end of what was predicted to happen gradually just a few years ago.

Local residents have shared their fears they will have to leave their homes.

Lauren Baynes, a 22-year-old who runs the village butcher’s with her partner, told Wales Online: "We have two young children. It would be nice to hand the business down to them one day and for the whole family to stay here.

"I’ve lived in the area my whole life and I’ve never known Fairbourne to flood badly."

Rising sea levels – what's the problem?

Here's what you need to know...

- The global sea level has been gradually rising over the past century
- Sea levels rise due to two main reasons
- The first is thermal expansion – as water gets warmer, it expands
- The second is melting ice on land, adding fresh water into seas
- This has a cyclical effect, because melting ice also warms up the planet (and oceans), causing more even ice to melt and boosting thermal expansion
- It's currently rising at a rate of around 0.3cm per year
- The sea is huge, so that might sound harmless
- But rising sea levels can have a devastating effect over time
- Low-lying coastal areas can disappear completely, even putting areas of the UK at risk
- It can also mean sea storms and tsunamis can have a more devastating effect, reaching further in-land than they would have previously
- There's also an increased risk of flooding ■

Stuart Eves, chair of the local community council, who has lived in Fairbourne for 43 years, said the Shoreline Management Plan has "destroyed" the village.

He said: "You can't get a mortgage here anymore. There's lots of young people here who want to stay and buy houses, but they can't. Banks won't give them the money."

A Gwynedd Council spokesperson said: "It is important to stress that Gwynedd Council has not decided to 'decommission' Fairbourne.

"Whilst decommissioning has been suggested, no firm decision has been made, and such a step will be a matter that will need to be considered by Natural Resources Wales, Welsh Government, Snowdonia National Park and the community itself."

"The frontline of climate change" The Norfolk village falling into the sea

Sabrina Johnson

Published: 6:00 AM January 30, 2021 **Updated:** 2:51 PM January 30, 2021

Coastal erosion at Happisburgh. Picture: Danielle Booden - Credit: Danielle Booden

A campaigner working to protect a Norfolk village from falling into the sea has made an emotional plea for more to be done to save it.

The rate at which Happisburgh is being lost to the sea is increasing, but the village is not just being attacked by the waves - surface water running off the land is also causing the cliffs to crumble.

The village in North Norfolk, has long been facing the threat of coastal erosion and climate change. In recent weeks the cliffs along the coastline have been the location of a number of landslides and cliff falls, leading authorities to issue several safety warnings.

Coastal erosion at Happisburgh. Picture: Danielle Booden - Credit: Danielle Booden

A Second World War pillbox is now perilously close to the cliff edge and in November a landslide took out a portion of the coastal footpath.

But the recent spate of land loss has not been caused by the sea but surface water running off the fields which has saturated the cliffs.

Malcolm Kerby, one of the co-founders of the village's Coastal Action Group which campaigned for improved coastal defences around the country and remedies for communities affected by coastal erosion, said the village was being pincered by the land and the sea.

The 80-year-old said: "There are months left for the pillbox and years left for the lighthouse but the whole lot is scheduled to go, it's all likely set to go in the next 50-years. The rate of erosion has increased, it's much greater than it was 20, 25 years ago."

Mr Kerby said: "Climate change is no longer debatable, it's started and it's getting stronger and stronger, bigger and bigger.

"It's not a problem that's going to go away, it will go on and on and it will get worse. We're on the front line of climate change, there's no doubt about that."

A spokesman for the Department for Environment and Rural Affairs (Defra) said: “Flooding and coastal erosion can have terrible consequences for people, businesses and the environment.

“That is why we are doubling our funding for flood defences in England to £5.2 billion over the next six years, helping build 2,000 new defence schemes and protect 336,000 properties.

“Local authorities are best placed to understand their coastline and manage the risks through Shoreline Management Plans, but we are working on a £36 million six-year programme to help them better understand the risks that climate change poses to those living and working on our coasts.”

Malcolm Kerby from Happisburgh's Coastal Concern Action Group on the beach. Picture: Danielle Booden - Credit: Danielle Booden

Mr Kerby said surface water running off the fields, which in winter froze and expanded, having much the same effect on the cliffs as icy conditions on a frozen pipe "caused the biggest problem".

"What is happening now with the gouges in the field, it's not being eroded, it's the slumping of the cliff because it's saturated with water.

"It reaches a point where the combined weight of cliff material is such that it can't cling to the cliff anymore so it just runs," he said.

Mr Kerby said Happisburgh was "on the frontline of climate change" with residents facing losing their homes but like many places facing coastal erosion had been "abandoned" by government.

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Beyond a climate of comfortable ignorance

Kevin Anderson and Isak Stoddard | 8th June 2020

We must begin a deep and profound transformation towards a progressive, sustainable and zero-carbon future.

We have a little time to reflect with honesty and clarity on the prospects for the global community to deliver on its climate change commitments, now that the Glasgow climate negotiations (COP26) have been re-scheduled for 2021 due to Covid-19.

Source: Flickr
©Tony Webster

To shed light on this, we have written a paper that considers the implications of the Paris Agreement for wealthier and industrialised nations. In particular, the paper focuses on the mitigation proposals of two self-avowed 'climate progressive' countries, the UK and Sweden. Both have developed high-profile legislation, ostensibly designed to cut their emissions in line with holding the rise in temperature to "well below 2°C" and "pursing ... 1.5°C".

Yet as the paper demonstrates, peel away the layers of obfuscation and even these 'climate leaders' are actively choosing to fail – and by a huge margin.

Failure

As such, and without a rapid sea change in the policy environment, the future for both humankind and many ecosystems looks bleak.

For thirty years we've swallowed the delusion offered by the blue pill, nonsense models of utopian tech and cheery tales of green growth. But in 2020, even the blue pill dealers are having their doubts. Perhaps now is the time to embrace the unpalatable reality revealed by the red pill?

Since 1990, and the publication of the first report from the Intergovernmental Panel on Climate Change (IPCC), global emissions of carbon dioxide from energy and industry have risen by 62 percent - pumping another 870 billion tonnes of carbon dioxide into the atmosphere.

Set against this global failure, several countries claim to have demonstrated real leadership in cutting their emissions, the UK and Sweden amongst them. Such nations are regularly held up by academics, journalists and the 'great and the good' of the climate world as offering genuine hope that our climate commitments can yet be delivered within the existing economic paradigm.

But is such optimism well founded? This is the question our latest paper seeks to answer.

Budget

As the science makes clear, it is the total quantity of carbon dioxide emitted that most closely relates to the rise in global temperature, and by extension climate impacts. Whilst such a carbon budget framework comes with inevitable scientific uncertainties, it is sufficiently robust to provide an adequate guide for assessing strategies and policies for reducing emissions.

The real challenges with a carbon budget framework are political. First, what chance of meeting the 2°C and 1.5°C temperature commitments is implied by the language of the Paris Agreement?

Second, how should a global carbon budget be divided between nations so as to provide a 'fair' national share? And third, how can we guard against governments (and others) adopting accountancy ruses to hide how their emissions are set to exceed their budget.

The Paris Agreement requires the global community to cut emissions in line with holding rising temperatures to "well below 2°C" and ideally "pursue .. 1.5°C". But let's be clear, for lots of people around the world, for future generations and for many ecosystems, even these temperature limits do not represent safe thresholds.

Nevertheless, we're in 2020, and safe rises in temperature passed us by some years back. So, in terms of temperature, Paris now represents the best (or perhaps more accurately, the least-worst) outcome we can achieve.

Challenges

Based on this, and using the headline carbon budgets from the latest IPCC report (SR1.5), we derive a 'Paris-compliant' global carbon budget. With careful consideration of non-energy emissions of CO_2 from industrial processes (particularly cement) and deforestation, and updating the budgets to the start of 2020, we estimate a Paris-compliant global carbon budget for energy-related emissions of around 660 billion tonnes of CO_2 (660GtCO_2).

This is the total quantity of CO_2 that can be emitted from the start of 2020 out to and beyond 2100. To put this in perspective, it is around eighteen years of current (2019) global emissions. Whilst there are uncertainties as to the science underpinning this 660Gt, for now it represents our best interpretation of the Paris Agreement and the latest science.

However, it should be noted that the early 'earth system model' runs that will feed into the next IPCC report (AR6), hint that this value may be too optimistic. Consequently, we suggest that somewhere around 660Gt is considered the maximum value for guiding policy.

Having established a Paris-compliant global carbon budget (for CO_2 from energy only), the next challenge was to divide it between the nations of the world. In doing this we took seriously the issue of equity contained within global climate agreements from Rio (1992) through to Paris (2015).

Under the guise of the long-established concept of "common but differentiated responsibilities & respective capabilities" (CBDR-RC), we initially split the world into "developing country parties" and "developed country parties" (Parisian language, that broadly means poorer and wealthier nations). Within these categories, China still classifies as a "developing" country, having a GDP per capita of 23 percent of a typical "developed" nation and just 14 percent of an average US citizen.

Equity

Informed by the concept of CBDR-RC and the equity steer of Paris, we assumed "developing" nations would take a little longer, than developed nations, to achieve a fully zero carbon energy system. Nevertheless, the emissions pathway we finally established for this group was more demanding than anything yet described in the mainstream literature, with the estimated total CO_2 per person/year out to 2050 still well below that of developed nations.

This enshrining of ongoing unfairness emerged as an unavoidable and practical repercussion of there now being only a whisper of carbon budget remaining, even for 2°C.

Whilst we did not elaborate on the unfairness imposed on developing nations by wealthier countries choosing to maintain high levels of emissions, such unfairness is clearly a key issue in determining the appropriate transfers of climate-finance between "developed" and "developing country parties".

Bringing together the IPCC's carbon budgets for a likely chance of 2°C with the equity steer of Paris, we produced a carbon budget for developed nations of 95 to136 billion tonnes of CO_2 (again from 2020 out to, and beyond, 2100). The question then, was how do we divide this budget between all the developed nations, with a specific focus on the implications of any such division for the UK and Sweden.

Grandfathering

There are many options for dividing a finite carbon budget, some informed by population, others based on historical emissions, and still others guided by economic indicators. All of these have their respective merits and drawbacks.

The option we judged most appropriately reflects national circumstances within the developed country parties was 'Grandfathering'. Under this regime, each nation received a proportion of the future carbon budget in line with their recent proportion of emissions.

In essence Grandfathering captures many elements of the other options – from structural lock-in of existing infrastructure through to the economic capacity for reform. Using this approach we estimated that the UK and Sweden had post-2020 carbon budget ranges of, respectively, 2.8-3.7 and 0.28-0.37 billion tonnes.

To reiterate, these budget ranges are for CO2 arising solely from their national energy systems, including an estimate for fuel used in international aviation and shipping. They also relate to a likely chance of staying below 2°C, but only an unlikely chance of 1.5°C.

To put the budgets in context, for the UK, this range is between seven and nine years of current emissions (based on 2018 data), with Sweden's range representing six to eight years. Transposing these budgets into emission reductions, points to immediate and double-digit mitigation rates (e.g. for the UK, 10 percent per year starting January 2020).

Assuming a five year period to overcome political and physical inertia, this equates to a rapid ramping up of mitigation to around 10 percent by 2025, 20 percent by 2030 and achieving a real-zero carbon energy system by around 2035.

Legislation

The question then arises as to how these Paris-compliant carbon budgets and emission pathways compare with those implied in the 'climate progressive' legislation and policy frameworks of the UK and Sweden?

As it stands, whilst the UK does have a near term and five-year carbon budget framing, the latest government legislation, and indeed the Committee on Climate Change's (the CCC) 'net-zero' report, do not provide a total carbon budget for the UK. Sweden's much weaker 2017 legislation makes no reference to any budgeting framework, providing little more than long-term (*not in my term of office*) carbon-reduction targets and loosely defined criteria of an emission pathway.

Consequently, we had to estimate the total national carbon budgets implied in the legislation. Perhaps not surprisingly, the budgets prescribed by both the UK and Swedish governments were far more generous to their own nations than those forthcoming from our analysis.

At 9GtCO2 for the UK, the official national budget is between 2.4 and 3.2 times greater than what we judge is Paris-compliant. For Sweden, at 0.83GtCO2, the range is between 2.2 and 3.0 times larger than our estimate.

Mitigation

There are two immediate interpretations of the UK and Swedish governments' choice of weak mitigation agendas. It could be an extrapolation of a long history of colonialism, arrogantly expecting poorer nations to accept still smaller carbon budgets to compensate for richer countries reluctance to question their socio-economic paradigm.

Or, perhaps there's widespread but silent acceptance of Paris as little more than a rhetorical device, with the temperature thresholds serving as a convenient delusionary distraction.

Both of these see the Agreement as a useful tool for encouraging incremental greening of business as usual and offering NGOs and more concerned citizens something to cling to, but ultimately they reduce Paris to a mere handmaiden of existing power structures and the dominant economic model.

The scale of the failure seemingly locked in to the UK's 'climate progressive' legislation really becomes evident when played out at a global level. If every nation failed to deliver their respective Paris-compliant carbon budget by a factor similar to that of the UK, the global emissions would relate to holding the temperature rise to "well below 2.6 to 3°C" and "pursuing ... 2 to 2.3°C".

This is a profoundly different human and ecological world to the Paris framing of "well below 2°C" and pursue ... 1.5°C". But it does facilitate near-term business-as-usual.

Reform

What we currently have is polished green tweaks, a focus on efficiency rather than absolute emissions, rousing speeches by ministers, academics rewarded for evermore reductionist tinkering, journalists regurgitating soothing technical balms – and with anyone daring to ask system-level questions quickly admonished and silenced.

And as the decade passes and today's great and the good good have either retired with their ill-gotten gains to Tuscany or are pushing up the daises beneath a headstone of titles, gongs and prizes, so our children will begin witnessing the legacy of climate chaos we have knowingly bequeathed them.

It did not have to be like this, and, with luck, we may still have an opportunity to exchange white lies and delusion for uncomfortable truth and fundamental reform.

If climate sensitivity plays in our favour (and sadly this looks to be increasingly unlikely), then a mitigation agenda aligned with "well below 2°C" is still within our grasp. As for "pursuing ... 1.5°C" – this has almost certainly gone the way of the Dodo.

The only glimmer of resurrection is if we deliver real-zero informed by 2°C and 'negative emission technologies' (NETs) do become viable and sustainable at scale. In stark contrast and under the fluttering banner of 'reality', we are already relying on 'NETs' and other ruses even for many of our 3°C scenarios; so the prospects of 1.5°C are vanishingly slim, with 2°C also now rapidly striding towards extinction.

Catalyst

Recognising where we are today, whilst waking up to the Orwellian recycling of failure into narratives of success, risks extinguishing glimmers of hope and undermining any drive for action.

But as 1.5°C drifts into history and the prospect of 2°C rapidly fades, it is essential to understand that these temperatures are not simple thresholds. Staying below 2.1°C is better than 2.3°C, which itself is an improvement over 3°C.

Yes, the higher the temperature the more people will die and the greater will be the levels of societal disruption and ecological breakdown. But how all this finally plays out is subject to suites of interacting uncertainties, from scientific through to societal responses.

So acknowledging our pitiful and callous failures should not be used as an excuse for despair and acquiescence, but rather as a catalyst for a real mitigation agenda far removed from the spin and prestige of today's nonsense.

The only absolute on climate change is that the future will be radically different. Either we continue with deception and dithering only to be battered by the consequent climate impacts, or we immediately begin a deep and profound transformation towards a progressive, sustainable and zero-carbon future.

Alternative

Ultimately both are different worlds from where we reside today. The former allows high-emitters a few years reprieve at the cost of long-term devastation for many, if not all.

Whilst the latter repurposes the labour, resources and productive capacity of society from serving primarily the high consumption lifestyles of the relative few, to delivering a sustainable epoch for the many.

We shouldn't be here, but this is where our myopic choices have brought us. Whilst the increasingly shaky hands of the old guard continue to dispense blue pills, there are now firmer and younger hands offering a red pill alternative. It is not sweet – but it offers a viable home and a chance to develop a more life-affirming future.

These Authors

Isak Stoddard is a PhD researcher at the Natural Resources and Sustainable Development, Uppsala University. Kevin Anderson is Professor of Energy and Climate Change, with joint appointment between the Universities of Manchester, Uppsala and Bergen. This article summarises and expands on a paper, *"A factor of two"*, published in Climate Policy, May 2020.

Imperial College London

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Briefing paper No 28

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BECCS deployment: a reality check

MATHILDE FAJARDY, DR. ALEXANDRE KÖBERLE, DR. NIALL MAC DOWELL, DR. ANDREA FANTUZZI

Headlines

- Bioenergy with carbon capture and storage (BECCS) is presented as a pivotal technology in most pathways for limiting global warming to 1.5 or 2°C. However, it is doubtful that BECCS can fulfil this role alone.
- BECCS is not a single technology. Understanding the value and challenges associated with each BECCS technology is complex but vital.
- Depending on the conditions of its deployment, BECCS may be beneficial but it can also be detrimental to climate change mitigation, due to its lifecycle CO_2 balance, energy balance and resource use.
- It is challenging to ensure that BECCS delivers timely and sustainable net carbon removal, while also generating energy at an appropriate scale.
- Considering these uncertainties and the potential impact on resources, biodiversity and soil health, the scale of BECCS deployment should be limited only to circumstances where it is proven to be beneficial.
- Good governance and financial incentives are required to stimulate high-quality BECCS at this limited scale.
- Policy makers should be sceptical about a future that is uniquely or heavily reliant on BECCS, and instead prepare for and implement alternative mitigation options as soon as possible.

Introduction

The Paris Agreement, ratified by 181 countries, agrees to limit global warming to "well below" 2°C. To fulfil this pledge, total global carbon dioxide (CO_2) emissions post-2010 must keep below 1,200 gigatons (Gt). This is known as a carbon budget[8]. Keeping within 1.5°C warming since pre-industrial times requires even more drastic action: a lower carbon budget of about 400 to 600Gt of CO_2, leading to a 45% emission reduction by 2030 and net zero CO_2 emissions by 2050[10]. Current annual total CO_2 emissions are close to 40Gt (2007-2016 average[12]), and deploying the technologies and policies required to roughly halve these annual emissions is a challenging task for two reasons.

Contents

Grantham Briefings analyse climate change and environmental research linked to work at Imperial, setting it in the context of national and international policy and the future research agenda. This paper and other publications are available from **www.imperial.ac.uk/grantham/publications**

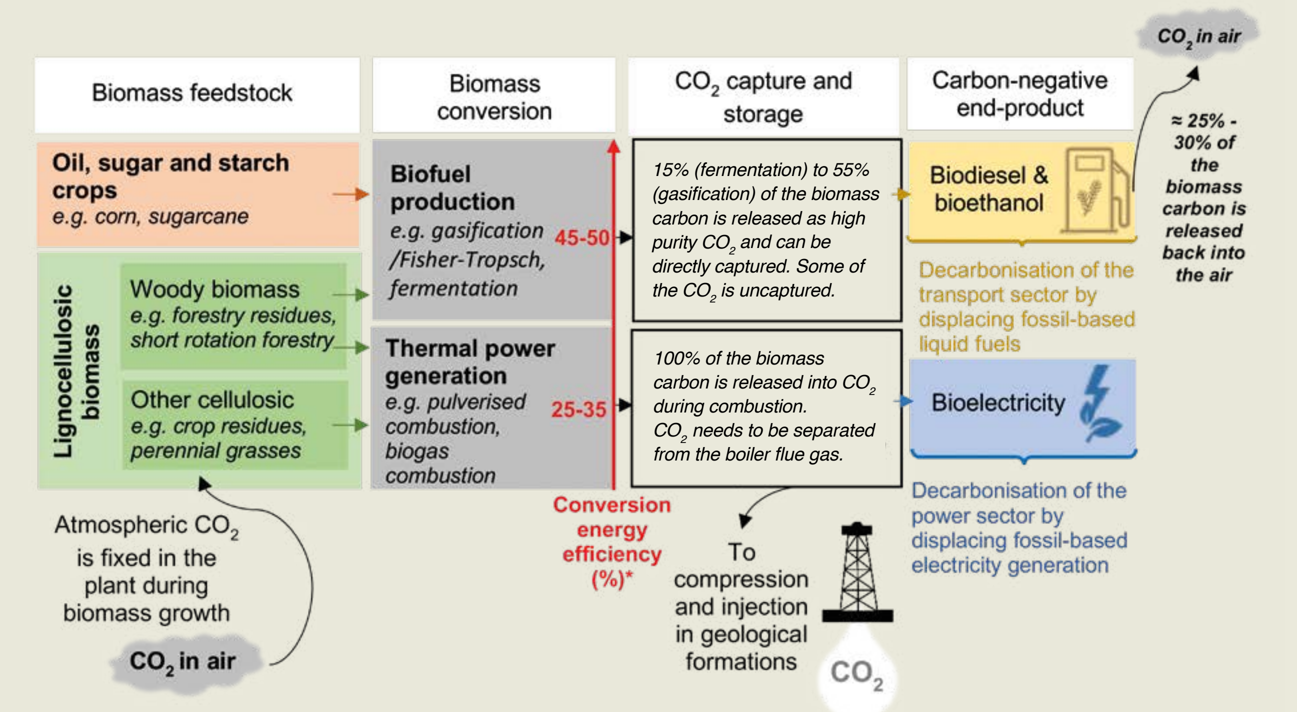
First, while commercially viable alternatives to carbon-intensive power-generation technologies already exist, decarbonising industry, transport and agriculture remains a challenge. Second, the pace of change required to keep within Paris Agreement temperature limits is larger than both current trends and historic precedents. If we cannot reduce our emissions quickly enough, some degree of carbon dioxide removal (CDR) from the atmosphere may be required[13].

CDR technologies deliver net negative emissions by actively removing more CO_2 than they emit through their operation. They are also referred to as negative emissions technologies, or NETs[16, 17, 18]. Scenarios featuring NETs deployment were first summarised in the Intergovernmental Panel on Climate Change's 4th Assessment Report[20], but grew to prominence during the 5th Assessment Report cycle[2], when many of the climate mitigation scenarios that were published featured large amounts of BECCS[18]. Afforestation (planting new forests) is another, equally prominent NET.

