Biomass in a low-carbon economy

Committee on Climate Change
November 2018

Acknowledgements

The Committee would like to thank:

The team that prepared the analysis for this report. This was led by Jenny Hill and Sam Friggens with oversight and direction from Chris Stark, Adrian Gault, Mike Thompson and Dr David Joffe. The team included Sasha Abraham, Tom Andrew, Owen Bellamy, Dr Ellie Davies, Dr Aaron Goater, Rachel Hay, Mike Hemsley, Dr Sarah Livermore, Dr Cheryl Mackenzie, Dr Richard Millar, Alexandra Scudo, Dr Steve Smith, Indra Thillainathan, Tanja Wettingfeld and Nathan Wyatt.

Other members of the Secretariat who contributed to this report: Jo Barrett, Kathryn Brown, Brendan Freeman, Steven John Harry and Ewa Kmietowicz.

The Expert Advisory Group led by Prof Patricia Thornley and which included Dr Stephen Cornelius, Prof. Ian Donnison, Dr Jo House, Prof. Richard Murphy, Prof. Pete Smith, Prof. Gail Taylor, Ian Tubby and Prof. Kathy Willis.

A number of organisations and stakeholders for their support, including Carbon Disclosure Project, Dr Sam Cooper, the Department for Business Energy and Industrial Strategy, the Department for Environment Food and Rural Affairs, the Department for International Development, the Department for International Trade, the Department for Transport, E4Tech, the Energy Systems Catapult, the Energy Technology Institute, Forestry Commission England, Forest Research, the International Energy Agency, Keith Kline, Prof Lee Lynd, the Mineral Products Association , Ofgem, Dr Alison Mohr, UN Food and Agricultural Organisation, Dr Jeanette Whitaker, Dr Jeremy Woods.

A wide range of stakeholders who participated to our workshops, engaged with us, submitted evidence or met with the Committee bilaterally.

© Committee on Climate Change Copyright 2018

The text of this document (this excludes, where present, the Royal Arms and all departmental or agency logos) may be reproduced free of charge in any format or medium provided that it is reproduced accurately and not in a misleading context. The material must be acknowledged as Committee on Climate Change copyright and the document title specified.

Permission from copyright holders must be sought before any photographs are reproduced. You can download this publication from www.theccc.org.uk/publications

All enquiries related to this publication should be sent to: communications@theccc.gsi.gov.uk

Contents

The Committee

The Rt. Hon John Gummer, Lord Deben, Chairman

Lord Deben was the UK's longest-serving Secretary of State for the Environment (1993 to 1997). He has held several other high-level ministerial posts, including Secretary of State for Agriculture, Fisheries and Food (1989 to 1993). He has consistently championed the strong links between environmental concerns and business interests. Lord Deben also founded and chairs Sancroft, a corporate responsibility consultancy working with blue-chip companies around the world to help them improve their environmental, social and ethical impact. He is Chairman of Valpak Limited and the Personal Investment Management and Financial Advice Association.

Baroness Brown of Cambridge

Baroness Brown FRS is an engineer and a crossbench member of the House of Lords. She is Deputy Chair of the Committee on Climate Change (CCC), Chair of the CCC's Adaptation Committee, Chair of the Carbon Trust and the Henry Royce Institute for Advanced Materials, a Non-Executive Director of the Offshore Renewable Energy Catapult, and Sector Champion for the Offshore Wind Sector deal. Her previous roles include: Non-Executive Director of the Green Investment Bank, senior engineering and manufacturing roles at Rolls-Royce plc, academic positions at Cambridge University and Imperial College London, and Vice Chancellor of Aston University.

Professor Nick Chater

Nick Chater is Professor of Behavioural Science at Warwick Business School. He has particular interests in the cognitive and social foundations of rationality, and applying behavioural insights to public policy and business. Nick is Co-founder and Director of Decision Technology Ltd, a research consultancy. He has previously held the posts of Professor of Psychology at both Warwick University and University College London (UCL), and Associate Editor for the journals: Cognitive Science, Psychological Review, Psychological Science and Management Science.

Paul Johnson
Paul Johnson is Director of the Institute for Fiscal Studies and a visiting professor at University College London (UCL). He is widely published on the economics of public policy, and he co-wrote the 'Mirrlees review' of tax system design. He was previously Chief Economist at the Department for Education (2000 to 2004) and Head of Economics of Financial Regulation at the Financial Services Authority (1999 to 2000).

Professor Corinne Le Quéré
Corinne Le Quéré FRS is Professor of Climate Change Science and Policy at the University of East Anglia (UEA), specialising in the interactions between climate change and the carbon cycle. She is also Director of the Tyndall Centre for Climate Change Research, a lead author of several assessment reports for the UN's Intergovernmental Panel on Climate Change (IPCC), and Director of the annual update of the global carbon budget by the Global Carbon Project (GCP).

Professor Jim Skea
Jim Skea is Professor of Sustainable Energy at Imperial College, with research interests in energy, climate change and technological innovation. He is also Co-chair of Working Group III (Mitigation) of the Intergovernmental Panel on Climate Change (IPCC). Jim was Research Director of the UK Energy Research Centre (2004 to 2012) and Director of the Policy Studies Institute (1998 to 2004). He was awarded a CBE for services to sustainable energy in 2013 and an OBE for services to sustainable transport in 2004.

Dr. Rebecca Heaton
Rebecca Heaton is Head of Sustainability and Policy at Drax Group. She is responsible for the sustainability of the global forest supply chains used to produce biomass for its power station, and for research and policy work. She has extensive experience working for a number of energy businesses on a range of topics, including biofuels, land-use and forestry, and climate change adaptation.

Dr Rebecca Heaton opted to stand back from this report in Autumn 2017, in line with CCC's policy on conflicts of interest.