BECCS is a group of technologies that span many sectors, and often several geographical regions. In a BECCS chain, CO_2 from the atmosphere is absorbed via photosynthesis into the biomass of plant materials. It is then burned or converted (e.g. via gasification) in power plants, industrial facilities or biorefineries equipped with technologies that capture the CO_2, preventing the gas from returning to the atmosphere[22]. The captured CO_2 is then injected in deep geological formations. This process results in a net transfer of CO_2 from the atmosphere to the ground, provided that emissions associated with supplying the biomass and capturing the CO_2 do not exceed the amount removed from the air by photosynthesis. In theory, by delivering net-negative emissions in the long-term, BECCS compensates for any short-term increases of greenhouse gas emissions caused by delays in implementation of climate policy.

This paper explores some of the questions that emerge in relation to BECCS – a technology that has not been deployed at scale but might be required to meet global climate change goals. Key questions, only some of which are covered here, include the uncertainties as to the actual carbon removal potential of BECCS, wider sustainability considerations of biomass production, the ability to scale up such a complex technology, and balancing reliance on BECCS in the long-term with other short-term greenhouse gas-reduction priorities.

Box 1: Two examples of biomass conversion routes for BECCS: bioelectricity and biofuels



*This efficiency does not include the energy demand for growing, transporting and processing the biomass prior to conversion. Not to confuse with BECCS' net energy efficiency (Box 3).

Box 2: BECCS in Integrated Assessment Models (IAMs)

IAMs combine energy, economy, and climate system models into a single framework to project the trend of CO_2 emissions and their impact on the world climate. CO_2 emissions pathways, as currently projected by IAMs, feature massive deployment of BECCS, thereby raising questions about the sustainable scalability of the technology[1,2].

- Across IPCC scenarios with a 66% or better chance of limiting temperature increase to 1.5°C, median CO_2 removal by BECCS is 12Gt of CO_2 per year (1/4 of current emissions)[3,4]. For the 1.5°C target, CO_2 removal by BECCS has been evaluated to 0-22.5Gt of CO_2 per year by 2100, while agriculture, forestry and land-use related NETs remove 1-5Gt of CO_2 per year in 2100[5,8].
- This massive deployment of BECCS would require between 0.4 and 1.2 billion hectares of land (25% to 80% of current global cropland[3,4].
- BECCS requires significant inputs of land, nitrogen, phosphorus and water, with substantial CO_2 and nitrous oxide emissions arising from these inputs[7]. It also raises the prospect that BECCS "may largely transfer environmental risk from the atmosphere to the land"[9].
- The deployment of BECCS is not limited to the power sector. In fact, on average, IAMs project at least 60% of primary energy from BECCS going to production of liquid biofuels[11]. Different IAMs make different assumptions about BECCS, and therefore deploy different shares of liquid biofuels, which emerge as an important strategy to offset emissions from freight and air transportation, where low-carbon options are lacking.
- Importantly, the extent to which IAMs properly consider and account for energy demand and CO_2 emissions from the biomass supply chain – growing, processing, transporting the biomass – is unclear. From most recent scenarios[5,8], 400 exajoules of BECCS are required to remove 22.5Gt of CO_2 per year. Assuming 60% of primary energy going into biofuels and 40% to bioelectricity, and carbon efficiencies of 90% and 55% (theoretical maxima), 26Gt of CO_2 could be removed, which suggest that some level of supply chain emissions are considered in IAMs.
- Land productivity (yield) is the key assumption governing deployment of BECCS in IAM scenarios, but the literature is scant and not very transparent. However, it does indicate that sustained yield improvements are assumed through to the end of the century in these scenarios. Smith and Torn[7] report that current yields would need to improve by 0.6% to 2.3% per year for 90 years to reach end-of-century yields assumed in one IAM. This pattern is most likely general across IAMs.
- FAOSTAT[14,15] data shows historical crop yield growth of 1.6% per year over the last 50 years, but yield improvements have been declining lately, suggesting most of the easy improvements have been made[19]. On the other hand, the crop yield gap in some underperforming regions could be closed through institutional innovations and capacity building, particularly in sub-Saharan Africa, Ukraine and south-west Russia[18], but this is fraught with non-technical challenges[21]. If successful, however, it could relieve pressure from land and enhance the sustainability of BECCS. Genetically modified crops have the potential to be yield game-changers, although they tend to raise economic and biological concerns.
- What emerges from the literature regarding BECCS in IAM results echoes the conclusion from Minx et al.[18] that "any single NET is unlikely to sustainably achieve the large NETs deployment observed in many 1.5°C and 2°C mitigation scenarios. Yet, portfolios of multiple NETs, each deployed at modest scales, could be invaluable for reaching the climate goals".

Understanding the role of BECCS in decarbonising the economy

BECCS can be deployed via a range of technologies. So far, research and industrial efforts have focussed on two main routes:

1) BECCS via liquid biofuel production (biodiesel or bioethanol[23]) and

2) BECCS via biomass conversion to heat and power, with direct pulverised combustion of biomass being the most common approach[24].

Other niche options include CO_2 capture from biogenic industrial emissions, e.g. in the pulp and paper industry[25]. Box 1 illustrates the different steps of the power and fuel routes, representing the different biomass feedstock options, biomass conversion technologies and carbon-negative end-products.

Because of inherent differences in biomass conversion technologies, the quantity of useful energy (biofuel or bioelectricity) and the amount of CO_2 removed from the atmosphere per unit of feedstock differ from one route to another.

For example, in the fuel route, 25-30% of the biomass carbon is not released during biomass conversion to biofuel but as unabated CO_2 when the biofuel is used[26-28]. Of the CO_2 released during the conversion process, 15% (fermentation[28]) to 55% (gasification[27]) comes out at a high purity[23], and can be directly captured, sent for compression and injection for storage. Some of the CO_2 is released in a more diluted form and can be captured, but at a higher cost.

In the bioenergy to power route, however, all of the carbon fixed in the biomass is released as CO_2 during combustion, but in diluted form in the exhaust gas. Further separation and more energy use is required before compression and injection.

The energy efficiencies of the conversion of biomass to either power or fuels reflect the percentage of the energy content in the original biomass that is available in the final energy carrier and not lost in the conversion process. Power generation efficiencies for biomass firing with post-combustion capture and storage can be as low as 17%[29] and as high as 38%[30]. The energy efficiency of fuel production is typically higher, around 45-50%[27, 28, 31, 32].

Furthermore, because both routes produce energy in addition to providing negative emissions, they can further decarbonise different sectors – such as power and transport – by displacing other fossil-based electricity and fuels. Rather than considering BECCS as a single 'black box' technology, identifying the challenges and opportunities of individual BECCS technology routes is key to understanding its value in decarbonising the economy.

BECCS: a controversial solution

Theoretically, BECCS permanently removes CO_2 from the atmosphere and provides reliable low-carbon energy, while displacing fossil-based fuel and power. We assume that BECCS can be deployed in the medium-term at a relatively low cost, as it partly relies on existing or mature technologies[33]. For these reasons, BECCS has been consistently featured in projected greenhouse gas emissions pathways, reaching levels of deployment as high as 400 exajoules (EJ) per year in terms of primary energy production, and 22.5Gt of CO_2 per year of carbon removal[5,8]. However, understanding the assumptions about BECCS in these pathways can be challenging. Box 2 provides insight into BECCS' representation in integrated assessment models (IAMs) that produce greenhouse gas mitigation pathways.

Such a high reliance on a technology which has not yet been deployed at scale has triggered questions regarding sustainability and risks. These concerns include:

- the potential scale of the industry – some IAMs have BECCS deployed at a scale that is two thirds of the size of today's fossil industry by the end of the century,
- the related reliance of BECCS at this scale on a significant quantity of sustainable biomass, water, land and nutrients,
- the possibility of encouraging delays in mitigation action, and
- if BECCS failed to deliver, it would result in missing the 2100 temperature target[34].

The next section explores these caveats in more details.

The risks of BECCS deployment

The energy and carbon costs of supplying biomass

Supplying biomass will incur different energy costs and associated CO_2 emissions, depending on the feedstock and end process. For each process, biomass feedstock might differ by type – grasses, wood, oil crops or sugar and starch – and by quality – high or low moisture, ash content. In all cases feedstock needs to be collected from a source – farm, waste plant, forest – conditioned into a proper fuel for transport – pellet, bale – and transported to the biomass conversion facility. Each of these steps incurs an energy and CO_2 cost.

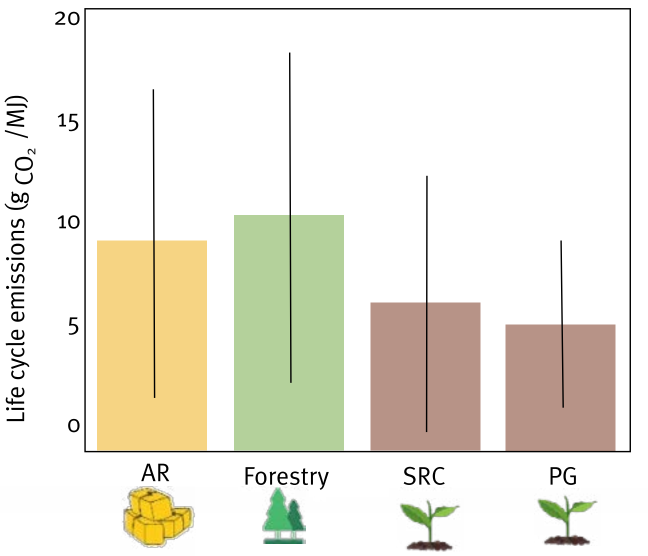


Figure 1: average (bars) and ranges of life cycle greenhouse gas emissions of agriculture residues (AR), forestry products, short rotation coppice woody biomass (SRC) and perennial grasses (PG), adapted from Creutzig et al.[6]

The life-cycle impacts of the biomass supply-chain have been studied intensively, both in the context of BECCS[6,26,35] and bioenergy alone[36-39]. The results strongly depend on the boundaries of each case study and on the feedstock – dedicated agriculture, crop residue, forestry residue, algae. Figure 1 highlights the potentially high supply-chain emissions of different biomass feedstock and the uncertainty of these calculations. Similar ranges can be obtained for the whole life-cycle final primary energy use of biomass. Factors such as biomass yield, fertiliser application, and biomass drying for high moisture biomass (such as woody biomass) have been found to have a great impact on both emissions and energy use of the biomass life cycle[40].

Conversion of land for bioenergy production purposes – defined as direct land use change (LUC) and indirect land use change (iLUC) – may cause greenhouse gas emissions which must be added to these supply chain emissions, as illustrated in Figure 2. LUC is the change in total carbon stock present in the vegetation and soil of converted land, while iLUC emissions occur when the previous activity on land that is converted to bioenergy moves to a different location and causes land use change, and emissions, elsewhere. LUC emissions are a function of the vegetation types, and can be found to be as low as 6kg of CO_2 per hectare for marginal land and as high as 3,052,000kg of CO_2 per hectare for a peatland forest[41]. On the other hand, iLUC emissions are much more difficult to evaluate with certainty, as they are highly dependent on the economic conditions, activity displaced, time horizon, etc. These factors have been found to have a great impact on feedstock life-cycle emissions[3,6,40].

Is BECCS actually carbon negative and energy positive?

Including the biomass life-cycle energy use in the BECCS energy balance can dramatically decrease estimates of potential net energy production. Furthermore, the combination of a lower quality fuel – biomass – and the carbon capture and storage process, means the conversion efficiency of a BECCS facility would be lower than an unabated fossil fuel based power plant. Considering this low efficiency in combination with the potentially high energy demand of the biomass supply chain, the energy 'positivity' of BECCS, i.e. its ability to yield more energy than it requires to operate, has been subject to scrutiny[42]. The energy balance can be referred to as energy return on investment (EROI). EROI values below one mean that the system requires more energy as input, than it provides as output. However, EROI values less than three are often considered problematic. There is debate about the possible and optimal average global EROI[43]. For example, a BECCS system using low yield and high-moisture woody biomass pellets transported from distant sources could have a low EROI[44].

The same observation can be made for net carbon balance of BECCS. High biomass life cycle CO_2 emissions in the carbon balance of BECCS could potentially outweigh the amount of CO_2 captured. A BECCS power plant importing low yield and high moisture woody biomass from a grassland could, for example, result in a 'carbon positive' BECCS system, i.e. with ultimately a larger amount of CO_2 emitted than captured[40]. In the case of liquid biofuel, life-cycle emissions need to be even more limited for the system to be carbon negative, because less CO_2 is captured upon conversion of the biomass to biofuel. For example, in the case of biomass to ethanol via fermentation, if only the fermentation process emissions (15% of the biomass carbon content) are captured[a], the biomass life cycle emissions need to be very low for the overall process to be carbon negative[45].

Direct and indirect emissions associated with land use change from cropland to bioenergy production

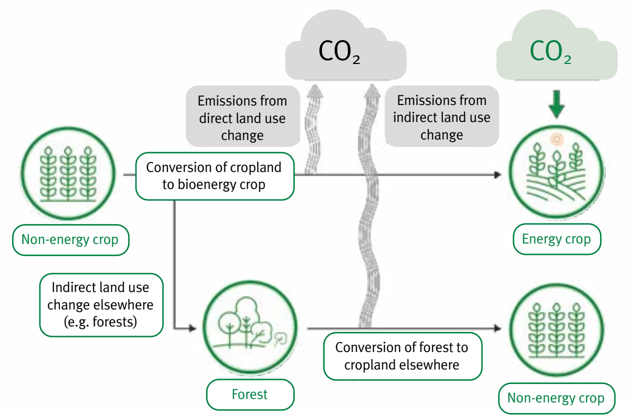


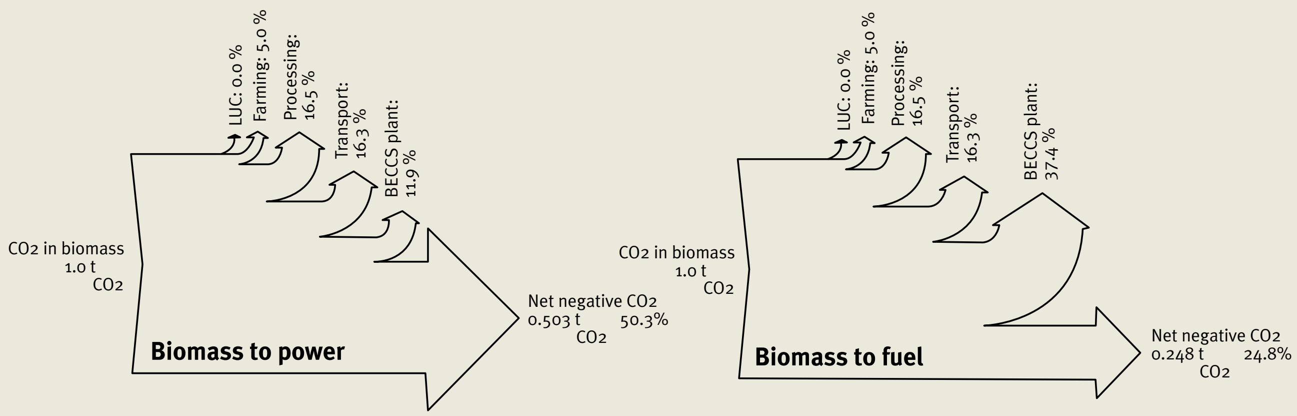
Figure 2: Direct and indirect land use change emissions might occur when land is converted to bioenergy production.

a The lowest cost option, but not the technical limit. An additional 52% of emissions can be captured but at higher cost.

Box 3[b]: BECCS efficiencies: converting raw biomass into CO_2 removal and useful energy

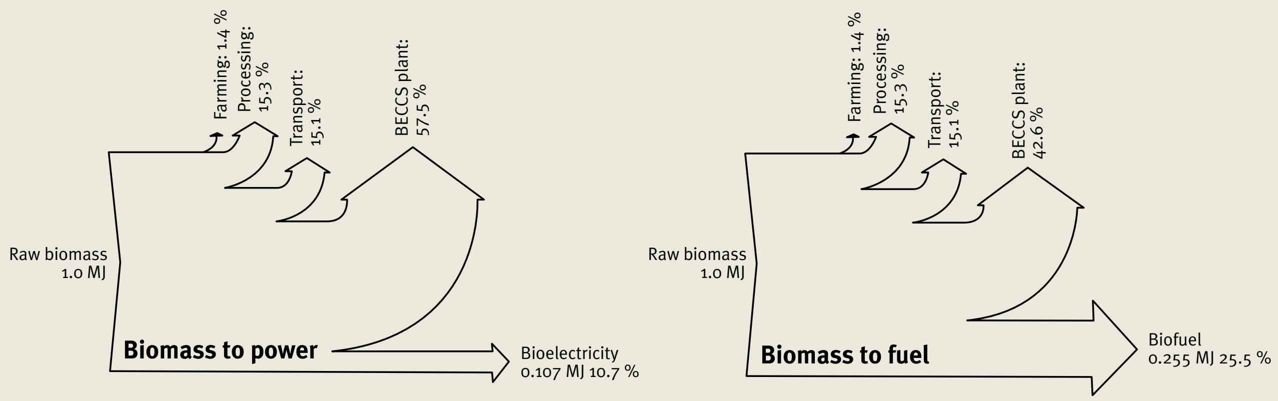
BECCS **carbon efficiency** measures how much of the CO2 fixed in the biomass is removed from the atmosphere.

Figure 2: carbon flow diagram of BECCS. The power route leads to a higher carbon efficiency (50%) than the biofuel route (25%).



BECCS **net energy** efficiency measures how much of the primary energy from biomass is converted into useful energy (biofuel or electricity).

Figure 3: energy flow diagram of BECCS. The power route leads to a lower energy efficiency (11%) than the biofuel (26%).



[b]Supply chain energy demand and emissions data, as well as power generation efficiency (26%) were obtained from the MONET framework for miscanthus production in Brazil transported to the UK, to illustrate the potential impact of long distance transport[38]. For the biofuel route, an energy efficiency of 45%, and a CO2 efficiency of 55% for biomass conversion to biofuels were assumed[22,29].

BECCS' performance can be measured by how much net carbon it captures (carbon efficiency) and how much net energy it produces (energy efficiency) along the whole supply chain. As illustrated in Box 3, while the power route yields higher carbon efficiency – more CO_2 is removed per unit of feedstock – biofuel routes deliver more energy per unit of feedstock. Therefore, there are trade-offs to consider when comparing BECCS deployment options.

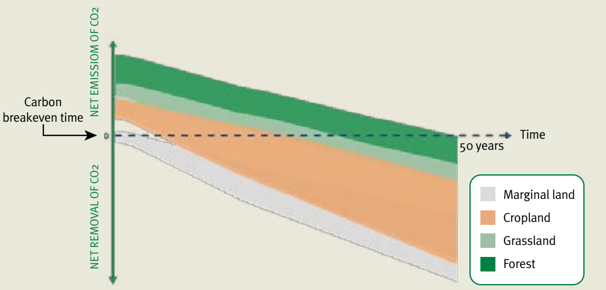
Carbon and energy efficiency are not the only trade-offs to consider. As illustrated in Box 3, while BECCS in the power sector could achieve more negative emissions, carbon negative biofuels, can displace carbon intensive fuels, such as aviation fuels, for which fewer alternative technologies are available[46]. The cost of CO_2 capture also differs on each route, with the cost of capturing one tonne of CO_2 typically lower in biofuel routes than in power routes, because of the higher CO_2 purity in the biomass-to-fuel routes[11].

Time also matters

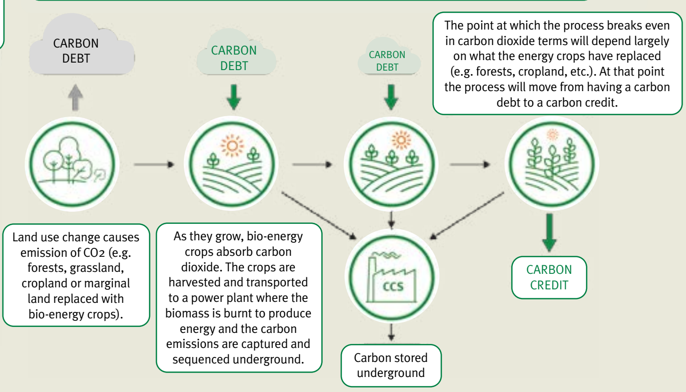
If land use change occurs at the beginning of a BECCS project resulting in emissions, an initial 'carbon debt' is incurred in the system, which needs to be paid off before the project brings net negative emissions. The time taken to pay off this debt is referred to as 'carbon breakeven time'. Box 4 shows that, while cultivating biomass on marginal land leads to breakeven times of one or two years, breakeven times can be greater than 50 years when converting forests[40]. Carefully evaluating the impact of land use change is crucial from both a land-competition perspective, and a carbon-accounting perspective.

Box 4: The impact of land use change on BECCS carbon breakeven time

Breakeven time for the carbon debt when converting different land use types to bioenergy crops. Data based on the conversion of Southern US land to miscanthus production, taken from the MONET framework (Fajardy et al. 2018).



Dynamic carbon balance of Bio-energy with Carbon Capture and Storage



Broader environmental challenges

The impact of BECCS on resources, soil health and biodiversity have been identified as important limitations for its projected deployment[7,40,47,48].

Land use, in particular, has been raised as a major concern. As illustrated in Figure 3, to remain within 1.5°C of warming, scenarios project significant land areas could be allocated to bioenergy production by the end of the century. Estimates of land required range from between 100 million hectares in scenarios with limited (P2) or no BECCS (P1), to up to about 800 million hectares in scenarios where BECCS is deployed at a large scale (P4)[5,8].

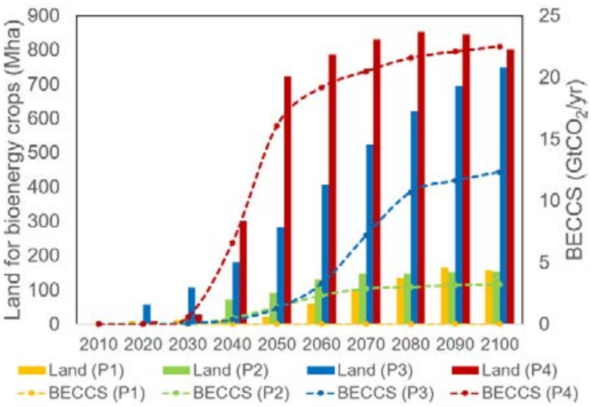


Figure 3: BECCS (lines) and land requirements for bioenergy crops (bars) in four representative pathways to 1.5°C: low energy demand (P1), sustainability oriented (P2), middle-of-the-road (P3), fossil-fuel intensive (P4)[5,8].

The world cropland area is around 1.5 gigahectares today; using high quality land such as grassland or cropland to grow bioenergy crops for BECCS is likely to result in competition with other land-based activities, such as food production, potentially increasing food prices[49,50]. This negative effect can be partially mitigated through agricultural intensification – increasing crop yields in general, reducing the amount of land required to produce the same quantity of products. This approach can lead to biodiversity loss and increased biochemical flows, both critical indicators of the environmental impacts of BECCS deployment. It is also possible to avoid land use change without relying on agricultural intensification by, for example, using crop residues as biomass feedstock or growing biomass on so-called 'marginal land'. However, the extent to which crop residues can be sustainably removed from the field without causing soil depletion and erosion remains uncertain. Marginal lands, on the other hand, are diverse in quality and type, which makes it difficult to predict how much marginal land is actually available, and what the biomass productivity response could be[51-54]. Using algae to substitute for and/or in addition to lignocellulosic biomass in a biofuel route could also relieve pressure on land use[6,35], although concerns of high water and nutrient use remain.

Water use is another challenge to the sustainability of BECCS. Water-use intensity includes the water used for crop growth, water pollution resulting from fertiliser application at the farm level, and the intensity of water use in the BECCS power plant. Table 1 provides ranges of water requirements needed to meet the middle-of-the-road level of BECCS deployment of 12Gt of CO_2 per year (P3).

Table 1: Water implications of removing 12Gt CO_2/yr via BECCS

	Water use (Bm³/yr)
Smith & Torn 2013[55]	5.3 – 24.4
Smith et al. 2016[47]	0.72
MONET[40]	3.6 – 9.7

The water footprint for BECCS was found to be highly dependent on the biomass type and region of production[40], which explains the wide range of values. To put these numbers in context, current total water consumption in agriculture is close to 8 billion m³ per year[56].

Considering these potentially large impacts on resource use, soil health, and forest and nature conservation, it is unlikely that levels of BECCS deployment as projected in middle-of-the-road (P3), let alone fossil-fuel intensive (P4), scenarios to 1.5°C, may be achieved sustainably.

The scale up challenge

Because the biomass supply chain has such a dramatic impact on the environmental and technical performance of BECCS, it is crucial to not only define what sustainable biomass is, but more importantly how much biomass can be sustainably produced. Controversy around what truly is sustainable explains the wide range reported in the literature. For example, the potential for using agricultural residue depends on how much can be removed from the field without compromising soil quality[57]. Studies on biomass potential in Brazil point to about 50% of residues being physically harvestable, and of those, only 10% are available for bioenergy[58,59].

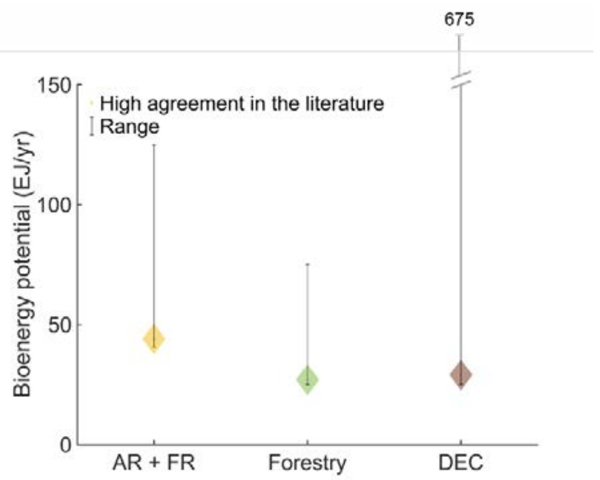


Figure 4: Ranges (bars) and high literature agreement (diamond) on global sustainable bioenergy potential per feedstock type (AR + FR = Agriculture and Forestry residues, DEC = dedicated energy crops). Adapted from Creutzig et al.[6].

The technical potential of energy crops depends on the productivity of land available for bioenergy, but this is also subject to debate. IAMs project significant agricultural yield gains in the future, which helps improve the competitiveness of bioenergy options in the modelled scenarios. Some scenarios project future yield growth rates above historical levels, which averaged 1.9% per year between 1961 and 2007[60]. However, there is much controversy around the future growth rate of global average yields, with perhaps the easy improvements having already been acheived[19]. The yield improvements of the past were enabled by measures such as fertilizer application, irrigation and land-ownership concentration. Extending the yield gains of the last 50 years into the future may require higher inputs of fertilizers, biocides, and irrigation, exacerbating the environmental problems caused by the so-called Green Revolution. In that way, we may be solving one problem by creating another, transferring the climate problem from the atmosphere to the land[9].

There are many assessments of global bioenergy potential in the literature[6,19,61-63]. Figure 4 represents ranges of uncertainty of global sustainable bioenergy potential by sector (bars), as well as the availability levels with high agreement in the literature (diamonds). The figure implies that only about 100 exajoules (EJ) per year, or likely less, can be sustainably produced globally[6]. This sustainable potential, with high agreement in the literature, sits at the lower end of the biomass production range in existing scenarios, although other studies point to somewhat higher sustainable potentials (see for example[63], who point to a 80-160EJ per year potential).

Other studies point to even higher biomass availability and, with such a high range of uncertainty, one could easily overestimate the amount of sustainable biomass available for BECCS. However, the consensus seems to be on the conservative side.

Adding up residues, forestry biomass and bioenergy crops, less than 100EJ of modern bioenergy could be sustainably sourced, which still represents a fivefold increase to what is currently produced[64]. Assuming these 100EJ are deployed with carbon capture and storage, and that 60% of bioenergy goes to biofuel production, and 40% to bioelectricity, three to four gigatons of CO_2 could be removed from the atmosphere per year within this constrained bioenergy supply.

The CCS dimension

BECCS deployment is intrinsically dependent on the existence of carbon capture and storage (CCS) infrastructure. To date, there are 17 operating CCS projects in the world, reaching a cumulative capture capacity of 31.5Mt of CO_2 per year, of which only 3.7 is stored in geological formations[65]. Though technology advances have brought down the cost of capture[66], low investor confidence remains the main bottleneck in the way of unlocking a CCS economy. Currently, medium-term physical and financial risks associated with full CCS chain integration[c] represent a significant fraction of CCS project capital investment[67]. In addition to lowering this financial risk, other opportunities to lower the cost of CCS include the clustering of CO_2 sources to facilitate economies of scale for the transport and storage of CO_2, and the retrofitting of large power stations to benefit from technology learning[33].

BECCS: a governance problem

While climate change mitigation scenarios propose that large-scale BECCS deployment might help avoid dangerous climate change, it would also steer the world closer to the planetary boundary of freshwater use. This large-scale deployment of BECCS would push us beyond other planetary boundaries such as land-system change, biosphere integrity and soil health[48]. The first and foremost challenges are therefore to (a) limit BECCS deployment to a sustainable scale, both in models and policy frameworks, and (b) ensure that the most sustainable BECCS options get deployed within this scale, by setting clear resource, carbon and energy efficiency guidance and constraints.

Another challenge is to make BECCS economically feasible. Deployment is tied to the deployment of CCS, and therefore directly affected by the difficulty in financing a CCS project. With reduced financial risks for CCS, a carbon price in the range \$30-280 per ton of CO_2 would be required to make a BECCS power production project economically attractive[22,68]. So far, carbon prices such as those of the EU Emissions Trading Systems have been insufficient in incentivising CCS deployment, let alone BECCS[62]. The implementation of a carbon credit, such as the '45Q' budget allocation in the US, which was recently upgraded to credit up to \$50 a ton of CO_2 sequestered, and \$35 a ton of CO_2 used for 'enhanced oil recovery', could well help jumpstart CCS projects.

Financing carbon removal through BECCS is made more challenging because the value chain is likely to be geographically dispersed. Regions with high biomass potential such as South America and sub-Saharan Africa[69] are not necessarily regions with well characterised CO_2 storage capacity compared with the USA, Japan or northern Europe[63]. It is also complex to ensure fair allocation of the share of carbon removal across all stakeholders of the BECCS value chain, from both a political (fulfilling individual national carbon removal targets) and a financial (cascading carbon credits to all stakeholders) point of view.

In channelling financial support towards BECCS, it is important for policy makers to weigh up this support against other proven mitigation options that might cost less, and have less damaging side effects.

BECCS deployment will need assistance – even to deliver at this limited scale

Even with a more limited ambition for BECCS deployment, going from today's megaton-scale industry to removing a few gigatons of CO_2 by the end of the century remains an important challenge. Reaching these levels of sustainable activity in a timely fashion requires the right regulation and incentive frameworks to be put in place. Some ideas about where the policy focus should lie to unlock sustainable BECCS deployment are provided below.

Broadening the scope of the biomass sustainability standard

Establishing sustainability standards is essential to ensure that the most sustainable options are deployed instead of focusing only on what is commercially viable.

Strong policies are needed to set clear standards for biomass sustainability, not only on carbon intensity of biomass feedstocks, but also on water, CO_2, and energy efficiencies, as well as carbon breakeven time.

For example, the low carbon fuel standard in California, enables fuels demonstrating a lower carbon footprint than the gasoline standard to earn a carbon credit. Compliance to the fuel standard is evaluated through life cycle analysis with the GREET tool[70]. Applying this method but broadening the scope of indices evaluated, could be a useful way to discriminate unsustainable from sustainable scenarios.

In a European context, the UK Bioenergy strategy includes a sustainability criterion ensuring a minimum of 60% emission reduction from the average European power carbon-intensity for bioelectricity[71]. This target represents a maximum carbon intensity of 79g of CO_2/MJe (i.e. electric energy delivered), which translates into a minimal carbon efficiency between 47% and 60%. The more recent European RED II directive goes further by stating that large scale heat and power biomass plants deliver an 80% emissions reduction compared to fossil fuel, with a life cycle emissions accounting framework that includes land-use change emissions. Such constraints could limit BECCS deployment to sustainable routes, thereby making room for other low-carbon technologies, or emphasising the merit of more stringent mitigation action today.

c Where a single entity owns and operates the full CCS chain and long-term risk associated with monitoring the dispersion or movement of the CO_2 in storage sites.

Deploying BECCS instead of bioenergy, not in addition to it

It is likely that only a limited amount of bioenergy will be available if social and environmental sustainability constraints of feedstock production are met. Therefore, this sustainable potential should be allocated in a way that yields the most benefits. One way to maximise CO_2 removal is to impose a requirement that any bioenergy deployment should be accompanied by capture and storage of as much CO_2 as possible, effectively requiring that any bioenergy used from now on should be in the form of BECCS, or BECCS enabled.

Thinking in terms of carbon negative products and their value

With a bioenergy supply that is likely to be limited, careful consideration should be made about where to use this bioenergy – power generation or liquids.

Although BECCS via biofuels is less carbon efficient than BECCS via bioelectricity, it presents the advantages of being more energy efficient and decarbonising the transport sector, for which fewer low-carbon alternatives are available than in the power sector.

Aviation stands out as having very few decarbonisation options, and biofuels are the main alternative for the sector. From this perspective, biofuel production proves to be a better business case than power production. As an illustration, the only operating BECCS plant to date is the Decatur corn-bioethanol CCS plant[72]. However, being more carbon efficient, power production enables more carbon removal per unit of resource – biomass, water and land. The trade-offs between BECCS deployment options therefore need to be better understood when valuing its contribution to climate change mitigation. These trade-offs are likely to manifest themselves on a case-by-case basis.

Lowering the financial risks of CCS

A transfer of some of the risks and liabilities associated with CCS value chain integration and long-term CO_2 storage monitoring from the private to the public sector would lower the risks for investors, and therefore the financial costs associated with a CCS project, thereby encouraging private capital to be invested in the CCS economy[33].

Conclusions

Before BECCS is implemented in the hope it will play a role in climate change mitigation, it is crucial to establish whether it works as a means of generating net energy to sequester net carbon. For this it is crucial to have clarity about the value and challenges of each BECCS technology route, and to understand what makes the value chain sustainable. Relevant regional regulations with regard to water, energy and carbon will be required to make sure deployment does not compromise other societal objectives such as the Sustainable Development Goals. This will encourage the deployment of a regionally tailored mix of technologies, including but not limited to BECCS, instead of blindly betting on a single one.

Importantly, we have shown that BECCS cannot deliver the scale of negative emissions required in current emissions projections. The BECCS value chain is complex with significant energy and carbon inputs, among other factors. Therefore, we should expect BECCS to make a necessary but only limited contribution to meeting our climate change targets. Counting on BECCS to singlehandedly solve the climate change mitigation problem detracts attention from higher levels of short-term effort based on known low-carbon solutions that are already available today.

Glossary

Bioenergy potential	Bioenergy potential: how much bioenergy could be produced per year globally.
Carbon negative (positive)	Carbon negative (positive): said of a BECCS value chain which leads to a net removal (emission) of CO_2 from (to) the atmosphere, all life cycle CO_2 emissions considered.
Carbon (or CO_2) breakeven time	Time required for a BECCS value chain to be carbon negative.
Carbon (or CO_2) efficiency	The fraction of the carbon fixed in the biomass which becomes net negative emissions, all life cycle CO_2 emissions considered.
Energy efficiency (net)	The fraction of the biomass primary energy turned into useful energy, all life cycle energy inputs and outputs considered.
Energy positive (negative)	Said of a BECCS value chain which leads to a net production (consumption) of energy, all life cycle energy inputs and outputs considered.
EROI	The ratio between energy input to energy output.
High agreement in the literature	Many scientific studies pointing to a particular result.

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nature climate change

LETTERS

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Appendix 5

Corrected: Author correction

Biomass-based negative emissions difficult to reconcile with planetary boundaries

Vera Heck[1,2*], Dieter Gerten[1,2*], Wolfgang Lucht[1,2,3] and Alexander Popp[1]

Under the Paris Agreement, 195 nations have committed to holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to strive to limit the increase to 1.5 °C (ref. [1]). It is noted that this requires "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of the century"[1]. This either calls for zero greenhouse gas (GHG) emissions or a balance between positive and negative emissions (NE)[2,3]. Roadmaps and socio-economic scenarios compatible with a 2 °C or 1.5 °C goal depend upon NE via bioenergy with carbon capture and storage (BECCS) to balance remaining GHG emissions[4–7]. However, large-scale deployment of BECCS would imply significant impacts on many Earth system components besides atmospheric CO_2 concentrations[8,9]. Here we explore the feasibility of NE via BECCS from dedicated plantations and potential trade-offs with planetary boundaries (PBs)[10,11] for multiple socio-economic pathways. We show that while large-scale BECCS is intended to lower the pressure on the PB for climate change, it would most likely steer the Earth system closer to the PB for freshwater use and lead to further transgression of the PBs for land-system change, biosphere integrity and biogeochemical flows.

Negative emissions can fulfil several purposes. In a prospective, 2 °C or 1.5 °C warmer world with balanced sinks and sources of GHG emissions, they can allow for limited remaining fossil fuel use and/or compensate remaining agricultural or natural emissions (for example forest fires) or carbon leakages. If a complete decarbonization of the fossil fuel and agricultural sectors is achieved, NEs could reduce atmospheric CO_2 concentrations. BECCS is currently discussed as a promising NE technology[12]. It is therefore of considerable interest to examine the implications of NEs via BECCS in a holistic Earth system framework, such as the framework of a 'safe operating space'[10,11], delineated by nine PBs for human perturbations of the Earth system.

Here, we quantitatively assess trade-offs between BECCS and the status of five out of nine PBs for climate scenarios reaching 1.5 °C and 2 °C above pre-industrial. We consider the two PBs identified as core PBs, climate change and biosphere integrity[11], as well as the PBs for land-system change, biogeochemical flows and freshwater use, which are already transgressed except for freshwater use[11]. The latter four PBs have sub-global operating scales which are recognized in the definition of regional boundaries underpinning the global-level boundaries[11]. According to the precautionary principle, each PB is placed at the lower end of a scientific uncertainty range of its position. Upon transgression into the uncertainty zone, nonlinear shifts can no longer be excluded, while transgressing its upper end implies moving into a danger zone of high risk of irreversible shifts. To capture the importance of regional environmental change for the functioning of the Earth system we adopt the concept of a safe zone and a zone of increasing risk (uncertainty zone) also for the regional boundaries. These regional boundaries are: amount of remaining forest cover, biodiversity intactness index (BII), environmental flow requirements and imposed nitrogen fertilization limits, all calculated at the grid-cell level and subsequently aggregated to the analysis scale of regional boundaries (refer to Supplementary Table S2). We further compare our results to the originally defined global PBs.

Within this framework we distribute second-generation herbaceous or woody biomass plantations (irrigated or rainfed) using a spatially explicit multi-objective optimization approach in which biomass plantations can be allocated only on areas not required for food and feed production (see Methods). For this assessment, baseline agricultural land-use patterns are derived using the global land-use model MAgPIE[13,14] applied for the shared socio-economic pathways SSP1 (sustainability), SSP2 (middle of the road) and SSP5 (fossil-fueled development)[15] with and without climate policy to achieve RCP2.6 climate forcing levels (see Methods for details). Two alternative optimization objectives are examined: first, maximizing biomass production for NEs under the strict constraints of regional boundaries (safe) or the upper-end of their uncertainty zones (increasing risk); second, achieving certain biomass production for NE while minimizing the pressure on global PBs. We measure the state of the Earth system with respect to each PB via the global and regional control variables (Supplementary Table S2). The optimized biomass plantation patterns are combined with the agricultural baselines and assessed for PB impacts with the well-established biogeochemical model LPJmL, driven by an ensemble of climate scenarios scaled to reach a global warming of 1.5 °C and 2 °C in the second half of the century[16] and capturing differences in the spatial patterns produced by 19 climate models (see Methods). Results are averaged over 2051–2082 (covering four harvest cycles). To obtain NE and bioenergy potentials we consider two alternative conversion pathways: biomass conversion to hydrogen (B2H2) with high capture rates (90%) and conversion efficiencies (55%), and conversion to liquid fuels (B2L) with lower capture rates (48%) and efficiencies (41%) [ref. [17] and see Methods]. Input of fossil fuels for biomass production and transportation is assumed to be 10% of the primary energy content[18,19].

In all agricultural baseline scenarios (SSP patterns excluding biomass plantations for 2050) the global PBs for climate change, biosphere integrity, land-system change and nitrogen flows are transgressed even further than at present. Thus, in a strict sense, NEs via BECCS are not compatible with navigation of human development within the safe operating space for the agricultural land-use scenarios assessed, as BECCS would put additional pressure on the PBs.

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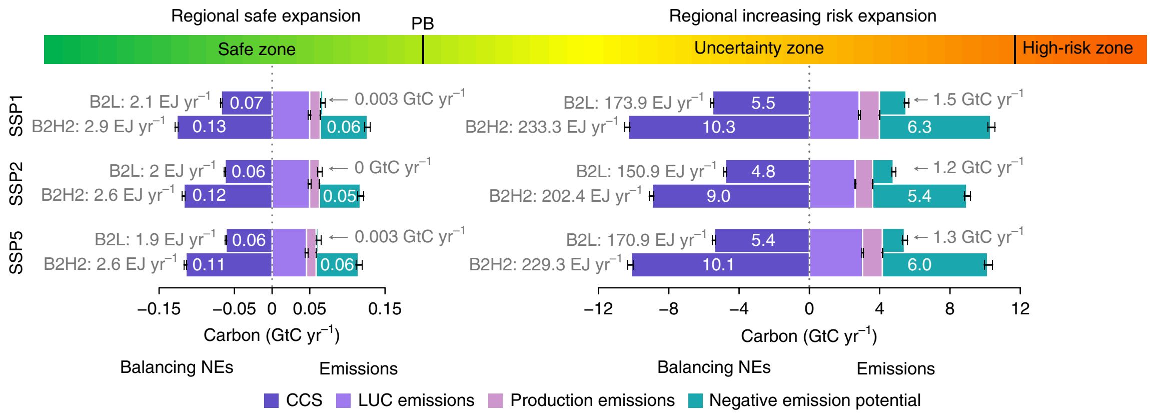

Fig. 1 | Emission balance of optimal biomass production within regional safe and increasing risk zones for two biomass conversion pathways. Biomass production is maximized around the agricultural baselines of SSP1, SSP2 and SSP5 (including climate policy of achieving RCP2.6 climate forcing levels) for 2050. NE potentials from biomass conversion to hydrogen (B2H) or liquid (B2L) are derived from CCS potentials, subtracting emissions associated with LUC, production and transportation of biomass. Bioenergy potentials (in exajoules) are calculated from biomass harvest and conversion efficiencies (Methods). Error bars reflect the range stemming from 19 climate scenarios with a global warming of 1.5 °C for 2050–2082 (see details in Methods).

However, the PB for climate change was identified as a core boundary, the transgression of which can have substantial consequences for the status of other boundaries and drive the Earth system out of the Holocene state[11]. Therefore, it might be feasible to counteract climate change while accepting some collateral transgression. As a minimal requirement, however, we assume that regional boundaries should not be altered to a state outside of their uncertainty ranges, to avoid feedbacks to large-scale processes[11].

We evaluate safe biomass-based NEs while ensuring adherence of biomass plantations to either the regional safe or uncertainty zones. The range of resulting potentials for NE via BECCS is large (Fig. 1). In the regional safe zone, small opportunities for biomass plantations, conditioned by the agricultural baseline scenarios, result in marginal CCS potentials of 0.11 GtC yr^{-1} to 0.13 GtC yr^{-1} with a highly efficient conversion to hydrogen (B2H2, Fig. 1). Taking into account the related land use change (LUC) emissions and input of fossil fuels for production, the resulting actual NE potential is <0.1 GtC yr^{-1} for all land-use baselines (Fig. 1), corresponding to ~0.5% of current carbon emissions. Thus, if regional safe zones are adhered to, BECCS can only marginally contribute to balancing remaining emissions or reducing atmospheric CO_2 concentrations.

Allowing the more risky exploitation of the full uncertainty zones of the regional boundaries considered increases the potential for NEs via BECCS significantly. With the highly efficient B2H2 pathway, the CCS potential in the assessed SSP scenarios ranges from 9.0 GtC yr^{-1} to 10.3 GtC yr^{-1} (Fig. 1) while producing 202 EJ yr^{-1}–233 EJ yr^{-1} in the form of hydrogen. Conversion to liquid fuels halves the CCS potentials and lowers bioenergy production by 25%. The actual NE potential, however, is smaller than the CCS potential because of substantial LUC emissions of 2.8 GtC yr^{-1} (averaged over a 32-year timespan) and emissions associated with biomass production and transportation (Fig. 1). Thus, in 2050, NEs of 1.2 GtC yr^{-1}(B2L, SSP2) up to 6.3 GtC yr^{-1} (B2H2, SSP1) could be achieved via BECCS in a riskier strategy that discards the precautionary principle and could trigger critical environmental feedbacks to the Earth system.