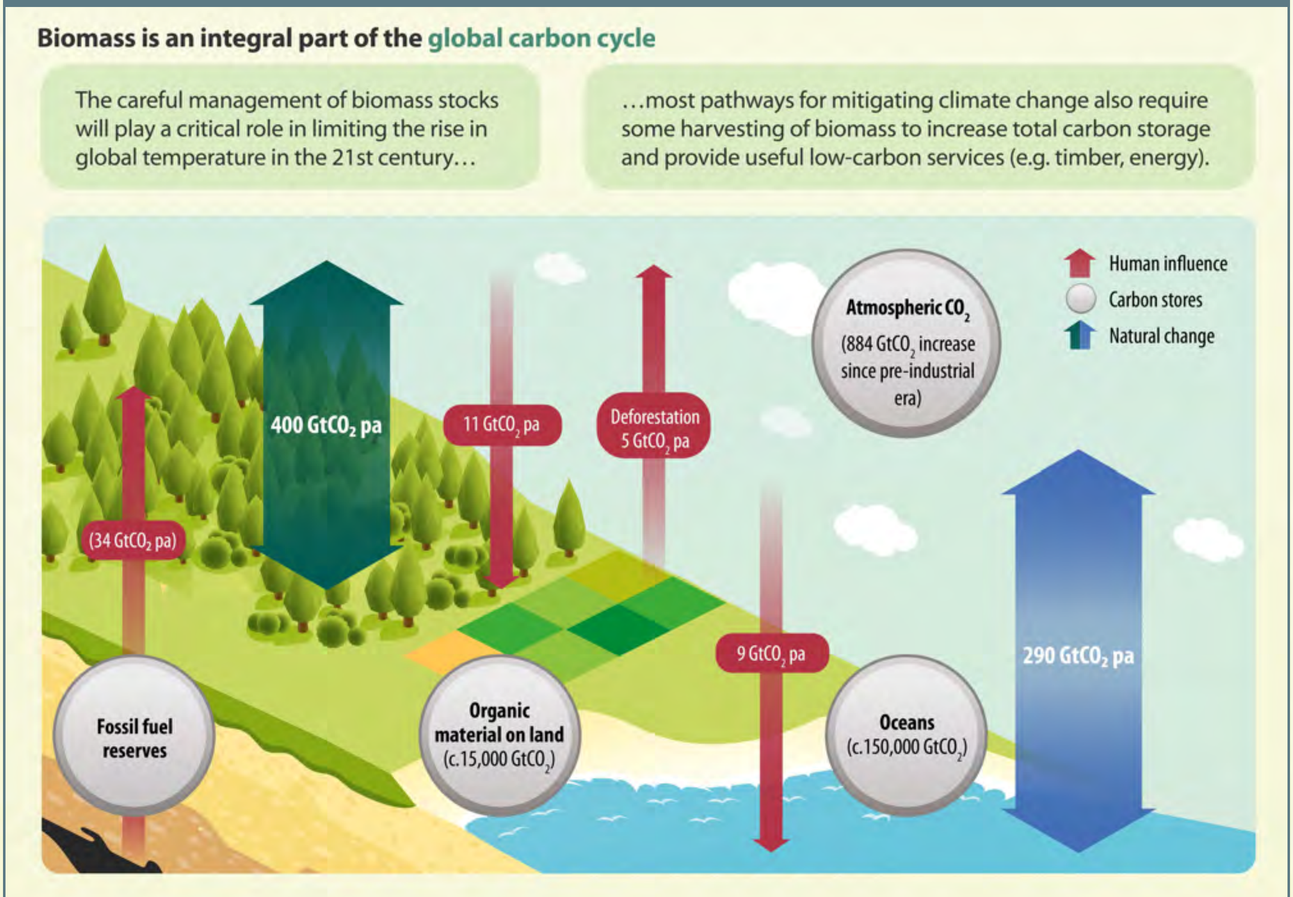
Executive Summary

Overview

Biomass is an integral part of the global carbon cycle. Carbon is absorbed from the atmosphere as plants grow, then released as biological matter decays or burns. These processes have played an important role in regulating Earth's climate in the past and the careful management of biomass stocks will play a critical role in limiting the rise in global temperature over the next century.

Biomass provides two main routes to mitigating climate change. Its growth *removes* carbon dioxide from the atmosphere and *stores* it for long periods of time in soils, trees and other plants. When managed and harvested in a sustainable way, biomass can also be used to *reduce fossil fuel emissions* to the atmosphere by directly displacing oil, coal and natural gas use or by displacing high-carbon materials such as steel and cement. Figure 1 illustrates the potential role of sustainable biomass within the global carbon cycle. Box 1 sets out what we mean by the term ‘biomass’ and the scope in which it is used in this report.

Figure 1. Sustainable biomass within the global carbon cycle



Notes: The carbon cycle diagram values are based from IPCC 2014, *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* and Le Quéré et al (2016)
Global Carbon Budget 2017, Earth System Science Data. It is drawn from Royal Society and RAEng (2018) *Greenhouse gas removal*, https://www.raeng.org.uk/publications/reports/greenhouse-gas-removal. The fluxes are mean annual averages over the past decade (2007-2016). Figures do not sum exactly due to uncertainty and rounding.

Box 1. What do we mean by 'biomass'?

At its broadest the term biomass includes all organic carbon-based materials including plants and animals. Biomass can be living and dead matter in terrestrial landscapes and oceans, or it can be harvested for use in human societies. This broad definition is most relevant to the parts of this report that discuss the carbon cycle, global biomass stocks and global mitigation strategies.

For the rest of the report we use a narrower definition that **excludes** unmanaged biomass in living ecosystems, as well as biomass used for food production or other established bio-based products such as clothing, medicines and cosmetics. We do however **include** residues from these activities as well as biomass harvested from sustainably-managed forests (including timber and low-grade wood used in building materials), crops grown specifically for energy, and organic wastes such as food waste and sewage.

We use the term **harvested biomass** when we wish to distinguish explicitly biomass that has been removed from the landscape for human use from biomass that remains in the landscape such as in forests and soils.

The term **biomass feedstocks** (or bioenergy feedstocks) refers to types of harvested biomass as well as other organic wastes and residues. These feedstocks include:

- **Energy crops** – Crops grown specifically for energy production (e.g. miscanthus).
- **Forestry residues** – Definitions of forestry residue vary but generally this term includes small branches, bark and thinnings left over from forestry operations and residues from wood processing industries (e.g. sawmills). Some residues should be left in the forest for soil health.
- **Agricultural residues** – These include materials left in the field after a crop has been harvested such as straw, rice husks and sugarcane bagasse. A proportion of the residues should be left in the field to support soil health. They also include leftover materials from the processing of crops for food or other products.
- **Organic wastes** – Some key types of organic waste including wood waste, the organic fraction of municipal solid waste, livestock manures, sewage sludge, tallow and used cooking oil. These wastes should be minimised then reused/recycled before being used for energy production.

Biomass feedstocks can either be combusted directly to produce heat and power, or processed into a range of **gases** or **liquid biofuels** for use across the energy system.

The emerging concept of the **bioeconomy** is defined at its broadest level as including all economic sectors that utilise biomass to make products. This includes traditional sectors such as agriculture, food and drink and wood-based products, but also new sectors such as bio-based chemicals, pharmaceuticals and plastics.

Source: CCC, Annex 1 Sustainable Forest Management, produced by Ian Tubby at Forestry Commission England; BEIS (2016) *Bioeconomy: Call for Evidence*.

As global emissions constraints tighten in line with commitments to mitigate climate change under the 2015 Paris Agreement, harvested biomass will be used most effectively where it maximises the removal and minimises the release of carbon into the atmosphere. This can be achieved through a combination of enhancing natural sequestration in forests and soils and by using harvested biomass in other large-scale permanent or long-lasting stores, such as wood in construction or potentially bioenergy with carbon capture and storage (BECCS) technology.

This report updates our advice to Government on the **role of biomass and bioenergy in decarbonising the UK economy through to 2050.** It is based on the latest evidence on the circumstances in which biomass can be both low-carbon and sustainable. It sets out scenarios and requirements for the future supply of **sustainable** biomass and where this limited resource can be **prioritised for the most valuable end-uses** ('best use') to maximise greenhouse gas (GHG) abatement across the economy to 2050.

- Our assessment of the carbon impacts of biomass includes consideration of full lifecycle GHG emissions, including those from changes in land-use (both direct and indirect – that is as a result of impacts on food or other materials production), carbon stocks and emissions relating to the harvesting, processing and transportation of biomass feedstocks. Alongside this biomass report we are publishing a report on land-use change, which in turn informs our UK biomass supply scenarios.[1]
- The broad concept of sustainability is central to our analysis. We include in this definition biodiversity, ecosystem impacts (including flood mitigation, water and soil quality) and social issues such as impacts on food production and land tenure. We recognise the importance of ecosystem services provided by land and forests and take into account the impacts of a changing climate. We consider the potential benefits of biomass production and use but also the significant risks of negative impacts - both on the climate and in terms of wider sustainability.
- Our updated assessment of the most effective use of limited resource considers non-energy uses of biomass, particularly wood in construction, as well as the development of carbon capture and storage (CCS) and the potential role of hydrogen in different sectors. The analysis has been undertaken in parallel to our *Hydrogen Review*, allowing us to assess the interactions in energy supply and use, including using biomass to produce hydrogen.

The analysis from these three reports will inform the Committee's 2019 advice on the UK's long-term emission targets, requested by the Government in October 2018.

This summary is set out in two sections and concludes with a summary of key questions and answers:

1. Key findings
2. Recommendations

1. Key findings

Our key findings demonstrate that biomass can be produced and used in ways that are both low-carbon and sustainable. However, improved governance will be essential to ensure this happens in practice. If this is achieved, biomass can make a significant contribution to tackling climate change. If this is not achieved, there are risks that biomass production and use could in some circumstances be worse for the climate than using fossil fuels.

- **Managing biomass stocks is an important component of global climate mitigation strategies**. However this must be as part of **a system of sustainable land use** where, as a minimum requirement, carbon stocks in plants and soils increase over time.
  - Maximising absorption of carbon from the atmosphere through the strategic use of land and biomass stocks is required to meet the goals of the Paris Agreement – to balance anthropogenic sources of emissions with enhanced removals by carbon sinks (and to achieve 'net zero' emissions within this century).

[1] CCC (2018) *Land-use change: preparing for climate change and reducing emissions.*

– Despite continued deforestation in some parts of the world (mainly in the tropics), global carbon stocks in forests, soils and other plants are growing overall. This is due to increased plant growth from higher levels of CO_2 in the atmosphere (the 'CO_2 fertilisation effect') and the regrowth of forests in some temperate and boreal regions, following wood harvest or the abandonment of agriculture. A concerted effort is needed to reverse declines in forest cover where this is happening and to build up carbon stocks on managed land where they have been degraded by human activities. Some harvesting and use of biomass can be compatible with this objective, providing sustainable land management practices are applied and lifecycle emissions are minimised (Box 2).

– Combining enhanced carbon stocks in forests and land with careful management and harvesting of sustainable biomass can help to increase the overall amount of carbon removed from the atmosphere. This is because forests begin to saturate once they reach their full growth potential - reaching a limit of their ability to absorb carbon - whereas combining growth with some harvesting and use in other long-term stores allows for ongoing sequestration. This could also help mitigate the risk that standing carbon stocks in forests may not be resilient to future climate change.

– Bringing degraded UK forests back under management has both GHG and biodiversity benefits and can improve resilience to a changing climate, pests and diseases.

- **Globally and in the UK, there is scope to increase carbon stocks in trees and soils as well as to increase the supply of sustainable harvested biomass. Stronger governance is required to ensure this happens in practice.**

– Woodlands cover 13% of the UK's land area, up from 9% in 1980. With current commitments this should increase to 16% by 2050. Our new UK land-use scenarios explore the potential to push this up to 19% by 2050, while still maintaining food production and other services required from land. Achieving these higher levels of afforestation would remove and store an additional 21 $MtCO_2e$ per year from the atmosphere by 2050 against current levels, equivalent to around 5% of current UK greenhouse gas emissions.

– Degraded peatlands are currently a substantial source of emissions from UK land. Restoring peatlands on 6% of UK land could save up to 11 $MtCO_2e$/yr by 2050. This will also deliver co-benefits such as enhanced biodiversity and improved water quality.

– By applying good practice and planning to avoid competition with food production, sustainable low-carbon biomass can be produced for use in construction, energy production and other bio-based products. This can support other priorities such as biodiversity and flood prevention as well as enhancing overall carbon stocks (Box 2). Where used for energy, it is good practice to aim to minimise competition with existing uses such as wood products, so as to limit the risks of associated indirect land-use change.

– By 2050 up to 1.7 million oven-dried tonnes of high-quality sawn wood suitable for construction and up to 27 million oven-dried tonnes of sustainably-produced biomass from forestry and agricultural residues and energy crops could be produced in the UK.[2] Combined with imports enabled by strong sustainability governance, this would support

[2] See Box 1: these two separate categories are largely distinct (very broadly - high-grade timber for construction vs residues and wastes for energy) but with some overlap on residues used for composite construction materials, waste straw and other natural insulation materials.

an expansion of the use of wood in construction and mean that bioenergy could meet between 5% and 15% of the UK's energy demand in 2050 (compared to around 7% today).

- There is significant potential to increase domestic production of sustainable biomass to meet between 5% and 10% of energy demand from UK sources by 2050. The lower end of this range can be delivered by fully exploiting the UK's organic waste resource (after reduction, reuse and recycling) whilst maintaining today's level of agricultural and forest residue use. The upper end of this range requires over 1 million hectares land to be used for energy crops (around 7% of current agricultural land) and increasing rates of tree planting (to 50,000 hectares every year by 2050).
- With imports supplementing domestic resources, a total of up to 15% of the UK's primary energy demand could, under certain conditions, come from sustainable biomass by 2050.[3] Achieving this would require the amount of imported biomass to increase at least threefold compared to current levels. This will only be possible if strong global sustainability governance is in place and under favourable conditions (limited population growth, diet change and agricultural yield improvements to allow for a release of agricultural land compared to today). High levels of global biomass supply could imply some trade-offs with other sustainability objectives such as biodiversity and water availability.
- Innovations in biomass production and agricultural strategies could enable high levels of sustainable supply to be achieved without the use of substantial amounts of productive land. Examples include algae production and the cultivation of highly water-efficient crops which can be grown in very dry environments not suitable for other crops.[4] The development of new low-carbon fertilizers could also play a role. These innovations are not included in our scenarios at this stage, but they offer the potential to increase the supply of sustainable biomass in the future. We will monitor developments in these areas closely.

– The evidence suggests that the UK's bioenergy sustainability rules (produced by Ofgem and DfT) are helping to limit the sustainability risks, although there is some evidence of negative local impacts (e.g. air quality), intensive forestry management practices, and disagreement around the use of some feedstocks (e.g. low-grade wood and 'thinnings').

– Strengthened governance is needed to manage the risks to sustainable low-carbon production as the global biomass market scales up, and for any new public subsidies. This requires:

- Ensuring that changes in terrestrial carbon stocks in managed forests are fully accounted for in current sustainability criteria, enhancing monitoring and reporting and looking at new mechanisms for driving best practice.
- A broader approach to managing risks (beyond the current practice of setting sustainability criteria in subsidies) - for example, by extending the use of sustainability criteria across procurement and finance rules and through further strategic coordination of development and trade policy.