Despite fundamental differences in the SSP storylines, the potentials for BECCS are remarkably similar for the SSP1, SSP2 and SSP5 agricultural baselines, albeit the largest BECCS potentials can be achieved in the SSP1 sustainability scenario. In all scenarios, the climate policies implemented towards an RCP2.6 climate forcing result in smaller agricultural land demands, and thus larger NE potentials compared to the reference SSP scenarios without climate policy (Supplementary information). If these NEs were completely used for balancing fossil fuel emissions, primary energy of 48 EJ yr^{-1} to 258 EJ yr^{-1} from coal could be offset (based on an emission factor of 90 gCO_2-eq/MJ_{th} for coal[20]), depending on the biomass conversion pathway and socioeconomic land-use scenario. This wide range of NE potentials reflects major uncertainties related to the mix of BECCS technologies, and smaller uncertainties related to future land-use change for agriculture.

Due to the considerable reduction of CCS potentials by LUC emissions (Fig. 1) we further performed the optimization with a modified objective of maximizing the net flux of biomass production minus LUC emissions. Overall, this increases NE potentials slightly (+2% for B2H2 and +27% for B2L in SSP1) because of avoided LUC emissions (Supplementary Fig. 2). Optimized biomass potentials, however, are smaller than those of biomass harvest optimization neglecting LUC effects. This reduces CCS rates and bioenergy generation by 7%. These findings highlight a trade-off between NE and bioenergy production: although NE potentials are higher if LUC emissions are considered, bioenergy production potentials decrease.

Our optimization allows allocation of biomass plantations only in regions where the agricultural baselines' impacts are small enough to allow for additional biomass plantations within regional safe or uncertainty zones of biosphere integrity, biogeochemical flows, land-system change and freshwater use (Supplementary Fig. 1). Even though regional environmental limits are being considered, allocation of additional biomass plantations adds to the transgression of boundaries at the global scale. Figure 2 illustrates that in the process of decreasing the pressure on the PB for climate change with BECCS, additional pressure is exerted onto other PBs. With the regional safe constraint, almost no biomass plantations can be implemented. Thus, the values of the PB control variables are almost the same as in the agricultural baseline of SSP1 (dashed blue line). Under the constraint allowing for exploitation of regional uncertainty zones, many global PB control variables are severely impacted while the NE potential increases, especially under the highly efficient biomass conversion pathway to hydrogen (B2H2) (Fig. 2).

In the scenario allocating biomass plantations around the SSP1 and SSP2 agricultural baseline and allowing for a transgression of regionally safe environmental limits up to the upper end of the regional uncertainty zones, biomass plantations are allocated on

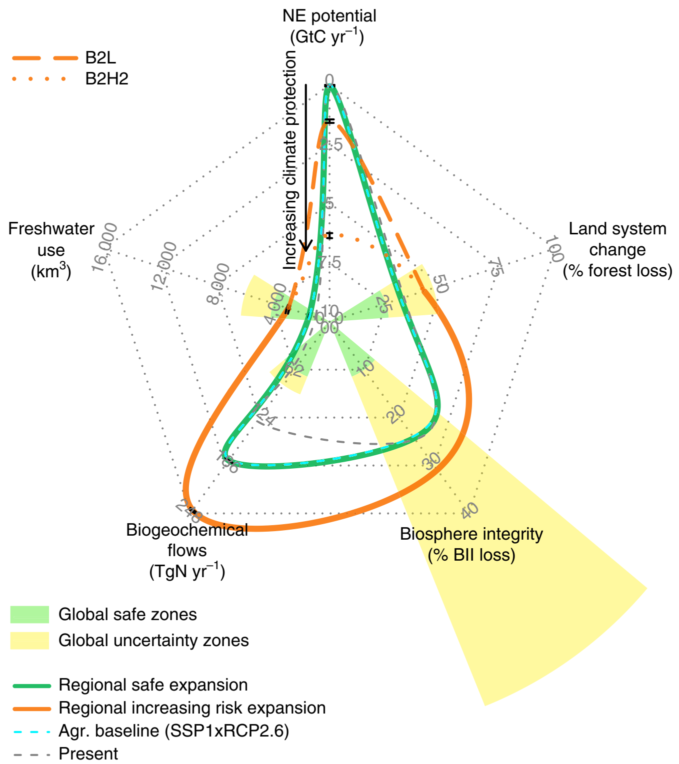

Fig. 2 | Status of global PBs considering agricultural land use in SSP1 and biomass production within regional safe and increasing risk zones. Optimally allocated biomass plantations for 2050 under the constraints of staying within regional safe (green line) and uncertainty zones (orange lines) are combined with the SSP1xRCP2.6 agricultural baseline for food and feed production (dashed blue). The present (2005) status of the PBs (dashed grey) is calculated based on the MAgPIE model initialization (see Methods). NE potentials are depicted for the biomass conversion to hydrogen (B2H2) and liquid (B2L). Error bars reflect the range under forcing from 19 climate scenarios reaching a global warming of 1.5 °C (see Methods). Green and yellow planes indicate the global safe and uncertainty zones[11].

870 Mha and 778 Mha, respectively. This increases land-use area by 19% (SSP1) and 17% (SSP2) compared to the agricultural baseline, with additional forest loss on 645 Mha, increasing the transgression of the land-system-change boundary (+10% forest loss, SSP1) and 586 Mha (+9% forest loss, SSP2). This adds significant pressure on biodiversity (+7% loss of biodiversity intactness, see Methods). The biomass potential largely stems from herbaceous biomass with relatively low nitrogen requirements[21]. Nonetheless, fertilizer requirements further alter global biogeochemical flows (+65 TgN yr^{-1} (SSP1) and + 56 TgN yr^{-1} (SSP2) fertilization). Most of the biomass plantations are set to be irrigated because regional water availability, even if accounting for environmental flow requirements, is generally high in productive regions without large agricultural water appropriation. Consequently, water consumption by biomass plantations more than doubles agricultural water consumption (+1167 km^3). Such massive irrigation benefits productivity of biomass plantations (on average 22 tDM ha^{-1}), reducing land requirements and impacts on biodiversity. However, a large share of irrigated areas is allocated to development countries where installation of large-scale modern irrigation technologies may be economically challenging.

We assess the interactions between freshwater use, biodiversity conservation and land-system change in more detail (Fig. 3 for the SSP1 baseline, see Supplementary Information for other agricultural baselines). For this, we adopt the alternative optimization objective prescribing a certain biomass harvest while minimizing the pressure on different global PBs disregarding regional constraints.

The pressure added to the boundaries of freshwater use, biosphere integrity and land-system change is sensitive to the prioritization of different conservation objectives, indicating trade-offs between the individual priorities. When prioritizing global biodiversity conservation (Fig. 3a), biomass plantations are mostly allocated on grasslands or savannahs with relatively low species richness. High biomass targets (up to 20 GtC yr^{-1} can thus be met without much further deterioration of biosphere integrity and land-system change but would require massive irrigation of biomass plantations (accounting for regional water availability but disregarding environmental flow requirements). Global water consumption transgresses the PB for freshwater use for targeted biomass production >5 GtC yr^{-1} and exits the global uncertainty zone for biomass production >10 GtC yr^{-1} (Fig. 3a).

Prioritizing freshwater conservation (Fig. 3b) leads to significant water-saving potentials for the same biomass production (2150–6000 km^3 yr^{-1}), because biomass plantations are allocated to productive regions with smaller water deficits. This implies, however, high forest loss, especially in the tropics, increasing biosphere integrity loss (by an additional 2–10%) and land-system change (3–21% additional forest loss, Fig. 3b). Furthermore, land-use-change emissions from deforestation result in overall smaller NE potentials.

All simulated NE potentials are to be considered rather optimistic because they imply implementation of large-scale modern irrigation and fertilization management of second-generation biomass plantations. Logistic and economic challenges related to management, possible carbon storage rates or the availability of geological storage sites near biomass plantations are not accounted for. Furthermore, BECCS potentials are subject to large uncertainties regarding the potential scale, conversion efficiencies, economic feasibility, as well as public and legal acceptance[22,23]. Currently only a few BECCS sites exist, and even obtaining the relatively small biomass to liquid efficiencies (B2L) would require substantial upscaling and development of CCS technologies[22].

Integrated assessment studies project total NE requirements of 0.6 to 4.1 GtC yr^{-1} (0.5 to 2.7 GtC yr^{-1}) in 2050 for limiting global warming to 1.5 °C (2 °C)[5,24], with a substantial increase throughout the century. Our internally consistent biogeochemical simulation results shed light on the feasibility and trade-offs of a BECCS contribution from dedicated bioenergy crops to NE requirements for three alternative storylines of future land-use development. We have shown substantial trade-offs between BECCS and PBs at regional and global scales, complementing previous assessments of biophysical limitations[25] and trade-offs with food production[26], biodiversity[27] and water use[28].

In conclusion, if regional boundaries were adopted as precautionary environmental guardrails, the potential for NEs from dedicated bioenergy plantation is marginal (<0.1 GtC yr^{-1}). The NE requirements projected could be met only if the precautionary principle of the planetary boundaries framework was discarded, and if highly efficient biomass conversion to hydrogen and carbon storage pathways were available. This shows that socio-economic pathways requiring substantial BECCS bear the risk of triggering potentially irreversible changes in the Earth system through extensive land-use change, water use, alteration of biogeochemical flows and compromising biosphere integrity. Pending ongoing improvements in the definition and quantification of PBs[11], relying on BECCS as a key decarbonization strategy should be considered highly risky. Thus, early and ambitious GHG reductions, rapid development of less invasive NE technologies[29] and use of other feedstocks for BECCS (for example, residues) are required to maintain a chance of keeping global warming well below 2 °C.

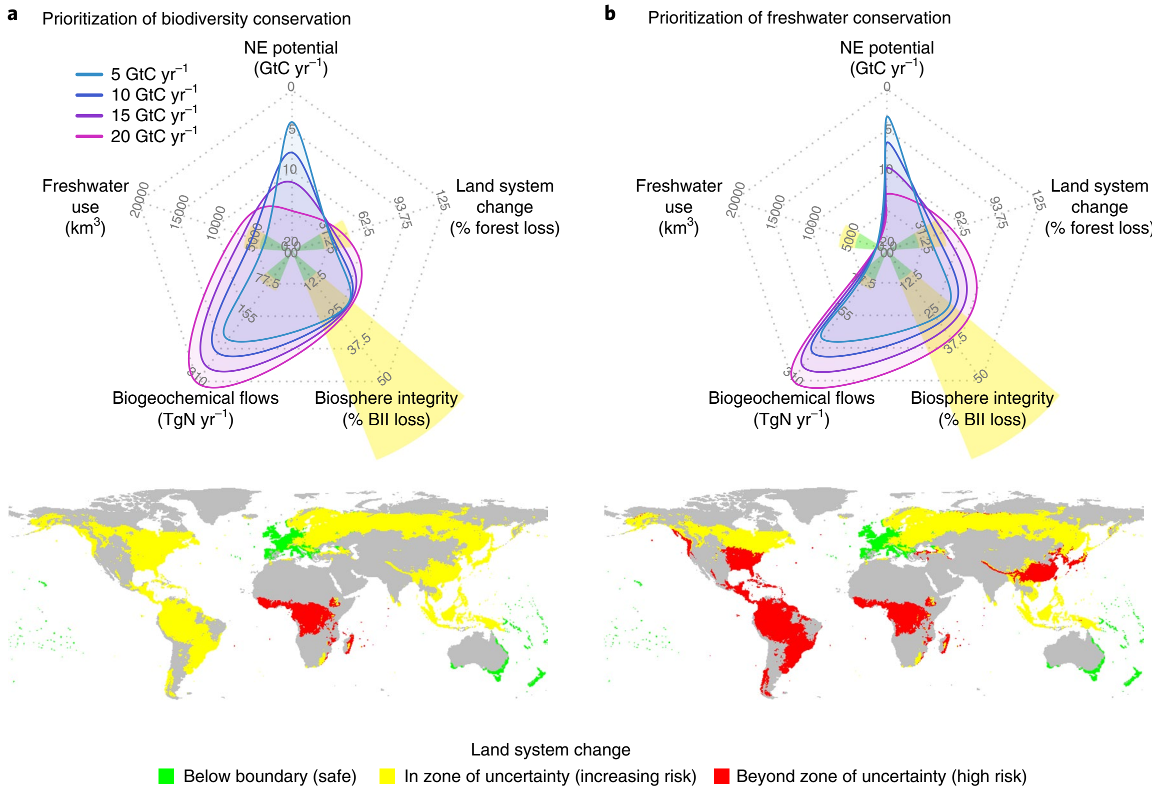

Fig. 3 | Effect of biodiversity and freshwater conservation objectives for fixed biomass production targets. Fixed biomass production targets reached under prioritization of biodiversity conservation (**a**) and prioritization of freshwater conservation (**b**). Biomass plantations are distributed around the SSP1xRCP2.6 agricultural baseline with a global warming of 1.5 °C. NE potentials are depicted for the highly efficient biomass conversion pathway to hydrogen (B2H2). Maps show exemplarily the regional status of the control variable for land-system change optimized for a global biomass production of 15 GtC yr^{-1} under the respective conservation objective.

Methods

Methods, including statements of data availability and any associated accession codes and references, are available at https://doi.org/10.1038/s41558-017-0064-y.

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Author contributions
V.H. designed the study with input from D.G., W.L. and A.P. V.H. developed the methodology, performed all simulations, analysed the results and created the figures. Land-use data from MAgPIE were provided by A.P. V.H. led the writing process with contributions from D.G., W.L. and A.P.

Competing interests
The authors declare no competing financial interests.

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Methods

We developed a multi-objective optimization model for the spatial allocation of biomass plantations. The model is based on simulations with the state-of-the-art dynamic vegetation model LPJmL, scenarios of baseline agricultural land use patterns for food production, and data sets on indicators of biodiversity. The optimization is driven by constraints and objectives according to global and regional representations of the planetary boundaries for biosphere integrity, biogeochemical flows, land-system change and freshwater use. The optimization model and its foundations are described in more detail in the following sections.

The dynamic vegetation model LPJmL. LPJmL represents natural ecosystems and managed croplands including biomass plantations to simulate key ecosystem processes and coupled carbon and hydrological cycles[30,31]. It has been extensively validated for carbon cycles[32], agricultural crop and biomass production[9,33,34], water flows and irrigation requirements[30,31]. Biomass plantations are a representation of highly productive herbaceous and woody second-generation biomass plantations, validated in refs [9,27]. Their parameterizations are based on observations of the growth and harvest characteristics of Miscanthus/switchgrass cultivars for the herbaceous biomass plantations, and willows/poplars and Eucalyptus plantations for temperate and tropical woody biomass plantations, respectively. Herbaceous biomass plantations are simulated to be harvested on a multi-annual basis, and woody biomass plantations every eight years with a plantation rotation time of 40 years.

LPJmL was applied to determine the potential changes in carbon pools and fluxes under conversion to biomass plantations, potential irrigation water requirements of biomass plantations and water availability for irrigation, as well as biogeochemical and hydrological impacts of the agricultural baseline scenarios. All simulations were preceded by a 5000-year spin-up with natural vegetation, bringing soil carbon pools and vegetation distribution into equilibrium. A subsequent second spin-up period of 390 years introduces historical agriculture with annual cropland extent and crop type distribution per 0.5° grid cell and irrigated fraction per crop type after ref. [35] from 1700–2005, allowing for a historical adjustment of carbon pools. During the spin-ups, the climate (historical climate data from CRU TS3.10[36] of the years 1901–1930) was repeated. Further simulations from 2005–2050 serve as spin-ups for the actual simulations using the different baseline agricultural land-use patterns without biomass plantations and a temperature-stratified climate scenario with a global warming of 2 K during the 30-year-mean around 2100, reproducing the median response of 19 general circulation models[16]. LPJmL simulations and their purpose for the optimization are summarized in Supplementary Table S1.

Biomass plantations are cultivated in regions where climate conditions allow biomass harvests >5 tDM ha^{-1} yr^{-1} (ref. [37]). For the generation of optimization inputs one medium-range climate model (MPI-ESM) is used to simulate changes in soil and vegetation carbon pools related to biomass plantations and deforestation, potential irrigated and rainfed biomass yields, potential water consumption of irrigated biomass plantations and regional water availability.

To allow for consistent biogeochemical and hydrological modelling, all optimized land-use patterns were simulated by LPJmL from 2051 to 2082 (that is, four harvest cycles of woody biomass plantations) on a spatial resolution of 0.5°, driven by an ensemble of 19 temperature-stratified climate scenarios with a global warming of 1.5 K and 2 K during the 30-year-mean around 2100[16]. In case of deforestation for biomass plantations, the natural vegetation replaced is treated as a one-time biomass harvest which is used as feedstock for BECCS.

Calculation of negative emission potentials. In BECCS systems, the harvested biomass can be converted to different types of secondary energy carriers via multiple technology pathways that allow for carbon capture and subsequent carbon storage, for example, in underground reservoirs. We consider two biomass conversion technologies: biomass conversion to hydrogen (B2H2) and biomass conversion to liquid fuels (B2L), which form the upper (B2H2) and lower (B2L) end of bioenergy conversion and carbon capture efficiencies[17]. B2H2 has potentially very high capture rates (up to 90%) because hydrogen is a carbon-free secondary energy carrier. In contrast B2L has a low capture rate (up to 48%) since the resulting fuel contains a significant share of carbon. Fossil fuel input to biomass production and transportation is assumed to be constant at 10% of the primary energy content[18,19].

The annual NE potential (P_{NE}) is calculated via:

$$P_{NE} = C_r \frac{H_{cum} - E_{LUC} - E_P}{n_y} \quad (1)$$

with c_r: capture rate, H_{cum}: biomass harvest, E_{LUC}: land-use-change emissions and E_P: production and transportation emissions. The cumulative biomass harvest (H) includes one-time-harvested timber from deforestation and cumulative harvest from biomass plantations. Land-use-change emissions are carbon emissions (soil and vegetation) due to land-use change from natural vegetation to biomass plantations, computed by LPJmL.

Agricultural baseline scenarios. The agricultural baseline consists of land-use patterns for food and feed production for SSP1, SSP2 and SSP5 under no-mitigation (reference) and ambitious mitigation (RCP 2.6), derived by the Model of Agricultural Production and its Impacts on the Environment (MAgPIE) for 2050[14,38]. These SSPs depict three different global futures with substantially different socio-economic conditions that aim to reflect different socio-economic challenges to mitigation and are of greatest interest to assess BECCS potentials. SSP1 describes a sustainable future in which environmental boundaries are respected, including climate change mitigation (RCP2.6 in the baseline) and hence bioenergy needs. SSP2 represents a world that follows a middle-of-the-road pathway with intermediate challenges for mitigation, whereas SSP5 describes a resource intensive world with high GHG emissions (RCP8.5 in the baseline), high challenges mitigation and hence bioenergy needs. Land-use patterns are designed to ensure demand-fulfilling food production, where demand is externally prescribed based on extrapolation of historical relationships between population and GDP on national levels[39]. Land-based mitigation for MAgPIE is driven by carbon prices and bioenergy demand from the REMIND model as implemented in the SSP exercise[13] and affects agricultural land for food and feed production. Besides land-use patterns, also spatially explicit information on N-fixation and inorganic fertilizer on agricultural land have been provided by MAgPIE, based on a detailed nitrogen-budget model in consistency with SSP1, SSP2 and SSP5[40]. Spatially explicit agricultural water consumption is simulated by LPJmL, and non-irrigation human water consumption under the SSP2 scenario (415 km^3 in 2050) was provided by the WaterGAP model[41] and used for all agricultural baselines.

Optimization model. We developed an optimization model (based on the R-package *lpSolveAPI* for linear optimization[42]) that distributes herbaceous or woody biomass plantations (irrigated or rainfed) on a 0.5° grid around the fixed baseline agricultural land-use patterns, considering two alternative optimization objectives:

1) maximization of global biomass harvest (H) given fixed regional boundary constraints (C_{PB}^{reg}) of biosphere integrity (B), land system change (L), nitrogen flows (N) and freshwater use (W):

$$\max_{f_j \in C_{PB}^{reg}} \left(\sum_{j=1}^{n} \sum_{p} f_j^p \; h_j^p \right) \quad (2)$$

with f_j^p: cell fractions and h_j^p: harvest of biomass plantations $p \in$ {herbaceous irrigated, herbaceous rainfed, woody irrigated, woody rainfed} in gridcells $j = 1\ldots n$. Biomass fractions are subject to regional constraints $\{C_B^{reg}, C_L^{reg}, C_N^{reg}, C_W^{reg}\}$.

2) minimization of impacts I on B, L, N, W for varied weights (w_{PB}) given fixed biomass harvest constraints (C^H):

$$\min_{f_j \in C^H} \left(\sum_{j=1}^{n} w_B I_j^B + w_L I_j^L + w_N I_j^N + w_W I_j^W \right), \quad (3)$$

with $C^H = \sum_{j=1}^{n} \sum_p f_j^p \; h_j^p \in \{5, 10, 15, 20\}$ GtC yr^{-1}.

Planetary and regional boundaries and optimization constraints. Under the first optimization objective (equation (2)), land-use expansion for bioenergy is allowed where regional environmental limits according to the planetary boundary concept are not transgressed in the agricultural baseline and until they are reached. The impacts on global control variables of the planetary boundaries are minimized in the second optimization objective (equation (3)). The global and regional control variables of the assessed PBs are summarized in the Supplementary Information (Supplementary Table S2).