[3] In terms of imported resources, we assume the UK would have access to an 'equal share' of the global sustainable biomass resource, based on the UK's projected share of global primary energy demand in 2050 (1.1%).
[4] Agave and other crops such as Opuntia use the Crassulacean Acid Metabolic (CAM) pathway as an adaptation to an arid environment. This allows them to maintain very high rates of water efficiency.

- In order to provide benefits at an aggregate level, policy needs to look beyond existing sustainable supply-chains, and drive up standards more widely. This is to ensure that the UK is not simply sourcing existing sustainable feedstocks while pushing less sustainable stocks elsewhere.

– We do not know the extent to which it will be possible to put in place robust and comprehensive sustainability governance globally; ongoing monitoring and evaluation is therefore required to inform policy decisions, along with a precautionary approach.

- **Sustainably harvested biomass can play a significant role in meeting long-term climate targets, provided it is prioritised for the most valuable end-uses.**

  – The amount of biomass used by the UK should be constrained by the supply of low-carbon sustainable feedstocks. Potential demand in the future is likely to exceed sustainable supply, implying action will be needed to ensure biomass is used effectively.

  – Harvested biomass will generally contribute most to mitigating climate change where it is used to sequester atmospheric carbon whilst also providing a useful energy service or product.[5] There are currently only limited options to use biomass in this way (principally through the use of timber in construction) but in the future this should increase if there are opportunities for bioenergy with carbon capture and storage (BECCS) technology.

    - The greatest levels of GHG abatement from biomass currently occur when wood is used as a construction material in buildings to both store carbon and displace high-carbon cement, brick and steel. Between 15% and 28% of new homes built in the UK each year use timber frame construction systems and wood is also widely used in traditional masonry systems. As a result, over 1 $MtCO_2$/yr is stored in new UK homes. Increasing timber in construction could increase this storage to around 3 $MtCO_2$/yr by 2050.[6] Savings of a similar magnitude may also be possible in the commercial and industrial sectors by utilising new engineered wood systems such as cross-laminated timber.

    - If BECCS applications were to be available - either to produce hydrogen, power, aviation biofuels or in industry - these would deliver more GHG abatement than other energy system uses. By 2050 between 20 and 65 MtCO2e/yr could be sequestered through BECCS in the UK (equivalent to up to around 15% of current UK CO_2e emissions). The range depends on the amount of sustainable biomass available.[7]

    - Should these sequestration opportunities for biomass use be exhausted, the remaining resource would be best used to displace residual fossil fuel emissions where other low-carbon alternatives do not exist (e.g. in aviation), where these give the greatest possible emission reduction.

    - Higher levels of sustainable bioenergy resource will reduce the overall cost of decarbonisation and help higher levels of ambition to be achieved. Our energy

[5] This conclusion assumes there is no more coal being used without CCS. If this were the case, using biomass to displace coal where it cannot be otherwise displaced is likely to deliver similar levels of abatement as CCS applications.

[6] These figures are net additional sequestered carbon per year in the residential sector. They represent the rate at which the overall stock of carbon stored in homes increases each year, taking into account demolitions.

[7] This range of sequestered CO_2e is based on the amount of sustainable biomass available to the UK in 2050 across our supply scenarios, assuming the UK accesses an 'equal share' of the global tradable resource.

system modelling shows that the UK's total emissions in 2050 could be 50 $MtCO_2e$/yr lower with 15% of energy demand coming from bioenergy rather than 5%.

– Most current uses of biomass do not sequester carbon and are in sectors where there are increasingly other viable low-carbon alternatives. Current uses of biomass will therefore need to change. Over time, Government policies should assist a transition towards increased use of biomass in construction and BECCS, and away from using biofuels in surface transport, biomass for heating buildings, or biomass for generating power without CCS (Figure 2).

Box 2. Good practice to produce biomass in a sustainable low-carbon way

Over the last decade a substantial body of scientific evidence has developed that explores the carbon and wider sustainability impacts of biomass production and use. The evidence suggests that sustainable low-carbon bioenergy *is* possible, but that this can *only* be achieved in certain circumstances, *if* certain practices and criteria are applied.

Where crops are grown specifically for energy it is essential that this does not compete with or undermine food production. This will be generally be achieved by growing non-food crops on lower quality agricultural, abandoned or contaminated land. However it may also be possible by integrating energy crops into integrated food and energy agricultural systems. Perennial grasses (e.g. miscanthus) and short rotation forestry (e.g. willow, poplar) can build up stores of soil carbon over time and can have a range of other positive sustainability impacts such alleviating flood risks. In all cases it is essential to avoid unsustainable land conversion that causes substantial emissions and other negative impacts.

Depending on how it is produced, forest biomass can correspond to a range of GHG outcomes, higher or lower than fossil fuel equivalents. Recent work by Forest Research has developed criteria to ensure forest bioenergy is low-carbon. These include the need for forests to be managed for a range of co-products (including long-lived construction products), disallowing supply from forests with slow growth rates, and focussing on wood feedstocks such as waste wood, industrial residues and fast-decaying forest residues (not needed for maintaining carbon stocks).

Organic wastes currently provide around a third of the UK's bioenergy supply, and along with agricultural residues these are likely to remain a substantial source of future bioenergy supply. Where these wastes would have otherwise decomposed (potentially releasing methane - a potent greenhouse gas), they can be considered as low-carbon. To remain sustainable in the future it will be essential that waste is reduced as much as possible, or reused and recycled, before any residual waste is used for bioenergy production. Only a share of agricultural residues should be used for bioenergy because of the need to maintain soil fertility and satisfy other competing uses (e.g. animal bedding).

For all types of biomass production it is necessary to reduce supply chain emissions as much as possible (those associated with cultivation, harvesting, processing and transport). Currently there is substantial variation in emissions between different supply chains. Application of best practice and low-carbon energy sources can help to minimise these emissions.

Sources: CCC; Forest Research (2018) *Biomass Carbon Impacts*, report for the European Climate Foundation; Matthews, R., et al (2014) *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*. Final Report for Department of Energy and Climate Change.
Notes: The work by Forest Research was originally undertaken for the European Commission in 2014 and subsequently updated for the European Climate Foundation in 2018.

Figure 2. Hierarchy of best use for sustainable biomass resources

Between now and 2050, the current uses of biomass in the UK need to change:

	Most effective use today	2020s and 2030s	By 2050
Bioeconomy	Wood in construction	Wood in construction, potentially other long-lived bio-based products (within circular economy)	
Buildings	Biomethane, local district heating schemes and some efficient biomass boilers in rural areas		Only very limited additional use for buildings heat: niche uses in e.g. district heat and hybrid heat pumps
Industry	Biomass use for processes with potential future BECCS applications		BECCS in industry alongside other low-carbon solutions
Power	Ongoing use in power sector in line with existing commitments or small scale uses	Demonstration and roll out of BECCS to make H_2 and/or power	Biomass used for H_2 production or power with CCS
Transport	Liquid biofuels increasingly made from waste and lignocellulosic feedstocks	Liquid biofuel transitioning from surface transport to aviation, within limits and with CCS	Up to 10% aviation biofuel production with CCS

Maximising abatement means using biomass to sequester carbon wherever possible (opportunities to do this will increase over time)

Source: CCC.
Notes: This has been updated since the 2011 *Bioenergy Review*. In particular, industrial process heat is no longer considered alongside long-term sequestration opportunities as 'best use', reflecting new evidence on industrial decarbonisation potential from fuel-switching to hydrogen and from possible BECCS uses.

2. Recommendations

Our findings lead us to the following recommendations:

- **Build up the UK's forest and land carbon stores and, at the same time, increase the supply of sustainable harvested biomass from UK sources.**
  - Deliver the current ambition to increase the annual rate of forest planting from 9,000 hectares per annum on average in the last five years, to 20,000 hectares p.a. by 2020 and 27,000 hectares p.a. by 2030. Explore the potential for this to be increased further by 2050. This will require new strategies in England, Scotland, Wales and Northern Ireland to address barriers and incentivise planting.
  - Undertake more work to deliver the commitment to bring 67% of England's forests back under active management (from 59% currently),[8] and seek to extend the ambition where the evidence supports this.
  - Introduce policies to increase planting of perennial energy crops on lower-grade agricultural lands where this can contribute to increasing soil carbon and deliver other ecosystem benefits. This will require clear signals of Government commitment, planting rate targets and a number of economic, policy and regulatory barriers to be addressed.
  - Build rewards for carbon sequestration in forests and soils and other ecosystem services such as alleviation of flood risk into the UK successor to the Common Agricultural Policy. Energy crop production should be included in this rewards scheme where it delivers these wider benefits and provided is not already incentivised through other subsidies.

[8] The 67% target was set to be achieved by 2018, under the Defra (2013) *Government Forestry and Woodlands Policy Statement*. The 59% estimate is given at 31st March 2018 in Forestry Commission England (2018) *Corporate Plan Performance Indicators 2018*.

– Ensure food and other biodegradable wastes are collected separately in all areas across the UK and then used in line with the waste hierarchy (i.e. prioritising reuse and recycling). By 2025 no biodegradable wastes such as food, paper, card, wood, textiles and garden waste should be sent to landfill. Agricultural residues could also play a long-term role provided soil fertility requirements are met and other uses satisfied.

- **Improve UK and international governance over biomass feedstocks. The long-term role of biomass imports to the UK must depend on the success of these efforts.**

  – As a general rule, unsustainable or high-risk feedstocks (e.g. feedstocks from primary, high-carbon, highly biodiverse or slow-growing forests) should be regulated out and best practice encouraged (e.g. use of organic wastes and genuine agricultural or forestry residues,[9] certain perennial crops grown on marginal land). BEIS and DfT should update sustainability criteria to reflect the growing evidence base in this area (building on criteria recently developed by Forest Research). They should also assess better ways to incentivise a 'race to the top' in lifecycle greenhouse gas emissions.

  – BEIS and DfT should address the current weakness in the criteria on preserving carbon stocks in existing forests by requiring that any long-term changes in forest carbon stock at landscape scale are included in the calculation of the climate impacts of bioenergy systems. The general principle is to rule out feedstocks sourced from areas with falling carbon stocks. In applying the principle, account should be taken of appropriate spatial scales, the CO_2 fertilisation effect and relevant exclusions, for example in relation to diseased trees.[10] BEIS and DfT should also explicitly rule out the harvest of whole forest tracts exclusively for energy uses, in line with best practice as applied by the Green Investment Group.[11, 12]

  – Government (BEIS, DfT, DfID, DIT, FCO) should assess ways to encourage new supply-chains (e.g. in developing countries) in addition to sourcing from low-risk regions:[13] through wider trade and development activities, and through continued efforts to improve multilateral governance. It should extend the scope of governance beyond the current subsidy-linked criteria into a broader range of policy levers (e.g. to standards,

[9] i.e. genuine residues that are not needed for soil health and fertility or maintaining existing soil carbon stocks, and which would have otherwise been discarded.

[10] Scale is important – we typically assume that this would be at the landscape or 'wood-basket' level (i.e. the area which a mill sources its product from) rather than country-level. This could be supported by other measures such as requiring owners take steps to restock and encourage natural regeneration following a thinning.

[11] This is based on a requirement set by Green Investment Group (formerly UK Green Investment Bank, now part of Macquarie Group), which requires funded projects not to include biomass from forest tracts harvested exclusively for energy uses (with certain exclusions, e.g. for diseased trees). The requirement aims to ensure that forest management (such as felling decisions and determination of rotation length) continues to be driven by demand for higher value timber products rather than demand for bioenergy. Green Investment Group also have a requirement to source only from areas with stable or growing carbon stocks.

[12] The second part to our recommendation recognises the evidence that where used solely for energy, over 'climate policy relevant timescales (30 years, and in most cases significantly less)', using all of the stemwood from forest directly for energy leads to net increases in GHG emissions (see Forest Research (2018) Biomass Carbon Impacts, and Matthews, R., et al (2014) Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests). It does not rule out using all thinnings (including for example diseased trees, when removed as part of sustainable forest management).

[13] Country-level risk assessments are used in both forestry and bioenergy governance as part of a risk-based approach.

procurement rules, trade and development policy – following the forestry governance example).[14]

- The UK should lead a shift towards using improved monitoring techniques (e.g. satellite imaging, track and trace, improved soil carbon monitoring) and geographically-specific datasets. There should be high-quality independent monitoring and reporting of domestic UK stocks and supply chains at an aggregate level (and mapping these to other data such as international forest inventories).
- Standards should be designed so as to ratchet up over time, with regular review points.

- **Ensure biomass is used in the most effective way. This means current uses of biomass will need to change.**
  - BEIS, Defra, DfT and HMT must design biomass policies and support mechanisms to support long-term best use (Figure 2) and to ensure the amount of biomass used does not exceed sustainable levels of supply.
  - MHCLG should develop new policies to support a substantial increase in the use of wood in construction. This will need to focus on overcoming a range of cultural, skills and financial barriers in the construction sector. A new mechanism is needed to incentivise and drive whole-life carbon savings for new buildings. This should cover embodied emissions and carbon sequestration.
  - BEIS and HMT should develop support schemes (including carbon pricing) to ensure that removing CO_2 from the atmosphere and storing it for long-time periods is valued alongside emissions reductions.
  - BEIS should support the development of the key enabling technologies for carbon capture and storage (CCS) and gasification (Box 3).
  - Over the next decade Government policies should only support biomass use where this a) provides cost-effective abatement whilst avoiding 'lock-in' to sub-optimal uses, and/or b) develops key technologies and sustainable supply chains. This means:
    - Do not provide further policy support (beyond current commitments) to large-scale biomass power plants that are not deployed with CCS technology.
    - Phase out biofuel use in cars and vans in the 2030s. The RTFO mechanism should focus on developing key technologies that enable the use of organic wastes and other sustainable feedstocks.
    - Support deployment of aviation biofuels up to 10% of total aviation fuel demand by 2050, ensuring all aviation biofuels are produced with CCS as soon as this technology is available. Facilitate the transition to aviation uses by achieving more of the 2030 RTFO target through aviation fuels.
    - In industry, work towards a technology mix based on low-carbon hydrogen, fossil-fuelled CCS, BECCS and electrification. This means no long-term use of biomass as a fuel, unless in combination with CCS.
    - Limit support for bioenergy use in buildings to biomethane produced from anaerobic digestion and other niche uses (as part of hybrid heat pumps systems in

[14] See EU timber governance (EU FLEGT).

hard to treat off-gas homes, local combined heat and power systems and small-scale district heat networks) - whilst minimising air quality impacts.