Biogeochemical flows. The status of the global biogeochemical flows PB is approached via the intended nitrogen fixation (chemical N fixation in fertilizers and anthropogenically induced biological N fixation by legumes)[43]. As regional constraints we derive grid-cell-specific thresholds for nitrogen fixation considering the control variables used to assess the global PB for nitrogen flows[43]: atmospheric NH_3 concentrations and N concentrations in surface runoff (see Supplementary Table S2 for the proposed critical limits[43]). As proposed by de Vries et al.[43] we calculate critical global losses of a given N compound to either air or water by

$$N_{losses;crit} = N_{losses;present} \; RI_{Ncompound} \quad (4)$$

with the risk indicator $RI = [N]_{crit}/[N]_{present}$ and $[N]_{present}$ being the present concentration of the respective control variable. In contrast to de Vries et al.[43] we do not limit RI to values smaller than or equal to 1, as this would strictly forbid additional or initial fertilization in areas that are not close to the regional thresholds, thus forbidding fertilization on all primary and unfertilized land. Based on the respective range of critical limits, we obtain a range of global RI of 1.79–5.36 for atmospheric NH_3 concentrations and 0.61–1.53 for N in surface runoff using global average values of $NH_{3-present} = 0.56\ \mu g\ m^{-3}$ and $N_{runoff-present} = 1.63$ mg Nl^{-1}[43]. Assuming that the ratio between N fixation and polluting compounds does not change[43], we multiply the respective RI by the agricultural nitrogen fixation of 121.5 Tg N in the year 2000[44]. To derive grid-cell-specific thresholds for nitrogen fixation limiting NH_3 concentrations we divide the global critical value by the global land area. The grid cell threshold for limiting N runoff to surface waters is calculated by dividing the global critical value by surface runoff in the agricultural baseline scenario. Under the regional optimization constraints C_N^{reg}, biomass plantations can be allocated until the combined nitrogen fixation and fertilization of the agriculture baseline scenario and biomass plantations reaches one of the regional thresholds. Therefore, we derive nitrogen fertilizer requirements for biomass plantations from biomass harvest under the assumption that extracted nitrogen (0.15% N in dry matter for herbaceous biomass[21] and 0.5% N in dry matter for woody biomass[45]) is replenished with an efficiency of 50%[46].

Biosphere integrity. Several interim control variables have been proposed for the PB for biosphere integrity[11]. Acknowledging large uncertainties associated with the status of this PB, we calculate a measure similar to one of the proposed control variables, the biodiversity intactness index (BII)[11,47]:

$$BII = \frac{\sum_s \sum_l ER_s A_l I_{s,l}}{\sum_s \sum_l ER_s A_l}, \quad (5)$$

for species groups $s \in$ {amphibians, birds, mammals, vascular plants} and land cover $l \in$ {natural, cultivated, plantation}, with ER_s = endemism richness of species s, A_l = land area of land cover l and $I_{s,l}$ = intactness of species s with land cover l.

Endemic richness instead of proposed species richness is used to incorporate individual regional contributions to genetic diversity, which is the motivation for the second interim control variable[11]. Endemic richness data of terrestrial vertebrates were available on a 1° resolution and vascular plants for 90 terrestrial biogeographic regions[48]. Due to the lack of global impact data, we adopted expert impact estimates of South Africa[47] for a rough first estimate of species intactness on cultivated land or plantations. This implies that the absolute BII-values on the global or regional scale are highly uncertain. However, regional differences are respected in the spatial allocation of biomass plantations because the intactness estimates serve only as a factor to heterogeneously distributed endemic richness. The BII is calculated for the whole globe (global PB) and for 71 continental biomes. For the regional optimization constraint (C_B^{reg}) biomass plantations can be allocated in the respective biome as long as the BII (under combined agricultural and biomass plantation land use) is higher than 90% (safe limit) or 30% (uncertainty limit).

Freshwater use. The PB for freshwater use has two different control variables for the global and regional scale (human water consumption and environmental flow requirements, respectively). The basin-scale environmental water flows boundary limits blue water withdrawal along rivers to percentages of the mean monthly flow. It is calculated with the Variable Monthly Flow (VMF) method[49] accounting for intra-annual variability in terms of high-, intermediate- and low-flow months (ref. to Supplementary Table S2).

In the optimization, water availability for irrigation of biomass plantations is always limited at the grid-cell level and at the level of water basins. To account for upstream-downstream effects, upstream withdrawals (minus return flows) are subtracted from downstream water availability. Water availability is additionally limited at the basin level with an additional constraint that water withdrawals in each basin may not exceed the basin discharge. Without the regional boundary constraints, irrigation of biomass plantations is allowed to the extent of mean available water over the irrigation period after subtracting agricultural withdrawals and withdrawals for households, industry and livestock from the monthly water availability. This assumes that water can be stored during the irrigation period, but neglects irrigation water from fossil groundwater.

Under the regional boundary constraint on freshwater use (C_W^{reg}), the available water for irrigation of biomass plantations in each river basin is calculated as the mean available water over the irrigation period after subtracting monthly environmental flow requirements, agricultural withdrawals and withdrawals for households, industry and livestock from the monthly water availability. The same calculation is applied at the grid-cell level to limit water withdrawals and sustain environmental water flows at the grid-cell level.

Land-system change. The status of land-system change is derived from the potential forest cover simulated by LPJmL for historic climate data (CRU TS version3.1[36]). Regional constraints are on the scale of major forest biomes (tropical, temperate and boreal forests) of each continent (Supplementary Table S2). Under the global and regional land-system-change constraint, deforestation for biomass plantations is allowed as long as the respective global or regional boundary limits are not transgressed.

Data availability. The data that support the findings of this study are available from the corresponding author upon request.

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2019 Government greenhouse gas conversion factors for company reporting

Methodology paper for emission factors
Final report

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Contents

8. Air Transport Emission Factors

Section summary

8.1. This section contains Scope 3 factors only, related to direct emissions from and WTT emissions for business travel and freight transport by air. Air transport conversion factors should be used to report Scope 3 emissions for individuals flying for work purposes, and the related WTT factors account for the upstream emissions associated with the extraction, refining and transport of the aviation fuels prior to take-off. For freighting goods, emission factors are provided per tonne.km of goods transported.

8.2. Table 33 shows where the related worksheets to the air transport emission factors are available in the online sets of the factors.

Table 33: Related worksheets to air transport emission factors

Worksheet name	Full set	Condensed set
Business travel – air	Y	Y
WTT – business travel – air	Y	N
Freighting goods*	Y	Y
WTT – delivery vehicles & freight*	Y	N

Notes: * freight flights only

Summary of changes since the previous update

8.3. There are no major changes for the aviation factors in the 2019 update.

Passenger Air Transport Direct CO_2 Emission Factors

8.4. Emission factors for non-UK international flights were calculated in a similar way to the main UK flight emission factors, using DfT data on flights between different regions by aircraft type, and emission factors calculated using the EUROCONTROL small emitter's tool.

8.5. The 2019 update of the average factors (presented at the end of this section) uses the same updated data source first introduced in 2015. The EUROCONTROL small emitters tool was used as the basis for calculating the CO_2 emissions factors resulting from fuel burn over average flights for different aircraft. The principal advantages of the source are:

a) The tool is based on a methodology designed to estimate the fuel burn for an entire flight, it is updated on a regular basis in order to improve when possible its accuracy, and has been validated using actual fuel consumption data from airlines operating in Europe.

b) The tool covers a wide range of aircraft, including many newer (and more efficient) aircraft increasingly used in flights to/from the UK, and also variants in aircraft families.

c) The tool is approved for use for flights falling under the EU ETS via the Commission Regulation (EU) No. 606/2010.

8.6. A full summary of the representative aircraft selection and the main assumptions influencing the emission factor calculation is presented in Table 34. Key features of the calculation methodology, data and assumptions include:

a) A wide variety of representative aircraft have been used to calculate emission factors for domestic, short- and long-haul flights;

b) Average seating capacities, load factors and proportions of passenger km by the different aircraft types (subsequently aggregated to totals for domestic, short- and long-haul flights) have all been calculated from detailed UK Civil Aviation Authority (CAA, 2018) statistics for UK registered airlines for the year 2017 (the most recent complete dataset available at the time of calculation), split by aircraft and route type (Domestic, European Economic Area, other International)[19];

c) Freight transported on passenger services has also been taken into account (with the approach taken summarised in the following section). Accounting for freight makes a significant difference to long-haul factors.

Table 34: Assumptions used in the calculation of revised average CO_2 emission factors for passenger flights for 2019

	Av. No. Seats	Av. Load Factor	Proportion of passenger km	Emissions Factor, $kgCO_2/vkm$	Av. flight length, km
Domestic Flights					
AIRBUS A319	152	82%	33%	14.9	445
AIRBUS A320-100/200	175	80%	26%	15.0	476
AIRBUS A321	198	72%	4%	17.6	480
ATR72 200/500/600	70	64%	2%	6.1	226
BOEING 737-800	190	84%	6%	15.1	501
BOEING 767-300ER/F	259	71%	2%	25.8	536
BOMBARDIER DASH 8 Q400	78	71%	19%	7.1	393
EMB ERJ170 (170-100)	83	70%	1%	10.6	419
EMBRAER ERJ190	106	69%	5%	12.5	445

[19] This dataset was provided by DfT for the purposes of the Conversion Factors calculations, and provides a breakdown by both aircraft and route type, which is unavailable in publicly available sources, e.g. Annual Airline Statistics available from the CAA's website at: http://www.caa.co.uk/default.aspx?catid=80&pagetype=88&pageid=1&sglid=1

	Av. No. Seats	Av. Load Factor	Proportion of passenger km	Emissions Factor, $kgCO_2/vkm$	Av. flight length, km
SAAB 2000	35	74%	2%	6.7	371
SAAB FAIRCHILD 340	23	76%	1%	3.8	308
Average	***142***	***78%***	***100%*(total)***	***11.1***	***407***
Short-haul Flights					
AIRBUS A319	153	82%	12%	11.4	1,033
AIRBUS A320-100/200	180	80%	26%	11.3	1,355
AIRBUS A321	215	82%	12%	12.6	1,840
AIRBUS A330-200	352	85%	0%	22.4	2,390
AIRBUS A330-300	298	71%	0%	23.1	2,453
AIRBUS A350-900	298	82%	0%	27.1	1,851
ATR72 200/500/600	71	68%	0%	5.2	383
AVROLINER RJ85	94	71%	0%	13.6	523
BOEING 737-300	152	87%	1%	11.6	1,614
BOEING 737-400	85	77%	0%	11.9	1,776
BOEING 737-700	135	79%	1%	11.2	990
BOEING 737-800	189	87%	37%	11.5	1,522
BOEING 737-900	176	85%	0%	12.9	1,017
BOEING 757-200	177	89%	4%	14.7	2,345
BOEING 757-300	277	90%	1%	16.3	2,704
BOEING 767-300ER/F	220	78%	1%	20.6	1,806
BOEING 777-200	223	74%	0%	28.2	1,949
BOEING 777-300	357	75%	1%	30.5	2,840
BOEING 787-800 DREAMLINER	293	93%	0%	19.6	2,655
BOMBARDIER DASH 8 Q400	78	71%	0%	6.5	540
EMB ERJ170 (170-100)	85	74%	0%	8.9	722
EMBRAER ERJ190	105	72%	1%	10.2	879
Average	***185***	***84%***	***100%*(total)***	***11.8***	***1,335***
Long-haul Flights					
AIRBUS A310	246	82%	0%	18.5	5,488
AIRBUS A320-100/200	171	81%	1%	10.5	2,450
AIRBUS A321	158	81%	0%	11.8	3,592
AIRBUS A330-200	281	80%	5%	20.9	6,590
AIRBUS A330-300	278	78%	4%	21.7	6,294
AIRBUS A340-300	267	79%	1%	24.9	9,990
AIRBUS A340-600	307	81%	1%	31.7	6,021
AIRBUS A350-900	291	76%	2%	23.6	7,564
AIRBUS A380-800	499	82%	17%	47.0	6,968
BOEING 737-800	164	70%	0%	10.3	4,203
BOEING 747-400	344	81%	12%	38.1	6,928

	Av. No. Seats	Av. Load Factor	Proportion of passenger km	Emissions Factor, $kgCO_2/vkm$	Av. flight length, km
BOEING 757-200	170	74%	1%	14.4	5,487
BOEING 767-300ER/F	201	76%	4%	19.1	6,050
BOEING 777-200	246	80%	13%	25.6	6,738
BOEING 777-300	340	81%	16%	28.7	7,393
BOEING 777-300ER	300	83%	3%	30.6	8,546
BOEING 787-800 DREAMLINER	254	82%	9%	18.4	6,833
BOEING 787-900 DREAMLINER	263	82%	10%	19.8	7,517
Weighted average	***322***	***81%***	***100%*(total)***	***26.9***	***6,723***

Notes: Figures on seats, load factors, % tkm and av. flight length have been calculated from 2018 CAA statistics for UK registered airlines for the different aircraft types. Figures of $kgCO_2/vkm$ were calculated using the average flight lengths in the EUROCONTROL small emitters tool. * 100% denotes the pkm share of the aircraft included in the assessment - as listed in the table. The aircraft listed in the table above account for 93% of domestic pkm, 100% of short-haul pkm and 100% of long-haul pkm.

Allocating flights into short- and long-haul:

8.7. Domestic flights are those that start and end in the United Kingdom, which are simple to categorise. However, allocating flights into short- and long-haul is more complicated. In earlier versions of the GHG Conversion Factors it was suggested at a crude level to assign all flights <3700km to short haul and all >3700km to long-haul (on the basis of the maximum range of a Boeing 737). However, this approach was relatively simplistic, difficult to apply without detailed flight distance calculations, and was not completely consistent with CAA statistical dataset used to define the emission factors.

8.8. The current preferred definition is to assume that all fights to ‘Europe’ (or those of similar distance, up to a 3,700km maximum) are short-haul, and those that are to non-European destinations (or for flights over 3,700km) should be counted as long-haul. Some examples of such ‘long-haul’ flights have been provided in the following Table 35, and it is up to the users of the GHG Conversion Factors to use their best judgement on which category to allocate particular flights into.

Table 35: Illustrative short- and long- haul flight distances from the UK

Area	Destination Airport	Distance, km
Short-haul		
Europe	Amsterdam, Netherlands	400
Europe	Prague (Ruzyne), Czech Rep	1,000
Europe	Malaga, Spain	1,700
Europe	Athens, Greece	2,400
Average (CAA statistics)		**1,366**

Area	Destination Airport	Distance, km
Long-haul		
North Africa	Abu Simbel/Sharm El Sheikh, Egypt	3,300
Southern Africa	Johannesburg/Pretoria, South Africa	9,000
Middle East	Dubai, UAE	5,500
North America	New York (JFK), USA	5,600
North America	Los Angeles California, USA	8,900
South America	Sao Paulo, Brazil	9,400
Indian sub-continent	Bombay/Mumbai, India	7,200
Far East	Hong Kong	9,700
Australasia	Sydney, Australia	17,000
Average (CAA statistics)		**6,823**

Notes: Distances based on International Passenger Survey (Office for National Statistics) calculations using airport geographic information. Average distances calculated from CAA statistics for all flights to/from the UK in 2013

8.9. Aviation factors are also included for international flights between non-UK destinations. This relatively high-level analysis allows users to choose a different factor for passenger air travel if flying between countries outside of the UK. All factors presented are for direct (non-stop) flights only. This analysis was only possible for passenger air travel and so international freight factors are assumed to be equal to the current UK long haul air freight factors[20].

Taking Account of Freight

8.10. Freight, including mail, are transported by two types of aircraft – dedicated cargo aircraft which carry freight only, and passenger aircraft which carry both passengers and their luggage, as well as freight. The CAA data show that almost all freight carried by passenger aircraft is done on scheduled long-haul flights. In fact, the quantity of freight carried on scheduled long-haul passenger flights is nearly 8 times higher than the quantity of freight carried on scheduled long-haul cargo services.

8.11. The CAA data provides a split of tonne km for freight and passengers (plus luggage) by airline for both passenger and cargo services. This data may be used as a basis for an allocation methodology. There are essentially three options, with the resulting emission factors presented in Table 36:

a. **No Freight Weighting:** Assume all the CO2 is allocated to passengers on these services.

b. **Freight Weighting Option 1:** Use the CAA tonne km (tkm) data directly to apportion the CO_2 **between passengers and freight**. However, in this case, the derived emission factors for freight are significantly higher than those derived for dedicated cargo services using similar aircraft.

[20] Please note - The international factors included are an average of short and long-haul flights which explains the difference between the UK factors and the international ones.

c. **Freight Weighting Option 2:** Use the CAA tkm data modified to treat freight on a more equivalent/consistent basis to dedicated cargo services. This takes into account the additional weight of equipment specific to passenger services (e.g. seats, galleys, etc.) in the calculations.

Table 36: CO_2 emission factors for alternative freight allocation options for passenger flights based on 2019 GHG Conversion Factors

Freight Weighting:	None		Option 1: Direct		Option 2: Equivalent	
Mode	Passenger tkm % of total	gCO_2 /pkm	Passenger tkm % of total	gCO_2 /pkm	Passenger tkm % of total	gCO_2 /pkm
Domestic flights	100.00%	123.9	99.76%	123.6	99.76%	123.6
Short-haul flights	100.00%	78.9	97.77%	76.8	97.77%	76.8
Long-haul flights	100.00%	111.5	34.48%	41.6	85.65%	94.9

8.12. The basis of the freight weighting **Option 2** is to take account of the supplementary equipment (such as seating, galley) and other weight for passenger aircraft compared to dedicated cargo aircraft in the allocation. In comparing the freight capacities of the cargo configuration compared to passenger configurations, we may assume that the difference represents the tonne capacity for passenger transport. This will include the weight of passengers and their luggage (around 100 kg per passenger according to IATA), plus the additional weight of seating, the galley, and other airframe adjustments necessary for passenger service operations. The derived weight per passenger seat used in the calculations for the 2019 GHG Conversion Factors were calculated for the specific aircraft used and are on average over twice the weight per passenger and their luggage alone. In the **Option 2** methodology the derived ratio for different aircraft types were used to upscale the CAA passenger tonne km data, increasing this as a percentage of the total tonne km – as shown in Table 36.

8.13. It does not appear that there is a distinction made (other than in purely practical size/bulk terms) in the provision of air freight transport services in terms of whether something is transported by dedicated cargo service or on a passenger service. The related calculation of freight emission factors (discussed in a later section) leads to very similar emission factors for both passenger service freight and dedicated cargo services for domestic and short-haul flights. This is also the case for long-haul flights under freight weighting **Option 2**, whereas under **Option 1** the passenger service factors are substantially higher than those calculated for dedicated cargo services. It therefore seems preferable to treat freight on an equivalent basis by utilising freight weighting **Option 2**.

8.14. **Option 2** is the preferred methodology to allocate emissions between passengers and freight, **Option 1** is included for information only.

8.15. Validation checks using the derived emission factors calculated using the EUROCONTROL small emitters tool and CAA flights data have shown a very close comparison in derived CO_2 emissions with those from the UK GHG Inventory (which is scaled using actual fuel supplied).

8.16. The final average emission factors for aviation are presented in Table 37. The figures in Table 37 DO NOT include the 8% uplift for Great Circle distance NOR the uplift to account for additional impacts of radiative forcing which are applied to the emission factors provided in the 2019 GHG Conversion Factor data tables.

Table 37: Final average CO_2 emission factors for passenger flights for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Mode	Factors for 2019	
	Load Factor%	gCO_2/pkm
Domestic flights	77.7%	123.6
Short-haul flights	83.5%	76.8
Long-haul flights	80.6%	94.9

Notes: Load factors based on data provided by DfT that contains detailed analysis of CAA statistics for the year 2017

Taking Account of Seating Class Factors

8.17. The efficiency of aviation per passenger km is influenced not only by the technical performance of the aircraft fleet, but also by the occupancy/load factor of the flight. Different airlines provide different seating configurations that change the total number of seats available on similar aircraft. Premium priced seating, such as in First and Business class, takes up considerably more room in the aircraft than economy seating and therefore reduces the total number of passengers that can be carried. This in turn raises the average CO_2 emissions per passenger km.

8.18. There is no agreed data/methodology for establishing suitable scaling factors representative of average flights. However, in 2008 a review was carried out of the seating configurations from a selection of 16 major airlines and average seating configuration information from Boeing and Airbus websites. This evaluation was used to form a basis for the seating class based emission factors provided in Table 38, together with additional information obtained either directly from airline websites or from other specialist websites that had already collated such information for most of the major airlines.

8.19. For long-haul flights, the relative space taken up by premium seats can vary by a significant degree between airlines and aircraft types. The variation is at its most extreme for First class seats, which can account for from 3 to over 6 times[21] the space taken up by the basic economy seating. Table 38 shows the seating class-based emission factors, together with the assumptions made in their calculation. An indication is also provided of the typical proportion of the total seats that the different classes represent in short- and long-haul flights. The effect of the scaling is to lower the economy seating emission factor in relation to the average, and increase the business and first class factors.

8.20. The relative share in the number of seats by class for short-haul and long-haul flights was updated/revised in 2015 using data provided by DfT's aviation team,

[21] For the first class sleeper seats/beds frequently used in long-haul flights.

following checks conducted by them on the validity of the current assumptions based on more recent data.

Table 38: CO_2 emission factors by seating class for passenger flights for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Flight type	Cabin Seating Class	Load Factor%	gCO_2 /pkm	Number of economy seats	% of average gCO_2/pkm	% Total seats
Domestic	**Weighted average**	**77.7%**	**123.6**	**1.00**	**100.0%**	**100.0%**
Short-haul	**Weighted average**	**83.5%**	**76.8**	**1.02**	**100.0%**	**100.0%**
	Economy class	83.5%	75.5	1.00	98.4%	96.7%
	First/Business class	83.5%	113.3	1.50	147.5%	3.3%
Long-haul	**Weighted average**	**80.6%**	**94.9**	**1.31**	**100.0%**	**100.0%**
	Economy class	80.6%	72.6	1.00	76.6%	83.0%
	Economy+ class	80.6%	116.2	1.60	122.5%	3.0%
	Business class	80.6%	210.7	2.90	222.1%	11.9%
	First class	80.6%	290.6	4.00	306.3%	2.0%

Notes: Load factors based on data provided by DfT that contains detailed analysis of CAA statistics for the year 2017

Freight Air Transport Direct CO_2 Emission Factors

8.21. Air Freight, including mail, are transported by two types of aircraft – dedicated cargo aircraft which carry freight only, and passenger aircraft which carry both passengers and their luggage, as well as freight.

8.22. Data on freight movements by type of service are available from the Civil Aviation Authority (CAA, 2019). These data show that almost all freight carried by passenger aircraft is done on scheduled long-haul flights and accounts approximately for 82% of all long-haul air freight transport. How this freight carried on long-haul passenger services is treated has a significant effect on the average emission factor for all freight services.

8.23. The next section describes the calculation of emission factors for freight carried by cargo aircraft **only** and then the following sections examine the impact of freight carried by passenger services and the overall average for all air freight services.