- Support for the bioeconomy should reflect the current uncertainty and variability in lifecycle greenhouse gas emissions of emerging uses of biomass such as bio-based plastics. Policy should balance support for the development of these new products with recognition that they may not ultimately be in line with long-term best-use. A concerted effort will be needed to build sustainable supply-chains with efficient conversion processes and end-of-life material recovery and reuse.

This report is supported by five technical annexes which are published alongside it.[15] A summary set of Q&A responses is set out in Table 1.

Box 3. Developing key technologies to enable best use of biomass in future

Unlocking the full long-term benefits of biomass use in the energy system requires active near-term development of enabling technologies such as CCS and gasification.

- In our 2018 *Progress Report to Parliament* we recommended that by 2030, **CCS** should be deployed for power generation at a scale of around 10Mt$CO2_e$/yr, rising further over time. Our analysis also suggests BECCS could be competitive with other forms of abatement by this time. Government should support the demonstration and deployment of BECCS in the UK as part of its wider CCS strategy.
- **Gasification** to produce ultra clean synthetic gas from a range of biomass feedstocks is needed to provide a route to high-value energy products such as hydrogen and biomethane. However development of these technologies has been slow and technical barriers remain, with existing support under the Contracts for Difference mechanism failing to bring forward gasification plants capable of producing genuinely ultra-clean synthetic gas. Government should re-examine its incentive framework for gasification technologies with support shifting away from the power sector towards the transport and heat sectors where ultra-clean synthetic gas is a more useful intermediary product. Over time policy should evolve to support deployment with CCS and use of a wide-range of feedstocks.

Summary of key questions and answers

Table 1. Q&A at a glance

Question	Summary response
When is biomass production low-carbon and sustainable?	See Box 2.

[15] These include: Annex 1. Sustainable Forestry Management, by Ian Tubby at the Forestry Commission; Annex 2. What Works: International Sustainability Governance; Annex 3. Sustainable Supply Scenarios; Annex 4. Steps to Scaling up UK Sustainable Bioenergy Supply, by Jeanette Whitaker at the Centre for Ecology & Hydrology; Annex 5. Energy System Modelling for the Biomass and Hydrogen Reviews.

Table 1. Q&A at a glance	
Question	**Summary response**
How do the current accounting and sustainability frameworks manage sustainability risks?	International GHG accounting rules provide a framework where changes in land carbon stocks are included within climate targets, but it does not provide incentives to produce low-GHG biomass at a farm or forest level. EU and UK bioenergy sustainability rules are linked to subsidy schemes under the 2020 renewable energy target and have a number of important gaps which must be addressed. The EU and UK governance on forestry is more comprehensive and holistic than the framework for bioenergy. All timber must be licenced with records showing it is not the result of illegal logging. There is an EU-wide action plan which coordinates all relevant activities (e.g. bilateral trade agreements with developing countries, international development activities, financing and investment safeguards, and public procurement).
Is the current sustainability framework working?	The evidence suggests that the UK's bioenergy sustainability rules (produced by Ofgem and DfT) are helping to limit the sustainability risks, although there is some evidence of negative local impacts (e.g. air quality), intensive forestry management practices, and disagreement around the use of some feedstocks (e.g. low-grade wood and 'thinnings').There are a number of gaps in the framework which must be addressed (in particular around accounting for changes in carbon stocks in existing forests in the sustainability criteria). Issues such as indirect land-use change would benefit from taking a broader approach (as in EU forestry governance).
How much biomass could be available in the future?	The UK currently meets about 7% of its energy needs through biomass, mostly from domestic wastes and forestry residues. Whether the supply of sustainable biomass for energy or products such as wood panels increases or decreases over time will depend on a large number of factors. These include waste collection policy, measures to support the scale up of UK forestry and energy crop planting, and global drivers such as land availability and sustainability governance. Our scenarios suggest the UK could access enough sustainable biomass to provide between 5% and 15% of primary energy demand in 2050.
What is the role for imports in the future?	Biomass imports currently meet around a quarter of the UK's bioenergy demand, principally in the form of wood pellets from North America for the Drax power plant. Whether there is a role for substantial biomass imports in the long-term (post-2027, when existing Government support for Drax expires) will depend on the amount of biomass produced globally and, critically, the strength of global sustainability governance. Imports should only have a role if future efforts to develop this sustainability framework are successful (improved monitoring and transparency, closing gaps) and the UK can have confidence that all imports are both low-carbon and sustainable. This does not imply that the current imports are by definition unsustainable - instead, it recognises some ongoing uncertainty, public controversy and scope for improvement in the rules, particularly if scaling up imports.

Table 1. Q&A at a glance	
Question	**Summary response**
What are the impacts of increasing biomass supply on the landscape?	There are a number of ways of increasing biomass supply, some of which have very little impact on the landscape, for example by better collection of food waste and more biogas production from agricultural residues in farm anaerobic digestion plants. However for much higher amounts of biomass to be supplied, some land will need to be used in different ways. This includes increased afforestation and planting perennial energy crops such as miscanthus on lower quality agricultural land. Overall, a 2050 landscape could look similar to that of today, but with more woodland, some new perennial crops (e.g. miscanthus and willow) and less pasture land.
What is the best use of biomass in the long-term?	Whilst the supply is likely to be limited in the future, the flexibility of sustainable biomass as a low-carbon resource means potential demand could be high across multiple sectors. As a result, decisions will need to be made as to where this scarce resource is best-used across the economy to maximise its overall contribution to mitigating climate change. Our analysis points to end-uses that maximise sequestration (storage of carbon) as being optimal in 2050. These include wood in construction and the production of hydrogen, electricity, industrial products and potentially also aviation biofuels, all with carbon capture and storage. Many current uses of biomass are not in line with long-term best-use and these will need to change.
How should biomass be used to support a transition to long-term best use?	In the short to medium term (through to the 2030s) there are only likely to be limited options for using biomass as part of carbon storage strategies in the UK. As a result, during this transition period, biomass use should be focussed on delivering low cost GHG emissions reduction where this does not lock-in infrastructure or behaviours and where its use helps to create future options, for example by developing key technologies.
What role might BECCS play in achieving UK decarbonisation targets?	Our analysis suggests that bioenergy with carbon capture and storage (BECCS) could be an economically viable way to reduce GHG emissions by around 2030. From this point BECCS could then scale up significantly to make a substantial contribution towards meeting the UK's decarbonisation targets. Depending on the availability of sustainable biomass and the success in deploying BECCS from 2030 onwards, it is possible that between 20 and 65 $MtCO_2e$/yr could be sequestered through BECCS in the UK by 2050. This is equivalent to between 5% and 15% of current UK GHG emissions. There are a wide variety of potential BECCS applications including hydrogen production, the power sector, in industrial sectors and in aviation biofuel production.

Table 1. Q&A at a glance

Question	Summary response
What is the role for wood for heat in homes?	Currently around half of wood grown and used for heating homes in the UK is burnt on open fires (based on the 2014 domestic wood fuel survey), with most of the remainder consumed in wood-burning stoves. In total, wood for heating homes makes up two thirds of heat produced from bioenergy in the UK (not including power sector 'waste heat'). Our advice to Government is to not support any biomass for heat in urban areas because of the air quality impacts, including $PM_{2.5}$ (fine particulate matter with a diameter below 2.5 microns): • Burning wood on open fires is highly inefficient (both for energy production, and on an air quality basis, with $PM_{2.5}$ emissions of around 2950 g/MWh). It should not be counted towards renewable energy targets. • Wood-burning stoves range from $PM_{2.5}$ emissions of around 2660 g/MWh for conventional stoves to 335 g/MWh for a Defra-exempt Ecodesign Stove. The Government's proposed ban on the sale of inefficient stoves and associated proposals in the 2018 draft *Clean Air Strategy 2018* are a positive development. Biomass boilers perform better still (with $PM_{2.5}$ emissions around 216 g/MWh) and can play a role in certain niches (for example, hard-to-insulate rural properties where heat pumps are not viable).

Source: CCC, BEIS (2016) *Summary results of domestic wood use survey*, EMEP/EEA (2016) *Air pollutant emission inventory guidebook*.
Notes: The domestic wood use survey was undertaken in 2014. 'Defra-exempt' stoves are stoves that are cleared to burn specified fuels in smoke control areas - in this case, burning biomass.

Chapter 1: What is biomass and why is it important?

1. Introduction and purpose of the review

Biomass is an integral part of the global carbon cycle. Carbon is absorbed from the atmosphere as plants grow and is rereleased as biological matter decays or burns. These processes mean that changes in global biomass stocks have played a role in regulating the Earth's climate in the past and that careful management of biomass stocks over the next century will be critical to limiting the rise in global temperature to well below 2°C above pre-industrial levels, in line with our commitments under the 2015 Paris Agreement (Figure 1.1).

At a UK level, biomass plays an important role across the economy. Living biomass (e.g. forests) provides important habitats and ecosystems services; land used for agriculture provides food for humans and animals; harvested wood is used in construction, furniture and a range of other applications; and biomass from energy crops, residues and biogenic waste streams is used as a feedstock to produce bioenergy.

In this report we assess the role that harvested biomass and biogenic wastes can play in meeting the 2050 target to cut greenhouse gas emissions by at least 80% from 1990 to 2050, and tighter targets under the Paris Agreement. To do this we take a broad view of the potential role of biomass feedstocks and the land on which they are grown:

- This means recognising the importance of building up carbon stocks in both managed and unmanaged forests and soils and the need for biomass production to be part of integrated and sustainable land-use strategies.
- The broad concept of sustainability is central to our analysis and is used here to include biodiversity, ecosystem benefits (including alleviation of flooding, water and soil quality) and social issues such as impacts on food production and land tenure.

Box 1.1 provides a summary of the key biomass related definitions used in this report.

Our focus is on the role biomass can play in the UK's energy system ('bioenergy') and on its potential to sequester carbon through increased use in construction and other bio-based products. Our objective is to set out the circumstances in which biomass production and use can support decarbonisation objectives and to identify recommendations for policy to ensure that potential benefits are realised and risks minimised.

This report is published alongside parallel work by the Committee on UK land-use and the role of hydrogen in decarbonising the UK's economy.[16] The outputs of these studies will feed into the Committee's future work on long-term climate targets (to be published in 2019) and the UK's sixth carbon budget (published in 2020). It builds on the Committee's 2011 *Bioenergy Review*, which informed the Government's 2012 *Bioenergy Strategy* and our subsequent carbon budget advice (Box 1.2).

To inform our analysis we reviewed a wide range of scientific evidence and engaged with stakeholders from academia, Government, industry and the third sector. This process involved a public Call for Evidence in early 2018 (Box 1.3). We were also supported by a specially convened external expert advisory group with expertise across a range of relevant disciplines, which provided challenge and advice throughout the process.

---

[16] CCC (2018) *Land use: Reducing emissions and preparing for climate change* and *Hydrogen Review*.

Box 1.1. Defining biomass

Biomass - At its broadest this term includes all biological material, including plants, soils and animals. This definition is most relevant to the parts of this report that discuss the carbon cycle, global biomass stocks and global mitigation strategies. However we generally use a narrower definition of the term biomass that excludes unmanaged biomass in living ecosystems and biomass used for food production or other established bio-based products such as clothing, medicine and cosmetics. We do include biogenic wastes and residues from these activities as well as biomass harvested from sustainably-managed forests and crops grown specifically for energy. Harvested biomass can be processed into a range of fuels (such as **liquid biofuels** or **biomethane**) for use in different applications.

Harvested biomass - We use this term when we wish to explicitly distinguish biomass that has been removed from the landscape for human utilisation from biomass that remains in the landscape such as forests and soils.

Biomass resource and feedstocks - This refers to sustainably harvested biomass, wastes and residues that are available for human utilisation. We include in this definition types of biomass that might be considered suitable for energy or other bio-based products such as wood panels (wood panels are reproduced using forestry and sawmill residues). We generally exclude (unless otherwise stated) higher quality sawn timber that has a high value and is better used for structural purposes in construction or for furniture and fittings.

Bioenergy: This refers to the production of energy from biomass, which may also have been converted into liquid biofuels or biomethane.

Bioenergy feedstocks: This refers to biomass feedstocks used for bioenergy.

Biogenic wastes: This refers to solid, liquid or gaseous biomass that is left over from other activities or following the disposal of other products. See Box 1.7 for a breakdown of biogenic wastes.

Bio-based products: This refers to non-energy products wholly or largely made from biomass. It includes construction products such as wood-based panels and glulam beams, bio-based plastics and bio-based chemicals.

Box 1.2. CCC 2011 Bioenergy Review

2011 Bioenergy Review - overview and key findings

In our 2011 *Bioenergy Review*, we set out a framework for thinking about the role of biomass and biogenic wastes in meeting UK carbon budgets. This included estimates of future sustainable supply along with the expected best use of this finite resource. The framework fed through into the Government's *2012 Bioenergy Strategy*, along with our advice on the 2050 target which we published in 2012, the fourth carbon budget review in 2013 and the 2015 advice on the level of the fifth carbon budget (2028-2032).

Our assessment in 2011 was that up to around 10% of the UK's energy needs in 2050 could be met through sustainable bioenergy - from both UK sources and imports - although this would not be without risks of negative biodiversity impacts. We concluded that this could make an important contribution to meeting UK climate targets.