Emission Factors for Dedicated Air Cargo Services

8.24. Table 39 presents average emission factors for dedicated air cargo. As with the passenger aircraft methodology the factors presented here do not include the distance or radiative forcing uplifts applied to the emission factors provided in the 2019 GHG Conversion Factor data tables.

Table 39: Revised average CO_2 emission factors for dedicated cargo flights for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Mode	Factors for 2019	
	Load Factor%	$kgCO_2$/tkm
Domestic flights	52.5%	2.5
Short-haul flights	74.3%	1.0
Long-haul flights	73.9%	0.6

Notes: Load factors based on Annual UK Airlines Statistics by Aircraft Type – CAA 2012 (Equivalent datasets after this are unavailable due to changes to CAA's confidentiality rules)

8.25. The updated factors have been calculated in the same basic methodology as for the passenger flights, which was updated in 2015 to use the aircraft specific fuel consumption/emission factors calculated using the EUROCONTROL small emitters tool (EUROCONTROL, 2019). A full summary of the representative aircraft selection and the main assumptions influencing the emission factor calculation are presented in Table 40. The key features of the calculation methodology, data and assumptions for the GHG Conversion Factors include:

a) A wide variety of representative aircraft have been used to calculate emission factors for domestic, short- and long-haul flights;
b) Average freight capacities, load factors and proportions of tonne km by the different airlines/aircraft types have been calculated from CAA (Civil Aviation Authority) statistics for UK registered airlines for the year 2017 (the latest available complete dataset) (CAA, 2019).

Table 40: Assumptions used in the calculation of average CO_2 emission factors for dedicated cargo flights for the 2019 GHG Conversion Factors

	Average Cargo Capacity, tonnes	Av. Load Factor	Proportion of tonne km	EF, $kgCO_2$ /vkm	Av. flight length, km
Domestic Flights					
BAE ATP	8.0	47%	0.0%	0.00	153
BAE 146-200/QT	10.0	34%	0.0%	0.00	153
BOEING 737-300	15.2	45%	32.9%	26.20	156
BOEING 757-200	23.2	56%	64.6%	23.72	149
BOEING 747-8 (FREIGHTER)	126.9	19%	0.0%	0.00	153
BOEING 767-300ER/F	58.0	53%	2.5%	26.63	484
Average	***21.4***	***53%***	***100%***	***24.95***	***379***
Short-haul Flights					
BAE ATP	8.0	43%	0.0%	0.00	734

	Average Cargo Capacity, tonnes	Av. Load Factor	Proportion of tonne km	EF, $kgCO_2$ /vkm	Av. flight length, km
BOEING 737-400	15.0	45%	5.6%	14.63	581
BOEING 757-200	22.0	77%	80.8%	16.12	718
BOEING 747-8 (FREIGHTER)	124.3	33%	0.8%	54.52	630
Average	***23.5***	***74%***	***100%***	***16.44***	***1,432***
Long-haul Flights					
BAE ATP	8.0	16%	0.0%	0.00	3500
BOEING 737-400	21.6	79%	7.1%	15.28	1242
BOEING 757-200	129.4	73%	48.6%	37.75	4731
BOEING 747-8 (FREIGHTER)	29.6	74%	44.3%	19.25	4824
Average	***77.6***	***74%***	***100%***	***21.89***	***4,381***

Notes: Figures on cargo, load factors, % tkm and av. flight length have been calculated from CAA statistics for UK registered airlines for different aircraft in the year 2017. Figures of $kgCO_2$/vkm were calculated using the average flight lengths in the EUROCONTROL small emitters tool (EUROCONTROL, 2019).

Emission Factors for Freight on Passenger Services

8.26. The CAA data provides a similar breakdown for freight on passenger services as it does for cargo services. As already discussed earlier, the statistics give tonne-km data for passengers and for freight. This information has been used in combination with the assumptions for the earlier calculation of passenger emission factors to calculate the respective total emission factor for freight carried on passenger services. These emission factors are presented in Table 41 with the two different allocation options for long-haul services. The factors presented here do not include the distance or radiative forcing uplifts applied to the emission factors provided in the 2019 GHG Conversion Factor data tables (discussed later).

Table 41: Air freight CO_2 emission factors for alternative freight allocation options for passenger flights for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Freight Weighting:	% Total Freight tkm		Option 1: Direct		Option 2: Equivalent	
Mode	Passenger Services (PS)	Cargo Services	PS Freight tkm, % total	Overall $kgCO_2$ /tkm	PS Freight tkm, % total	Overall $kgCO_2$ /tkm
Domestic flights	4.7%	95.3%	0.2%	2.4	0.2%	2.4
Short-haul flights	22.8%	77.2%	2.2%	1.2	2.2%	1.2
Long-haul flights	81.7%	18.3%	65.5%	2.0	14.3%	0.5

8.27. CAA statistics include excess passenger baggage in the 'freight' category, which would under **Option 1** result in a degree of under-allocation to passengers. **Option 2** therefore appears to provide the more reasonable means of allocation.

8.28. **Option 2** was selected as the preferred methodology for freight allocation for the 2008 update, when this analysis was originally performed. The same methodology has been applied in subsequent updates and is included in all of the presented emission factors for 2019.

Average Emission Factors for All Air Freight Services

8.29. Table 42 presents the final average air freight emission factors for all air freight for the 2019 GHG Conversion Factors. The emission factors have been calculated from the individual factors for freight carried on passenger and dedicated freight services, weighted according to their respective proportion of the total air freight tonne km. The factors presented here do not include the distance or radiative forcing uplifts applied to the emission factors provided in the 2019 GHG Conversion Factor data tables (discussed later).

Table 42: Final average CO_2 emission factors for all air freight for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Mode	% Total Air Freight tkm		All Air Freight kgCO_2/tkm
	Passenger Services	Cargo Services	
Domestic flights	4.7%	95.3%	2.4
Short-haul flights	22.8%	77.2%	1.2
Long-haul flights	81.7%	18.3%	0.5

Notes: % Total Air Freight tkm based on CAA statistics for 2017 (T0.1.6 All Services)

Air Transport Direct Emission Factors for CH_4 and N_2O

Emissions of CH_4

8.30. Total emissions of CO_2, CH_4 and N_2O are calculated in detail and reported at an aggregate level for aviation as a whole are reported from the UK GHG inventory. Therefore, the relative proportions of total CO_2 and CH_4 emissions from the UK GHG inventory for 2017 (see Table 43) were used to calculate the specific CH_4 emission factors per passenger km or tonne-km relative to the corresponding CO_2 emission factors. The resulting air transport emission factors for the 2019 GHG Conversion Factors are presented in Table 44 for passengers and Table 45 for freight.

Table 43: Total emissions of CO_2, CH_4 and N_2O for domestic and international aircraft from the UK GHG inventory for 2017

	CO_2		CH_4		N_2O	
	Mt CO_2e	% Total CO_2e	Mt CO_2e	% Total CO_2e	Mt CO_2e	% Total CO_2e
Aircraft - domestic	1.61	98.97%	0.0014	0.09%	0.015	0.94%
Aircraft - international	34.45	99.06%	0.0025	0.01%	0.326	0.94%

Emissions of N_2O

8.31. Similar to those for CH_4, emission factors for N_2O per passenger-km or tonne-km were calculated on the basis of the relative proportions of total CO_2 and N_2O emissions from the UK GHG inventory for 2017 (see Table 43), and the corresponding CO_2 emission factors. The resulting air transport emission factors for the 2019 GHG Conversion Factors are presented in Table 44 for passengers and Table 45 for freight. The factors presented here do not include the distance or radiative forcing uplifts applied to the emission factors provided in the 2019 GHG Conversion Factor data tables (discussed later).

Table 44: Final average CO_2, CH_4 and N_2O emission factors for all air passenger transport for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Air Passenger Mode	Seating Class	CO_2 gCO_2/pkm	CH_4 gCO_2e/pkm	N_2O gCO_2e/pkm	Total GHG gCO_2e/pkm
Domestic flights	**Average**	**123.6**	**0.1**	**1.2**	**124.8**
Short-haul flights	**Average**	**76.8**	**0.0**	**0.7**	**77.5**
	Economy	75.5	0.0	0.7	76.2
	First/Business	113.3	0.0	1.1	114.4
Long-haul flights	**Average**	**94.9**	**0.0**	**0.9**	**95.8**
	Economy	72.6	0.0	0.7	73.3
	Economy+	116.2	0.0	1.1	117.3
	Business	210.7	0.0	2.0	212.7
	First	290.6	0.0	2.7	293.3
International flights (non-UK)	**Average**	**87.7**	**0.0**	**0.8**	**88.5**
	Economy	67.1	0.0	0.6	67.8
	Economy+	107.4	0.0	1.0	108.4
	Business	194.7	0.0	1.8	196.5
	First	268.5	0.0	2.5	271.1

Notes: Totals may vary from the sums of the components due to rounding in the more detailed dataset.

Table 45: Final average CO_2, CH_4 and N_2O emission factors for air freight transport for 2019 GHG Conversion Factors (excluding distance and RF uplifts)

Air Freight Mode	CO_2 $kgCO_2/tkm$	CH_4 $kgCO_2e/tkm$	N_2O $kgCO_2e/tkm$	Total GHG $kgCO_2e/tkm$
Passenger Freight				
Domestic flights	1.83	0.0016	0.0173	1.85
Short-haul flights	1.61	0.0001	0.0152	1.63
Long-haul flights	0.53	0.0000	0.0050	0.53
Dedicated Cargo				
Domestic flights	2.45	0.0022	0.0232	2.48
Short-haul flights	1.02	0.0001	0.0096	1.03
Long-haul flights	0.65	0.0000	0.0061	0.65
All Air Freight				
Domestic flights	2.42	0.0022	0.0229	2.45
Short-haul flights	1.15	0.0001	0.0109	1.16
Long-haul flights	0.55	0.0000	0.0052	0.55

Notes: Totals may vary from the sums of the components due to rounding in the more detailed dataset.

Indirect/WTT Emission Factors from Air Transport

8.32. Indirect/WTT emissions factors for air passenger and air freight services include only emissions resulting from the fuel lifecycle (i.e. production and distribution of the relevant transport fuel). These indirect/WTT emission factors were derived using simple ratios of the direct CO_2 emission factors and the indirect/WTT emission factors for aviation turbine fuel (kerosene) and the corresponding direct CO_2 emission factors for air passenger and air freight transport in sections “Business travel – air” and “Freighting goods”.

Other Factors for the Calculation of GHG Emissions

Great Circle Flight Distances

8.33. We wish to see standardisation in the way that emissions from flights are calculated in terms of the distance travelled and any uplift factors applied to account for circling and delay. However, we acknowledge that a number of methods are currently used.

8.34. An 8% uplift factor is used in the UK Greenhouse Gas Inventory to scale up Great Circle distances (GCD) for flights between airports to take into account indirect flight paths and delays, etc. This is lower than the 9-10% suggested by IPCC Aviation and the global atmosphere, and has been agreed with DfT based on recent analysis as more appropriate for flights arriving and departing from the UK. This factor has been used since the 2014 update of both the GHGI, and the GHG Conversion Factors.

8.35. It is not practical to provide a database of origin and destination airports to calculate flight distances in the GHG Conversion Factors. However, the principal of adding a factor of 8% to distances calculated on a Great Circle is recommended (for consistency with the existing approach) to take account of indirect flight paths and delays/congestion/circling. This is the methodology recommended to be used with the GHG Conversion Factors and is applied already to the emission factors presented in the 2019 GHG Conversion Factors tables.

Non-CO_2 impacts and Radiative Forcing

8.36. The emission factors provided in the 2019 GHG Conversion Factors sections “Business travel – air” and “Freighting goods” refer to aviation's direct CO_2, CH_4 and N_2O emissions only. There is currently uncertainty over the other non-CO_2 climate change effects of aviation (including water vapour, contrails, NO_X, etc.) which have been indicatively accounted for by applying a multiplier in some cases.

8.37. Currently there is no suitable climate metric to express the relationship between emissions and climate warming effects from aviation, but this is an active area of research. Nonetheless, it is clear that aviation imposes other effects on the climate which are greater than that implied from simply considering its CO_2 emissions alone.

8.38. The application of a ‘multiplier’ to take account of non-CO_2 effects is a possible way of illustratively taking account of the full climate impact of aviation. A multiplier is not a straight forward instrument. In particular, it implies that other emissions and effects are directly linked to production of CO_2, which is not the case. Nor does it reflect accurately the different relative contribution of emissions to climate change over time, or reflect the potential trade-offs between the warming and cooling effects of different emissions.

On the other hand, consideration of the non-CO_2 climate change effects of aviation can be important in some cases, and there is currently no better way of taking these effects into account. A multiplier of 1.9 is recommended as a central estimate, based on the best available scientific evidence, as summarised in

8.39. Table 46 and the GWP_{100} figure (consistent with UNFCCC reporting convention) from the ATTICA research presented in Table 47 below (Sausen , et al., 2005) and in analysis by Lee et al (2009) reported on by (CCC, 2009).

> *From CCC (2009): “The recent European Assessment of Transport Impacts on Climate Change and Ozone Depletion (ATTICA, http://ssa-attica.eu) was a series of integrated studies investigating atmospheric effects and applicable climate metrics for aviation, shipping and land traffic. Results have been published which provide metrics to compare the different effects across these sectors in an objective way, including estimates of Global Warming Potentials (GWPs) and Global Temperature Potentials (GTPs) over different time horizons (20, 50 and 100 years). Table 47 shows the 20-year and 100-year GWPs, plus 100-year GTPs, for each forcing agent from aviation. Based on estimates of fuel usage and emission indices for 2005, the emission equivalent of each agent for these metrics is given on the right, and on the bottom right is the overall ratio of total CO_2-equivalent emissions to CO_2 emissions for aviation in 2005.”*

8.40. It is important to note that **the value of this 1.9 multiplier is subject to significant uncertainty** and should only be applied to the CO_2 component of direct emissions (i.e. not also to the CH_4 and N_2O emissions components). The 2019 GHG Conversion Factors provide separate emission factors including this radiative forcing uplift in separate tables in sections “Business travel – air” and “Freighting goods”.

Table 46: Impacts of radiative forcing according to (Sausen, et al., 2005)

		RF [mW/m^2]							
Year	**Study**	**CO_2**	**O_3**	**CH_4**	**H_2O**	**Direct Sulphate**	**Direct Soot**	**Contrails**	**Total (w/o) Cirrus**
1992	IPCC (1999)	18.0	23.0	-14.0	1.5	-3.0	3.0	20.0	48.5
2000	IPCC (1999) scaled to 2000	25.0	28.9	-18.5	2.0	-4.0	4.0	33.9	71.3
2000	TRADEOFF	25.3	21.9	-10.4	2.0	-3.5	2.5	10.0	47.8

Notes: Estimates for scaling CO_2 emissions to account for Radiative Forcing impacts are not quoted directly in the table, but are derived as follows: IPCC (1999) = 48.5/18.0 = 2.69 ≈ 2.7; TRADEOFF = 47.8/25.3 = 1.89 ≈ 1.9

Table 47: Findings of ATTICA project

	Metric values			**CO_2e emissions ($MtCO_2$e/yr.) for 2005**			**LOSU**
	GWP_{20}	**GWP_{100}**	**GTP_{100}**	**GWP_{20}**	**GWP_{100}**	**GTP_{100}**	
CO_2	1	1	1	641	641	641	High
Low NO_x	120	-2.1	-9.5	106	-1.9	-8.4	Very low
High NO_x	470	71	7.6	415	63	6.7	Very low
Water vapour	0.49	0.14	0.02	123	35	5.0	–
Sulphate	-140	-40	-5.7	-25	-7	-1.0	–
Black carbon	1600	460	64	10	2.8	0.38	–
Contrail	0.74	0.21	0.03	474	135	19	Low
AIC	2.2	0.63	0.089	1410	404	57	Very low
				CO_2e/CO_2 emissions for 2005			
Low NO_x, inc. AIC				4.3	1.9	1.1	Very low
High NO_x, inc. AIC				4.8	2.0	1.1	Very low
Low NO_x, exc. AIC				2.1	1.3	1.0	Very low
High NO_x, exc. AIC				2.6	1.4	1.0	Very low

Source: Adapted by (CCC, 2009) from Lee et al. (2009) Transport impacts on atmosphere and climate; Aviation, Atmospheric Environment. The level of scientific understanding (LOSU) is given for each process in the right column. Values are presented for both high and low GWP values for NO_x reflecting the wide uncertainties in current estimates. The ratios on the bottom right are presented both including and excluding aviation induced cloudiness (AIC) because of uncertainties both in estimates of the magnitude of this effect and in the future incidence of AIC due to air traffic. The different time horizons illustrate how a unit emission of CO_2 increases in importance relative to shorter-lived effects as longer timescales are considered.

Government Office for Science

Foresight

The history of transport systems in the UK

Future of Mobility: Evidence Review

Foresight, Government Office for Science

The history of transport systems in the UK

Professor Simon Gunn

Centre for Urban History, University of Leicester

December 2018

Acknowledgements

I would like to thank Dr Aaron Andrews for his help with the research for this review, especially for creating the graphs, and Georgina Lockton for editing. The review has benefited from the input of an Advisory Group consisting of Professor Colin Divall (University of York); Professor Gordon Pirie (University of Cape Town); Professor Colin Pooley (Lancaster University); Professor Geoff Vigar (University of Newcastle). I thank them all for taking time to read the review at short notice and enabling me to draw on their specialist expertise. Any errors remaining are, of course, mine.

This report has an information cut-off date of February 2018.

Executive summary

The purpose of this review is to summarise the major changes affecting transport systems in the UK over the last 100 years. It is designed to enable the Foresight team to bring relevant historical knowledge to bear on the future of transport and mobility.

The review analyses four aspects of transport and mobility across the twentieth century. The first section identifies significant points of change in the main transport modes. The second section addresses the principal factors accounting for these changes. The third section examines the consequences for the economy, social inequality and the environment. Finally, the conclusion draws out a number of overarching issues relating to the future of transport and mobility.

What were the significant moments of change during the twentieth century?

There was no common pattern of historical experience among the various modes of transport during the twentieth century. The winners were automobility and air travel, both of which experienced growth rates that outstripped contemporary predictions. Almost all other transport modes suffered from competition with them. These included walking, which underwent continuous decline; passenger shipping, the main means of international transport before the 1950s; rail freight, under pressure from road haulage from the 1920s; and buses and trams which, like other forms of public transport, lost out to the private car. Some declining modes saw recovery in the late twentieth century, notably sea freight and passenger rail.

Significant periods of change include the years after the world wars, when much passenger travel and freight transport was reorganised. The 1960s, years of experiment in transport as in much else, saw containerisation and rapid expansion of air travel, car ownership and motorway construction; with the last decades of the twentieth century experiencing privatisation of important parts of the air and rail systems, and the state promotion of major infrastructure projects.

What were the main drivers of change?

Analysing why change occurred is tricky because of the intersecting pressures which have affected transport modes differently. Broadly, four ‘drivers’ served to shape UK transport systems during the twentieth century.

The most powerful was consumer demand, predicated on a rising standard of living for much of the century. It prompted the spread of the bicycle between the wars, the expansion of car ownership under conditions of ‘affluence’ from the late 1950s, and the growth of package holidays abroad from the 1960s, fuelled by cheap flights.

Two further drivers were war and technological innovation. Wartime, when the state took control of transport along with other national resources, was the precursor to post-war intervention in the name of greater efficiency. The two world wars boosted Britain's pioneering role in aviation and motor manufacturing, which transferred into peacetime gains. Technological innovation in these sectors was significant, especially in manufacturing, with the Mini and Concorde products of the expansionist 1960s. However, innovation in technology was not matched in infrastructure, where much of the stock remained antiquated. Only from the 1990s was large-scale investment in transport infrastructure other than roads undertaken, based on public-private partnership.

Government policy was a further, although less dynamic driver of change, setting the framework for transport, through regulation, ownership and subsequent privatisation. Through taxation it funded the motorways programme from the late 1950s and promoted transport research in areas such as road safety and civil aviation. But with some exceptions, government was reactive rather than proactive in relation to transport. Historically, Britain has not been a *dirigiste* state on French or German lines, although initiatives such as the Channel Tunnel and HS2 may be changing this pattern.

What were the consequences of changes in transport?

There have been consequences in three main areas. Transport changes had a significant effect, firstly, on the economic fortunes of regions and industries. Transport has consistently employed over a million workers with more in allied industries. It has had long-term consequences for regional economic growth and decline as the divergent fortunes of ports like Southampton and Liverpool indicate.

Secondly, mobility has been an important contributor to the growth of individual choice, especially for women. The car has been seen as a contributor to women's emancipation. At the same time, inequalities have been mirrored in and reinforced by lack of mobility, measured by the proportion of households in 'transport poverty', cut off from employment and services. Among those most affected have been the young, older people and people living in rural areas.

Thirdly the changes in transport have had a series of unintended consequences. These include traffic accidents and congestion, but the most fundamental have been the consequences for the environment from air pollution and climate change, emerging in the last third of the twentieth century. Automobility and roads were the main source of negative externalities, associated also with 'sprawl' and 'blight'.

Overarching trends and issues for consideration

From the historical analysis five issues were identified as relevant to the future of transport in the UK.

- Interactivity: while transport analysis and policy is often directed towards single modes (e.g. road, rail), it is clear that developments in some modes have been closely connected with those in others. Most journeys in the past were multi-modal.

- Mobility revolution: evidence points to a transformation in personal mobility in the later twentieth century, driven by consumer demand. Transformation has occurred in scale and scope in automobility, air travel and, more recently, rail travel.

- Overload: one of the results of the surge in the circulation of people and goods has been overloaded transport systems: congested roads, crowded trains and airports. UK transport can be read as a success story but old, under-funded infrastructure has consistently hampered expansion.

- Sustainability: since the oil crisis of 1973 the sustainability of transport has been a major issue, encompassing renewable resources, carbon emissions and pollution. Government has worked towards greater sustainability but it remains a major challenge.

- Alternatives: transport systems have been relatively stable over the last century, qualifying the idea of an imminent breakthrough to a new phase of transport. Most current options such as the electric car, road pricing and CAVs have existed for many decades. History suggests that change is as much a matter of recycling the old as introducing the new. The past thus remains an important resource for transport alternatives in the future.

Contents

1. Introduction

The purpose of this review is to bring a **historical perspective** to the project on the future of mobility in the UK. It aims to illuminate the project in a number of ways:

- Identifying long-term **trends** and patterns in UK transport;
- **'Learning from the past'**: understanding why developments succeeded or failed;
- Recognising **path dependence** and the limits to as well as the opportunities for change;
- The past as a repository: borrowing **examples** which might have benefits in the future.

This review is not therefore a narrative history but an attempt to bring historical knowledge to bear on future directions in UK transport policy. It is concerned with **transport systems** in the conventional sense (railways, roads, air, etc.) but also with **mobility**, forms of movement such as walking and cycling often omitted from transport history and policy.

The review concentrates on the century between the **end of the First World War** and the **present day** as the period most relevant to understanding future challenges. It is divided into four sections. The first section describes the most important points of change in the main modes of transport over the last 100 years. The second and third sections examine the principal causes and consequences of those changes. The concluding section identifies overarching trends and issues arising from the history of transport and mobility.

Aviation

Aside from automobility, civil aviation is the transport mode which has seen the most dramatic changes in the course of the twentieth century. The story of early flight is well known, but the development of British aviation began with the setting up of the **Advisory Committee on Aeronautics** in 1909 to instruct the government. **War** was to remain a significant catalyst for the development of aviation for much of the century. Firms involved in planes for war production, such as Armstrong–Whitworth and Bristol, subsequently moved into peacetime aeronautics (Edgerton, 1991).

Empire was also a major driver in the development of civil aviation between the wars: the first major airline was **Imperial Airways**, established in 1924 with government subsidies, and serving destinations in the empire such as Cape Town and Calcutta as well as European routes (Pirie, 2012). Both civil aviation and the requirements of the RAF drove **aircraft production**; by 1940 Britain was the largest producer in the world (Smith, 1984). But the infrastructure of civil aviation was, in other respects, relatively undeveloped. Imperial Airways operated from Croydon Aerodrome; in other cities, such as Manchester, **airports** were constructed under municipal ownership in the 1930s. Costs of air travel remained high between the wars and the numbers of people flying annually were counted in the thousands, not millions (Lyth, 2000).

The advent of **passenger jets** from the 1950s transformed air travel. Between 1950 and 1960 the number of air passengers carried in the UK increased from just over one million to six million. At the same period the major London **airports** were developed, Heathrow (1946) and Gatwick (1958) while Manchester and Glasgow (Prestwick) were expanded for increased passenger traffic in 1958 and 1964 respectively.

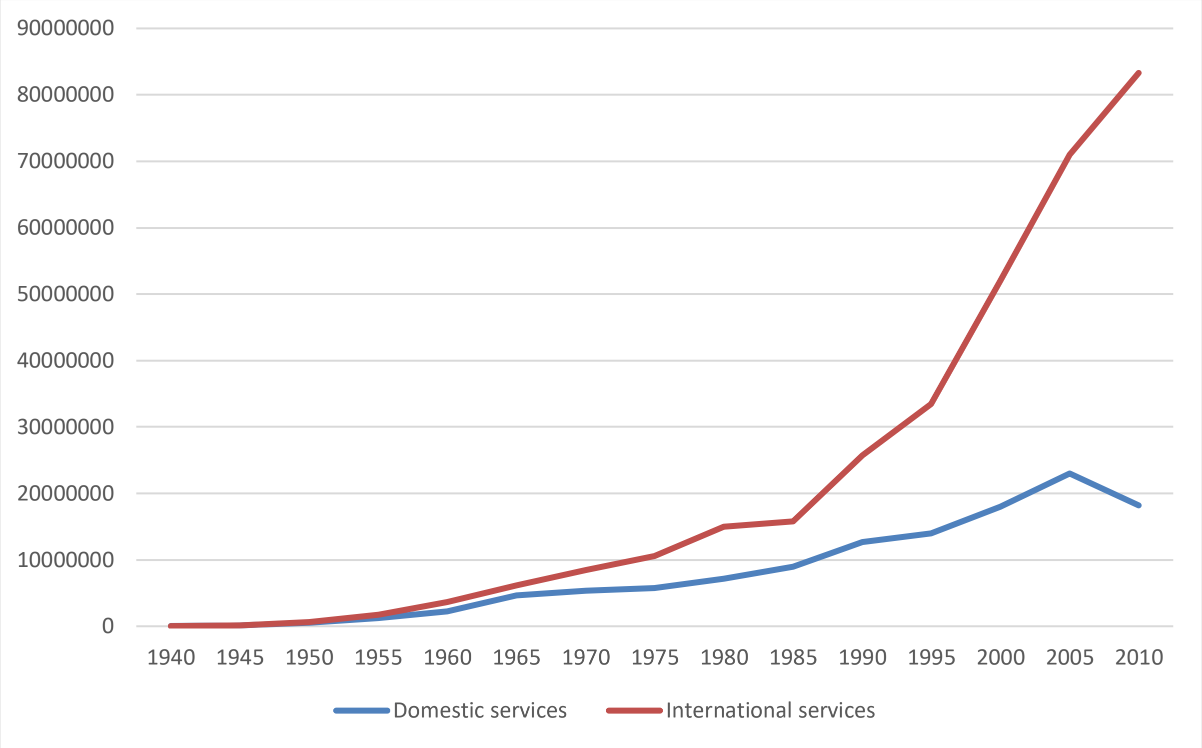

Figure 9. Passengers on UK airlines, 1940-2010
Source: Based on Mitchell, 1988; Annual Abstract of Statistics

While aircraft manufacture remained in private hands, the leading British airlines and airports did not. Imperial Airways had been merged and **nationalised** in 1939 to form the British Overseas Airways Corporation (**BOAC**), which in turn was divided with the creation of British European Airways (**BEA**) in 1946. BOAC and BEA were amalgamated to form **British Airways** in 1974. The major international airports – Heathrow, Gatwick, Stansted and Prestwick – were taken under the control of the **British Airports Authority** in 1966. The process of nationalisation was reversed in the 1980s. In the face of mounting debts British Airways was privatised in 1986 and the British Airports Authority followed suit. The **deregulation** of airlines in the UK and European Union from the early 1990s also encouraged the spread of **low-cost airlines**, including Easyjet and Ryanair, which helped feed the ever-rising demand for international air travel.

Like automobility, aviation caused **controversy** in the later twentieth century. The siting of the third London airport resulted in a fierce and protracted debate among planners, politicians and public, starting with the **Roskill Commission** in 1968. Roskill selected **Cublington** in Buckinghamshire but serious consideration was also given in 1973 to the development of **Maplin** in the Thames estuary. Faced with considerable local protest at both sites, the government decided to expand the existing airport at **Stansted** (Beckett, 2009). Like cars, aircraft have also been seen as a major source of carbon emissions, and thus a contributor to **climate change**. The current debate over the building of the new runway at Heathrow is a product of a long debate over amenity and environment (Lyth, 2016).

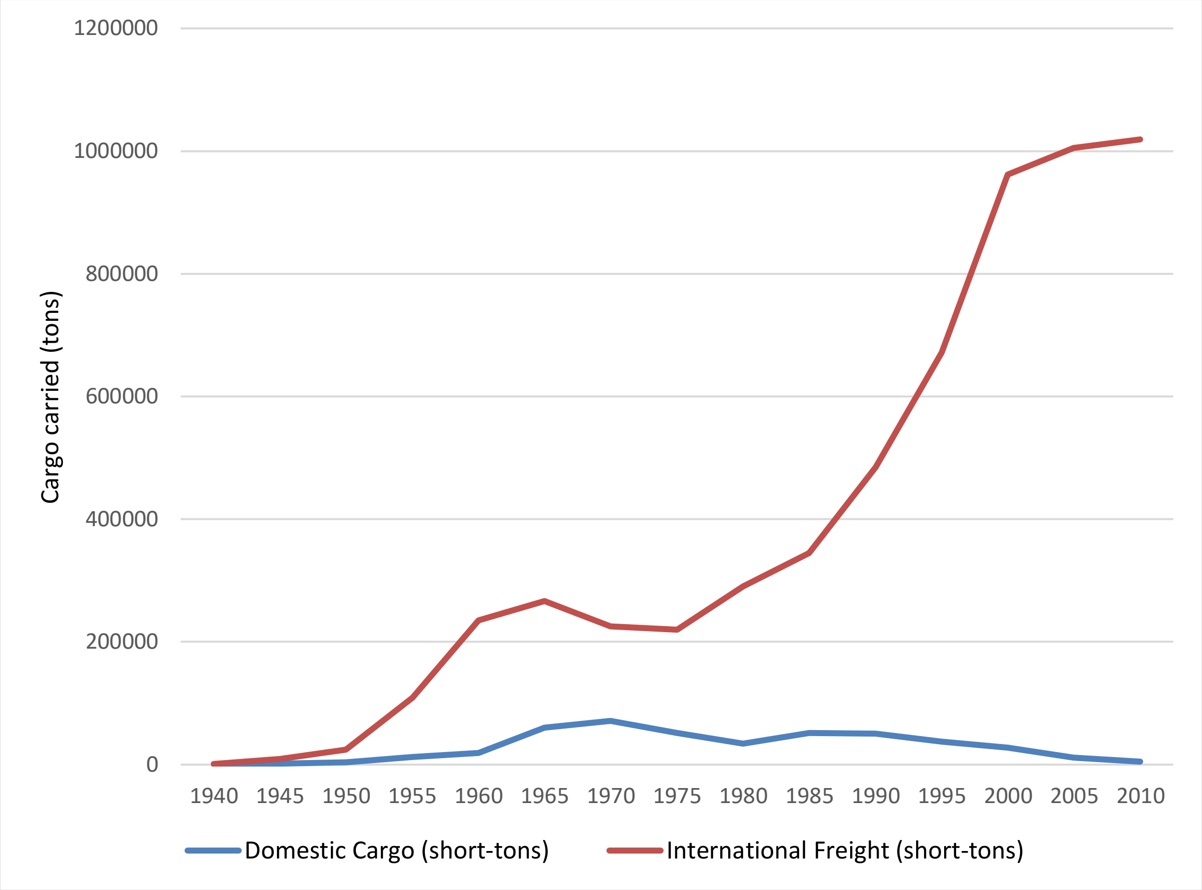

Figure 10. Cargo carried by UK airlines, 1940-2010
Source: Based on Mitchell, 1988; Annual Abstract of Statistics

All this reflects the fact that in the last third of the twentieth century, civil aviation saw an **unprecedented expansion**. Between 1970 and 2000 the number of UK flights more than doubled; the volume of international passengers carried from UK airports increased from 5 to 14 million; and the distance flown in passenger miles rose seven-fold. International **air cargo** increased three times in volume over the same period; but the continued dominance of road haulage meant that cargo was less important for aviation than the growth of passenger traffic. But whether judged in terms of aerospace manufacturing, passenger traffic or airport hubs, the UK remains a **major international player in aviation** as it has done since the 1930s.

TRANSPORTATION RESEARCH

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Aviation Demand Forecasting

A Survey of Methodologies

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

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A Survey of Methodologies

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Foreword

This Circular was prepared during the first half of 2002 by members of TRB's Committee on Aviation Economics and Forecasting (A1J02) and Committee on Light Commercial and General Aviation (A1J03) with substantial assistance from friends and associates who are not formal committee members. The objective of this Circular is to provide examples of the diversity of techniques used to forecast the many measures used in aviation system and market analyses.

By intent, almost all examples provided herein illustrate methodologies or approaches to forecasting used by private sector manufacturers and consultants. Forecast methodologies employed by the FAA and the International Civil Aviation Organization are documented in existing publicly available technical reports and manuals. Some manufacturers, most notably Boeing and Airbus, also provide documentation of their forecasts to the public. But while these forecasts and their related documentation are all helpful to aviation analysts, they comprise only a small fraction of the various forecast methodologies in current use.

The examples provided in this Circular illustrate approaches to aviation forecasting that receive less public attention. Yet these approaches provide equally valid insights into how to think about aviation activity measurement and future outlooks.

Most of these forecasts are quantitative, but not all are econometric. Some require extensive computer modeling; others require minimal computer capability. Some are descriptions of commercially available products, while the complete details of others are corporate confidential. The descriptions are provided using a common format to facilitate comparison, but the content varies with the individual and firm that prepared the description.

Preparation of this Circular was assisted by several persons. Mr. Saleh Mumayiz (Illgen/BAe Systems) was helpful in conceptualizing the kinds of approaches and issues to seek; Ms. Peg Young (Bureau of Transportation Statistics) assisted in converting papers into a reader-friendly style and format. The Board of the Air Transportation Research Forum helped disseminate the request for descriptions to its members.

My thanks to these persons and to those who submitted descriptions for supporting this effort to broaden public awareness of the diversity of approaches to air transportation forecasting.

Gerald W. Bernstein
Managing Director
Stanford Transportation Group
Chairman, Committee on Aviation Economics and Forecasting (A1J02)

Contents

Forecasts for a Multi-Airport Region

The three approaches to forecasting described in the following examples could all be applied to developing forecasts at a single airport. However, as these examples provide further insight into the travelers' choice of airport when alternatives are available, the methodologies are separately described.

In keeping with this distinction, the three approaches described require more detailed information on a variety of influences than do the forecasts previously described. The methodologies in this section typically require greater specification of such measures as:

- Local population and employment distributions based on some geographic (zone) distribution,
- Social and economic characteristics by analysis zone,
- Travel time from population and employment zones to the airport(s),
- Other travel-related costs such as parking and tolls, and
- Airline service measures for each airport, including frequency, aircraft type, and fares by market.

These models not only forecast total demand in a region, but allocate this demand to its point of origin and to individual airports within the analysis region.

One major distinction between these three approaches is the amount of background effort and time needed to construct the models. Those used by the Port Authority of New York and New Jersey (PANYNJ) and the Southern California Association of Governments (SCAG) require extensive survey and computer resources to calibrate and to exercise. Community air-service analysis (CASA) can be applied to smaller regions and permits a more simplified data collection and analysis procedure.

PORT AUTHORITY OF NEW YORK AND NEW JERSEY

Jojo Quayson and **Charlie Saunders**
Port Authority of New York & New Jersey

Purpose

PANYNJ currently operates four airports in the New York/New Jersey Region: Kennedy International and LaGuardia in New York, and Newark International and Teterboro (TEB) in New Jersey. TEB is a GA airport with no scheduled service. The PANYNJ air passenger forecast provides 10-year passenger estimates by market (domestic and international) and terminal building for the three airports with scheduled service. The forecast is further segmented into monthly estimates of activity for the first 2 years of the forecast. These forecasts are used for internal budgeting, financial projections, airport planning, and as input for other forecasts of airport activity.

Methodology and Approach

PANYNJ's passenger forecast model utilizes a top-down process that estimates passengers by market for the region. Forecasts of airport and terminal activity are derived from these aggregates using a combination of historical factor shares, airport and terminal specific developments, and airline schedules. These numbers are further combined with X-11 factors to produce monthly estimates. The X-11 factors are produced using the Census II method, a seasonal decomposition process developed by the U.S. Census Bureau. This technique can decompose a time series into trend, seasonal, and irregular components.

The forecast process involves three interactive phases including data collection, model estimation, and the disaggregation process. Phase 1 consists of data collection. Data comes from a multitude of sources including internal sources, Immigration and Naturalization Service (INS), Official Airline Guide (OAG), the FAA/USDOT, and DRI-WEFA.

Phase II is the model specification and estimation stage. Two, sometimes three, types of models are used and the results reconciled. Phase II utilizes time series techniques, in the form of single equation exponential smoothing models. Estimates of passenger activity are made separately for domestic and international markets.

The structure of the exponential model is as follows:

$$Pax_{t+1} = \beta Pax_t + (1-\beta)\, PPax_t$$

Where

Pax_{t+1} = Forecast of next year's passengers
Pax_t = Actual value for current passengers
β = Smoothing constant
$PPax_t$ = Forecast value of current period's passengers

This model progressively weighs values from the most to the least recent. Data from the current period is weighed by β. Data for t–1 is weighed by $\beta(1-\beta)$ and data for t–2 is weighed by $\beta(1-\beta)^2$. Before estimation an extrapolation technique is employed to smooth aberrations like the Persian Gulf War of 1993. Though exponential models are ideally suited for short-term forecasting, this model is used to provide a first approximation of passenger growth. At this stage we remember Professor C. L. Jain of St. John's University, New York, who advised "Forecasting with a time series model is like driving a car with the windshield glass completely blackened out, and the driver drives it looking out the rearview window. If you happen to be driving on a highway full of curves, this is a prescription for disaster." Time series models are quick and easy but for the above reason we use them only as guide to set the stage for a more in-depth modeling effort.

The forecast process proceeds with an econometric model. This is also a regional model. Passenger levels are dependent on real GDP and real yields. Dummy variables are used to allow for special events. This model is specified as follows:

$$\text{Log } Pax_t = \phi_0 + \phi_1 \text{Log RealGDP}(_{-1}) - \phi_2 \text{Log RealYield} + D_{1973} + E_t$$

Where

Pax_{t+1} = Next year's passenger levels
D_{1973} = Dummy variable, 1993 = 1 (Persian Gulf War), 0 otherwise,
ϕ_1 = Income elasticity,
ϕ_2 = Price elasticity, and
E_t = Error term

Estimates are again separately made for domestic and international passengers. The international modeling process is divided into residential and non-residential models, each with its own exogenous drivers. As always, variations of the above specifications are estimated before settling on final specifications. The final choice is based on several factors including diagnostics (MAPE, DW, R^2), coefficient signs and magnitude, and actual ex-post testing. The results of the two efforts are reconciled and estimates are made for regional levels of domestic and international passengers.

On occasion we approach the forecast from a third perspective and directly specify national passenger models using GDP and yields. The results of this model are then used against share models to produce forecasts for the region. These share models postulate that the region's share of traffic is dependent upon the region's share of income and the relationship between regional yields and national yields. When these three approaches are used all the results are reconciled before final decisions are made on forecast levels.

Phase III involves the disaggregation of the systemwide domestic and international passenger forecasts into airport specific forecasts. The guiding variables used to calibrate share-down factors are airport specific development, terminal expansion plans, new entrant plans and prospects, carrier plans, and advanced schedules. Terminal-specific and carrier-specific information at each airport is used to divide the airport forecast into terminal forecasts. Census X-11 factors are derived and used to disaggregate the annual forecast into monthly forecasts.

Observations and Comments

The PANYNJ models have performed reasonably well over the years as we constantly strive to challenge underlying assumptions, evaluate forecast performance, and adapt to new techniques. We always kept the following in mind when forecasting with models.

- The forecast must be updated periodically as new data becomes available.
- Choose simplicity over complexity. Sophisticated and complex models do not necessarily translate into results that are more accurate.
- Forecasting is a process; always crosscheck results with different approaches including judgmental ones.
- Changing market dynamics may cause models that work well historically to loose relevance.
- No matter how the forecast was derived, there should always be a coherent common sense story that motivates the forecast.

SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS

Michael Armstrong
Southern California Association of Governments

Purpose

The Regional Airport Demand Allocation Model (RADAM) is a state-of-the-art multinomial logit (MNL) model that generates and allocates current and forecast air passenger and cargo demand to airports. It was originally developed by the consultant firm Advanced Transportation Systems for the SCAG's 1994 Southern California Military Air Base Study in order to estimate the potential of closed or downsized military air bases in the region to attract air passenger demand as commercial airports. It was designed to significantly improve upon the level of accuracy that is obtainable in assessing the allocation of passenger demand between competing airports in complex multi-airport systems using more conventional gravity or MNL models. SCAG aviation staff's disappointing experience with simple gravity models in previous system studies led to the conclusion that a new and innovative analytical tool such as RADAM was needed to accurately assess the impacts of major capacity expansion proposals on the multifaceted Los Angeles regional aviation system. A more sophisticated methodology was needed that was capable of testing a range of airport system scenarios that are differentiated by a wide variety of discreet variables.

Methodology and Approach

The RADAM model is a bottoms-up model, generating air passenger and cargo demand by a geographically based zonal system (i.e., RADAM zones) that are compilations of SCAG transportation analysis zones. Socioeconomic data by RADAM zone is used in combination with airport choice criteria to generate passenger forecasts and allocations in terms of baseline, catalytic, and total air passenger demand for airports in actual or theoretical airport systems.

Demand generation is the first step in the RADAM methodology. Current and forecast air passenger demand is forecast for 100 RADAM aviation zones in the region, as well as additional zones in Santa Barbara and San Diego counties. For current demand, available airport O-D data is used. For forecast demand, the correlated data are applied to SCAG's forecast socioeconomic data for each RADAM zone. A variety of socioeconomic factors are used in the correlation process, including total population, total employment, retail employment, high-tech employment, median household income, disposable income, household size, number of households, and licensed drivers per household.

The demand generation process also includes the calculation of "catalytic" (or "induced") demand. This represents the increased propensity to fly (over baseline conditions) due to the more convenient provision of airport services, such as when a nearby military air base is converted to commercial use, or when an airport adds more frequent and/or less expensive flights. Because of the addition of this type of demand to baseline demand, the regional demand total is a variable that depends on the amount and distribution of airport capacity and quality of service around the region, and is not a fixed and independent parameter.

SCAG's surveys identified a number of variables which most influence the airport choices of air passengers. These variables were calibrated for different categories of air passengers using a sophisticated curve fit program. The categories of passengers (not mutually exclusive) include short-, medium-, and long-haul passengers, international passengers (with subsets of Pacific Rim, Europe, Latin America, and Canada/Mexico passengers), and business, pleasure, and exclusive tour passengers. The primary airport choice variables that are calibrated by the RADAM model for the various passenger groups noted include (as example) total number of flights, frequency of flights, nonstop destinations served, number of discount airlines, travel time from home and work, travel time from hotel/convention center, ground access congestion, air fare, terminal congestion and convenience, parking costs, and convenience and airport mode choice options. Most of these primary choice variables are comprised of smaller support modules with additional subvariables. In addition, a part of the RADAM calibration or weighting process is to determine the cross-elasticities between the variables. In short, this means replicating how the different passenger groups make implicit tradeoffs between the choice criteria in deciding which airport to choose.

The next step is that of demand allocation. Demand allocation is based on a process of matching major airport attributes (available flights, air fares, ground travel time, etc.) with the

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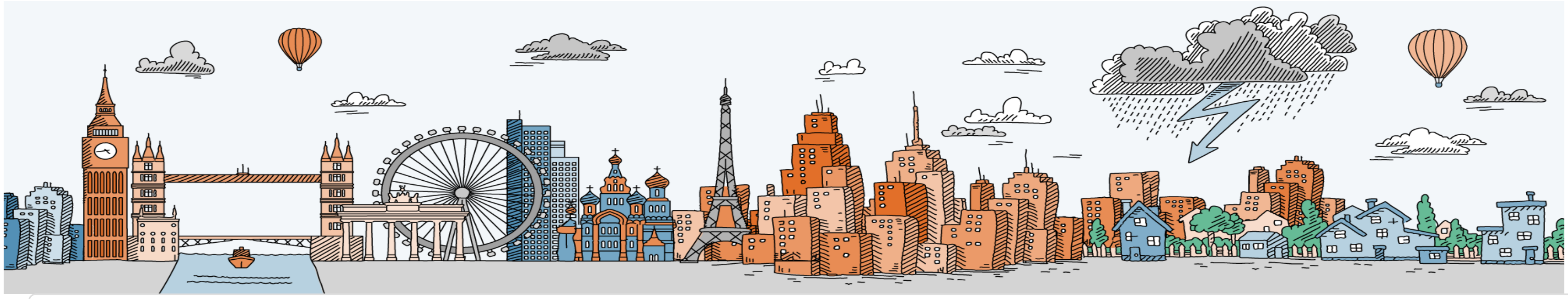

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The Tyndall Carbon Budget Tool

Setting Climate Committments

The Tyndall Carbon Budget Tool presents climate change targets for UK local authority areas that are based on the commitments in the United Nations Paris Agreement, informed by the latest science on climate change and defined by science based carbon budget setting.

To view the recommendations for a region or an individual local authority, use the buttons and links above. The initial view of the report is a short-form version with some interactive elements designed for viewing on our website. To print a copy, follow the link in the short-form report then print the page from your browser's menu (you can usually press *ctrl+p* as a shortcut for this. Most modern browsers provide an option to 'Save as PDF', or you can print a physical copy as normal.

We have also provided a means to create **Aggregate Budgets** for Combined Authorities, Unitary Authorities, County Councils and other combinations of local authorities. If the Aggregate Budget you are interested in is not available in the list above you can create a custom Aggregate Budget with our tool.

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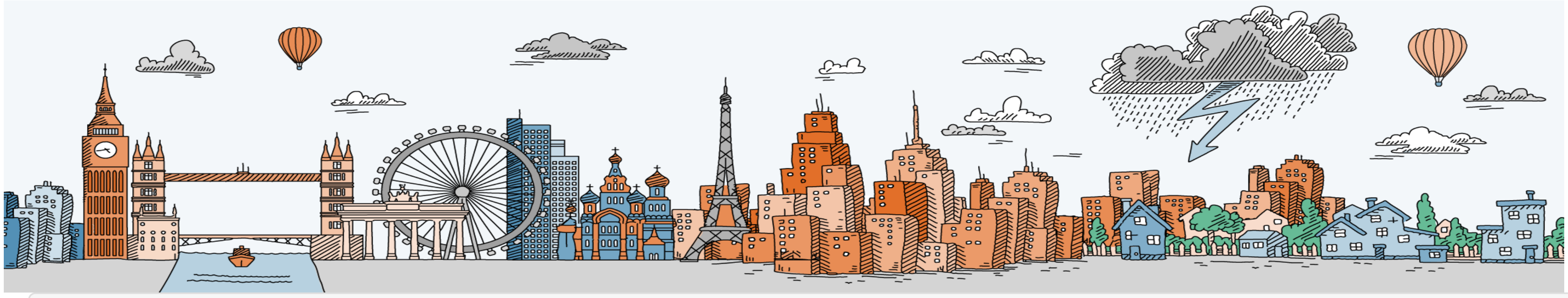

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Setting Climate Committments for North Somerset

Quantifying the implications of the United Nations Paris Agreement for North Somerset

Date:	June 2021
Prepared By:	Dr Jaise Kuriakose, Dr Chris Jones, Prof Kevin Anderson, Dr John Broderick & Prof Carly McLachlan

NB: All views contained in this report are solely attributable to the authors and do not necessarily reflect those of the researchers within the wider Tyndall Centre.

Key Messages

This report presents climate change targets for North Somerset[i] that are derived from the commitments enshrined in the Paris Agreement , informed by the latest science on climate change and defined in terms of science based carbon setting . The report provides North Somerset with budgets for carbon dioxide (CO_2) emissions and from the energy system for 2020 to 2100.

The carbon budgets in this report are based on translating the “well below 2°C and pursuing 1.5°C” global temperature target and equity principles in the United Nations Paris Agreement to a national UK carbon budget [ii]. The UK budget is then split between sub-national areas using different allocation regimes . Aviation and shipping emissions remain within the national UK carbon budget and are not scaled down to sub-national budgets. Land Use, Land Use Change and Forestry (LULUCF) and non-CO_2 emissions are considered separately to the energy CO_2 budget in this report.

Based on our analysis, for North Somerset to make its ‘fair’ contribution towards the Paris Climate Change Agreement, the following recommendations should be adopted:

1. Stay within a maximum cumulative carbon dioxide emissions budget of 6.9 million tonnes ($MtCO_2$) for the period of 2020 to 2100. At 2017 CO_2 emission levels[iii], North Somerset would use this entire budget within 6 years from 2020.
2. Initiate an immediate programme of CO_2 mitigation to deliver cuts in emissions averaging a minimum of -13.9% per year to deliver a Paris aligned carbon budget. These annual reductions in emissions require national and local action, and could be part of a wider collaboration with other local authorities.
3. Reach zero or near zero carbon no later than 2040. This report provides an indicative CO_2 reduction pathway that stays within the recommended maximum carbon budget of 6.9 $MtCO_2$. At 2040 5% of the budget remains. This represents very low levels of residual CO_2 emissions by this time, or the Authority may opt to forgo these residual emissions and cut emissions to zero at this point. Earlier years for reaching zero CO_2 emissions are also within the recommended budget, provided that interim budgets with lower cumulative CO_2 emissions are also adopted.

Sections 1, 2 and 5 of this report - **Introduction, Methods and References** - can be found in the full print report

3. Results

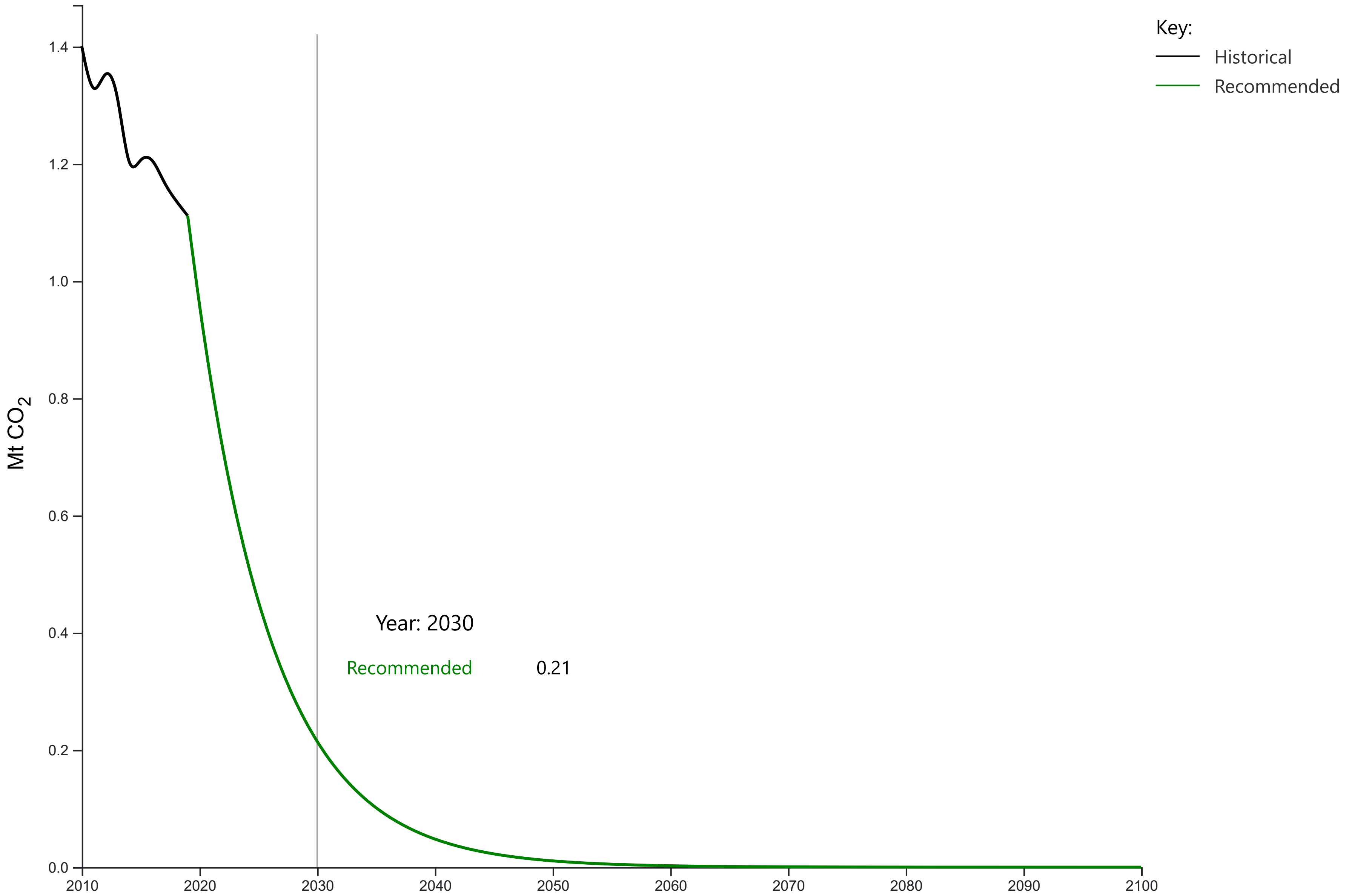
3.1 Energy Only Budgets for North Somerset

Following the Method the recommended energy only CO_2 carbon budget for the North Somerset area for the period of 2020 to 2100 is 6.9 $MtCO_2$. To translate this into near to long term commitments a CO_2 reduction pathway within the 6.9 $MtCO_2$ is proposed here. A consistent emissions reduction rate of -13.9% out to the end of the century is applied. In 2040 95% of the recommended carbon budget is emitted and low level CO2 emissions continue at a diminishing level to 2100.

Figure 1: *An interactive chart of Energy related CO_2 only emissions pathways (2010-2100) for North Somerset premised on the recommended carbon budget.*

Tracking your mouse over this chart will display the actual figures for each of the pathways, as well as for the lead-in historical values.

Pathway projections for North Somerset



☐*Show alternative pathway projections (see below)*

Table 1 presents the North Somerset energy CO_2 only budget in the format of the 5-year carbon budget periods in the UK Climate Change Act. To align the 2020 to 2100 carbon budget with the budget periods in the Climate Change Act we have included estimated CO_2 emissions for North Somerset for 2018 and 2019, based on BEIS provisional national emissions data for 2018 and assuming the same year on year reduction rate applied to 2019. The combined carbon budget for 2018 to 2100 is therefore 9.1 $MtCO_2$.

Table 1: *Periodic Carbon Budgets for 2018 for North Somerset.*

Carbon Budget Period	Recommended Carbon Budget (Mt CO_2)
2018 - 2022	4.7
2023 - 2027	2.3
2028 - 2032	1.1
2033 - 2037	0.5
2038 - 2042	0.2
2043 - 2047	0.1
2048 - 2100	0.1

The recommended budget is the maximum cumulative CO_2 amount we consider consistent with North Somerset's fair contribution to the Paris Agreement. A smaller carbon budget, with accelerated reduction rates and an earlier zero carbon year, is compatible with this approach. It is however important that for an alternative zero carbon year the proposed 5 year budget periods are the same or lower that those specified in Figure 2. Furthermore meeting the budget must not rely on carbon offsets.

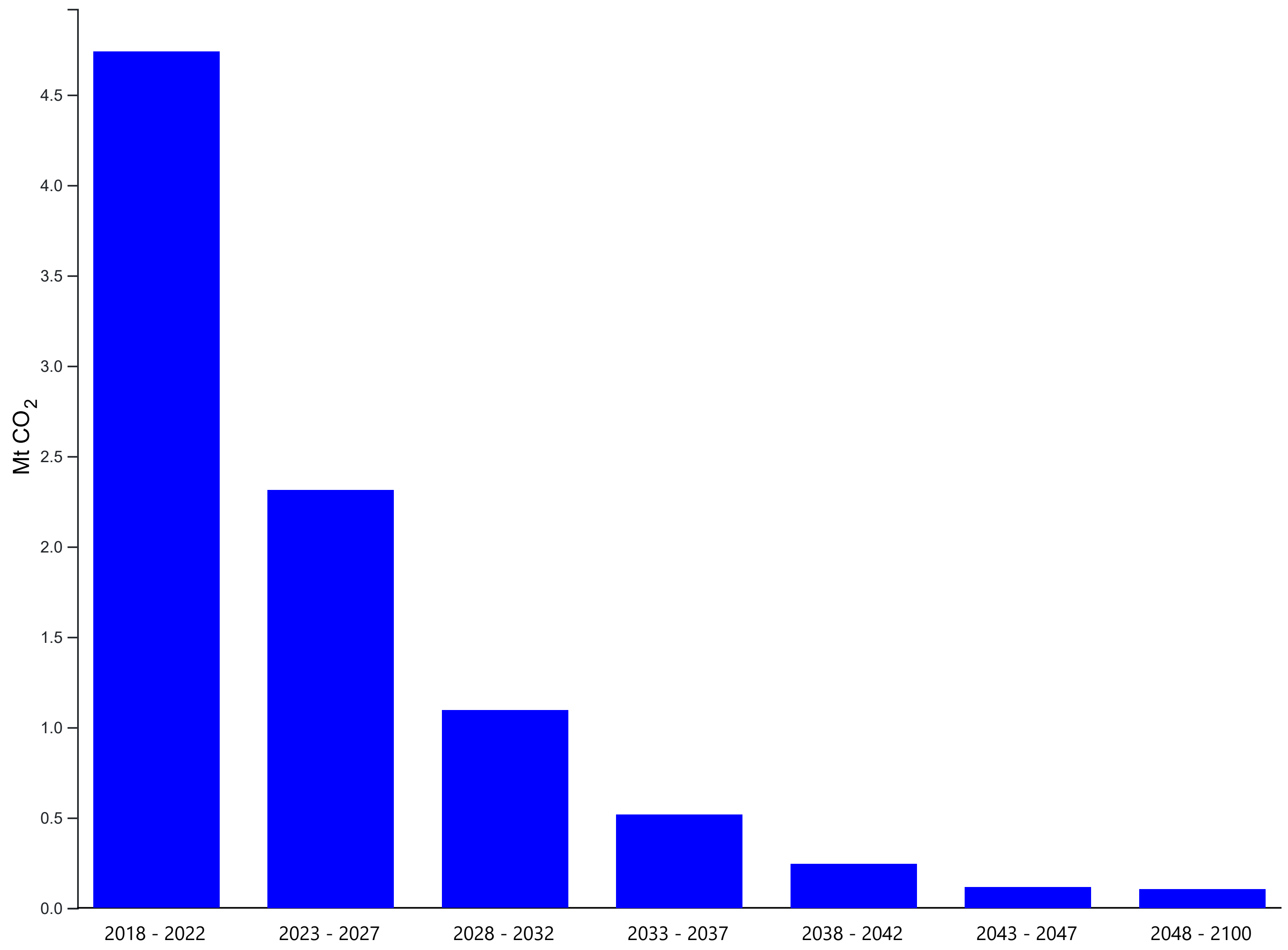


Figure 2: *Cumulative CO_2 emissions for budget period (based on Table 1) from 2018 to 2100 for North Somerset*

3.2 Recommended Allocation Regime for Carbon Budget

The recommended carbon budget is based on a grandfathering allocation regime for sub-dividing the UK sub-national energy only carbon budget. There are three distinct allocation regimes that can be applied to determine sub-national budgets. We have opted to recommend one common approach for allocating carbon budgets that can be applied to all Local Authority areas. This enables straightforward compatibility between carbon budgets set at different administrative scales. For example this makes it easier for individual Local Authorities to calculate their own carbon budgets that are compatible with a budget set at Combined Authority scale. It also means that under the recommended carbon budgets, all Authorities are contributing to a common total UK carbon budget. If for example all Authorities selected the allocation regime that offered them largest carbon budget the combined UK budget would not comply with the objectives of the Paris Agreement. The common approach to allocation we recommend therefore further assures that the carbon budget adopted is Paris Agreement compatible.

We have chosen a grandfathering as our common allocation approach because, based on our analysis, it is the most appropriate and widely applicable regime within the UK.

Population and Gross Value Added[iv] (GVA) are alternative allocation regimes. Population shares the carbon budget equally across the UK on a per capita basis. In this allocation regime the UK population is compared to that of North Somerset from 2011 to 2016. The carbon budget (2020-2100) for North Somerset is then apportioned based on its average proportion of the UK population for the period 2011-2016. For regions where per capita energy demand deviates significantly from the average (e.g. a large energy intensive industry is currently located there) the budget allocated may not be equitable for all regions, therefore it is not recommended as the preferred allocation. GVA is used as an economic metric to apportion carbon budgets. For example, the UK total GVA is compared to that of North Somerset from 2011 to 2016. The carbon budget (2020-2100) for North Somerset is then apportioned based on North Somerset's average proportion of UK GVA for the period 2011-2016. GVA can be useful as a proxy for allocation on economic value, however without an adjustment for the type of economic activity undertaken, areas with high economic 'value' relative to energy use can get a relatively large budget, while the inverse is true for areas with energy intensive industries, and/or lower relative economic productivity. We would therefore not recommend GVA as an appropriate allocation regime for all regions.

Table 2 presents the result outcomes for alterative allocation regimes – population and gross value added (GVA).

Table 2: *Energy only CO_2 budgets and annual mitigation rates for North Somerset (2020-2100) by allocation regime*

Allocation regime (% of UK Budget allocated to North Somerset	**UK Budget[v] (MtCO$_2$)**	**North Somerset Budget (MtCO$_2$)**	**Average Annual Mitigation Rate (%)**
Allocation regime (% of UK Budget allocated to North Somerset	**UK Budget[v] (MtCO$_2$)**	**North Somerset Budget (MtCO$_2$)**	**Average Annual Mitigation Rate (%)**
Grandfathering to North Somerset from UK (0.3%)	2,239	6.9	-13.9%
Population split to North Somerset from UK (0.3%)	2,239	7.2	-13.4%
GVA split to North Somerset from UK (0.2%)	2,239	5.3	-17.3%

To view the pathways for the Population and GVA allocation regimes, select the checkbox under Fig. 1

3.3 Land Use, Land Use Change and Forestry emissions for North Somerset

Land Use, Land Use Change and Forestry (LULUCF) consist of both emissions and removals of CO_2 from land and forests. We recommend that CO_2 emissions and sequestration from LULUCF are monitored separately from the energy-only carbon budgets provided in this report. North Somerset should increase sequestration of CO_2 through LULUCF in the future, aligned with Committee on Climate Change's high level ambition of tree planting, forestry yield improvements and forestry management . Where LULUCF is considered, we recommend it compensate for the effects of non-CO_2 greenhouse gas emissions (within the geographical area) that cannot be reduced to zero, such as non-CO_2 emissions from agriculture.

3.4 Non-CO_2 Emissions

The IPCC SR1.5 report identifies the importance of non-CO_2 climate forcers (for instance methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), sulphur dioxide (SO_2) and black carbon) in influencing the rate of climate change. However, a cumulative emission budget approach is not appropriate for all non-CO_2 greenhouse gases, as the physical and chemical properties of each leads to differing atmospheric lifetimes and warming effects . There are also substantial relative uncertainties in the scale, timing and location of their effects.

We do not provide further analysis or a non-CO_2 emissions reduction pathway in this report. However the global carbon budget in the IPCC Special Report on 1.5ºC, that our analysis is based on, assumes a significant reduction in rate of methane and other non-CO_2 emissions over time. Therefore to be consistent with carbon budgets North Somerset should continue to take action to reduce these emissions.

The Department of Business Energy and Industrial Strategy’s Local Authority emissions statistics do not at this time provide non-CO_2 emissions data at the regional level. Given the absence of robust non-CO_2 emissions data, any non-CO_2 emissions inventory by other organisations at scope 1 and 2 for North Somerset may form the basis of monitoring and planning for these emissions. We recommend considering the adoption of a LULUCF pathway that includes CO_2 sequestration sufficient to help compensate for non-CO_2 emissions within North Somerset's administrative area.

4. Conclusions

The results in this report show that for North Somerset to make its fair contribution to delivering the Paris Agreement's commitment to staying “well below 2°C and pursuing 1.5°C” global temperature rise, then an immediate and rapid programme of decarbonisation is needed. At 2017 CO_2 emission levels[vi], North Somerset will exceed the recommended budget available within 6 years from 2020. **To stay within the recommended carbon budget North Somerset will, from 2020 onwards, need to achieve average mitigation rates of CO_2 from energy of around -13.9% per year**. This will require that North Somerset rapidly transitions away from unabated fossil fuel use. For context the relative change in CO_2 emissions from energy compared to a 2015 Paris Agreement reference year are shown in Table 3.

Table 3: *Percentage reduction of annual emissions for the recommended CO_2-only pathway out to 2050 in relation to 2015*

Year	**Reduction in Annual Emissions (based on recommended pathway)**
2020	21.1%
2025	62.7%
2030	82.4%
2035	91.7%
2040	96.1%
2045	98.1%
2050	99.1%

The carbon budgets recommended should be reviewed on a five yearly basis to reflect the most up-to-date science, any changes in global agreements on climate mitigation and progress on the successful deployment at scale of negative emissions technologies.

These budgets do not downscale aviation and shipping emissions from the UK national level. However if these emissions continue to increase as currently envisaged by Government, aviation and shipping will take an increasing share of the UK carbon budget, reducing the available budgets for combined and local authorities. **We recommend therefore that North Somerset seriously consider strategies for significantly limiting emissions growth from aviation and shipping.** This could include interactions with the UK Government or other local authority and local enterprise partnership discussions on aviation that reflect the need of the carbon budget to limit aviation and shipping emissions growth.

CO_2 emissions in the carbon budget related to electricity use from the National Grid in North Somerset are largely dependent upon national government policy and changes to power generation across the country. **It is recommended however that North Somerset promote the deployment of low carbon electricity generation within the region and where possible influence national policy on this issue**.

We also recommend that the LULUCF sector should be managed to ensure CO_2 sequestration where possible. The management of LULUCF could also include action to increase wider social and environmental benefits..