Box 1.2. CCC 2011 Bioenergy Review

The 'best use' hierarchy we established (i.e. the highest priority uses of scarce biomass resources) demonstrated that priority should be given to uses which lock up and store the carbon in the feedstock rather than releasing it in to the atmosphere.

We concluded that using biomass for long-lived non-energy uses is likely to deliver high levels of greenhouse gas (GHG) abatement. This primarily means using wood as a construction material, storing carbon while also displacing high-carbon cement and steel. In an energy context, the greatest potential benefit is when used in combination with Carbon Capture and Storage (CCS) technology to sequester emissions.

We recommended that any remaining sustainable biomass resource should be prioritised for use in sectors without other low-carbon options, such as aviation and industrial process heat, but not (for example) in the power sector without CCS because other low-carbon alternatives exist here.

How does the new advice build on the 2011 report?

Our current advice takes a broader framing by looking at biomass growth, production and use in the context of natural sequestration and the range of human uses and ecosystem benefits. In part, this reflects a growing focus on the role of land, forests and agricultural systems in delivering the 2015 Paris Agreement. Whilst the findings support and build on the 2011 advice, we present an updated view of sustainable supply and best use, taking into account new evidence on sustainability, land availability and yields, fuel-switching potential to hydrogen and lessons learnt from sustainability governance.

Box 1.3. Call for Evidence and stakeholder engagement

The Committee regularly issues calls for evidence to gather the views of a wide range of experts when developing its advice. In December 2017 we launched a public Call for Evidence to enable the Committee to draw on the full range of up-to-date evidence relating to bioenergy supply, sustainability and use. This first stage of formal stakeholder engagement contained thirty five questions grouped into the following topics:

- Greenhouse gas emissions and sustainability of bioenergy imports (5 questions)
- Sustainability policy and certification (6 questions)
- Supply of bioenergy feedstocks (6 questions)
- Scaling up UK sustainable supply (5 questions)
- Best-use of bioenergy resources (7 questions)
- Greenhouse gas emissions reporting and accounting (3 questions)
- Indicators (2 questions)
- Any further evidence (1 question)

Evidence was submitted by a range of stakeholders including trade associations, energy companies, biomass producers, NGOs, government agencies, researchers and certification bodies. The majority of responses were from the UK, but evidence was also submitted by stakeholders in the USA, Canada and Europe.

Respondents were encouraged to only answer questions where they had particular expertise and to provide links to supporting evidence where possible. The question with most responses, focusing on the lifecycle greenhouse gas emissions of biomass and biofuels imported into the UK, received 21 answers. In total, over 600 sources of evidence were collected from the responses, which were each assessed against quality criteria. A summary report analysing the responses to each question and the quality of evidence submitted is published alongside this report.

The responses are published as supporting material to this report, unless otherwise requested.

Following the Call for Evidence, the Committee hosted a series of stakeholder workshops on key topics throughout 2018. Topics covered included the climate impacts of bioenergy, sustainability governance and steps to scaling up UK supply of sustainable biomass.

Notes: The Call for Evidence was published on our website: https://www.theccc.org.uk/bioenergy-review-2018-call-evidence

2. Why is biomass important?

The growth and use of biomass are key components of strategies for mitigating climate change. Biomass provides two overarching routes to reducing levels of greenhouse gases (GHG) in the atmosphere:

- Growing biomass has the potential to *remove* carbon dioxide (CO_2) from the atmosphere and *store* it for long-periods of time (decades or more) in soils, trees and plants. When harvested it can also store carbon through its use in construction, long-lived bio-based products, and in the future via its use for bioenergy with carbon capture and storage (BECCS).
- Harvested biomass can also *reduce fossil GHG emissions* by displacing fossil fuels as an energy source. For biomass used in this way to be low-carbon it must, as a minimum, be harvested from sustainably-managed land that has stable or increasing carbon stocks over time (measured over appropriate spatial and time scales).

Recent studies have explored global mitigation pathways capable of meeting the long-term temperature goal of the Paris Agreement (i.e. to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the increase to 1.5°C). These pathways typically require large-scale changes in land-use to increase stocks of biomass in terrestrial ecosystems and to provide substantial amounts of biomass for use within the economy (Box 1.4).

The prevalence of high levels of biomass within these pathways highlights the strategic importance of land-use, biomass, and potentially BECCS in achieving 'net zero' emissions by providing a route to removing GHG's from the atmosphere (Box 1.5). Our analysis presented in this report builds on this finding. In most circumstances using biomass to sequester carbon will result in more GHG abatement overall than simply displacing fossil fuels. It will typically be most beneficial to use biomass to both store carbon *and* displace fossil fuels.

The production of biomass feedstocks involves complex interactions with both biophysical and socio-economic systems and there are significant risks of high GHG emissions as well as other negative impacts if biomass is produced and used unsustainably. Furthermore, climate change mitigation is just one of a large number of social, economic and environmental drivers behind the use of land and biomass.

There is an increasingly robust evidence base to help distinguish between practices and feedstocks that can deliver positive outcomes for the climate as well as against wider sustainability criteria, and those that deliver negative outcomes. In this report we aim to reflect this evidence base and identify both the benefits and risks of biomass production.

Box 1.4. The role of land-use, biomass and BECCS in meeting global climate change mitigation goals

In many simulated pathways consistent with the long-term temperature goal of the Paris Agreement, the use of **harvested biomass is found to be a key resource** to achieve deep and rapid decarbonisation.

- Scenarios that have at least a 66% chance of limiting warming to below 2°C in 2100 have a share of primary energy from biomass between 7-46% in 2050 and the annual removal of CO_2 through BECCS of between 0-7.8 $GtCO_2$/yr in 2050 (compared to current global emissions of ~42 $GtCO_2$/yr), with deployment at scale generally beginning in the 2020s. The use of biomass for BECCS is consistent with the analysis presented in this report that shows using biomass as a route to sequestering carbon will generally deliver the greatest abatement from this scarce resource (see Chapter 5).
- Scenarios that pursue a 1.5°C warming goal by 2100 generally require even higher levels of biomass use (10-54% of primary energy), coupled with more ambitious reductions in near-term fossil fuel emissions. The production of these feedstocks requires large land footprints (which can range from 60-480 Mha in >66% chance 2°C scenarios and 0-680 million hectares (Mha) in 1.5°C scenarios).
- In many scenarios where the use of BECCS is excluded, **as much if not more** bioenergy feedstock is required to achieve the emissions reductions necessary to meet the same climate outcome. This is because biomass cannot be used as efficiently (in terms of emissions mitigation) as when BECCS is available. This underlies the high value of biomass in achieving mitigation across the economy and indicates that harvested biomass needs to be used strategically in order to maximise its contribution to global mitigation efforts. The preferential use of BECCS within these pathways is consistent with our assessment that applications involving long-term storage of carbon offer the best use of finite biomass feedstocks from a carbon perspective (Chapter 5).

Increasing land carbon stocks through afforestation is also a key mitigation lever in many global pathways. This is often required at the same time as providing large amounts of bioenergy feedstocks:

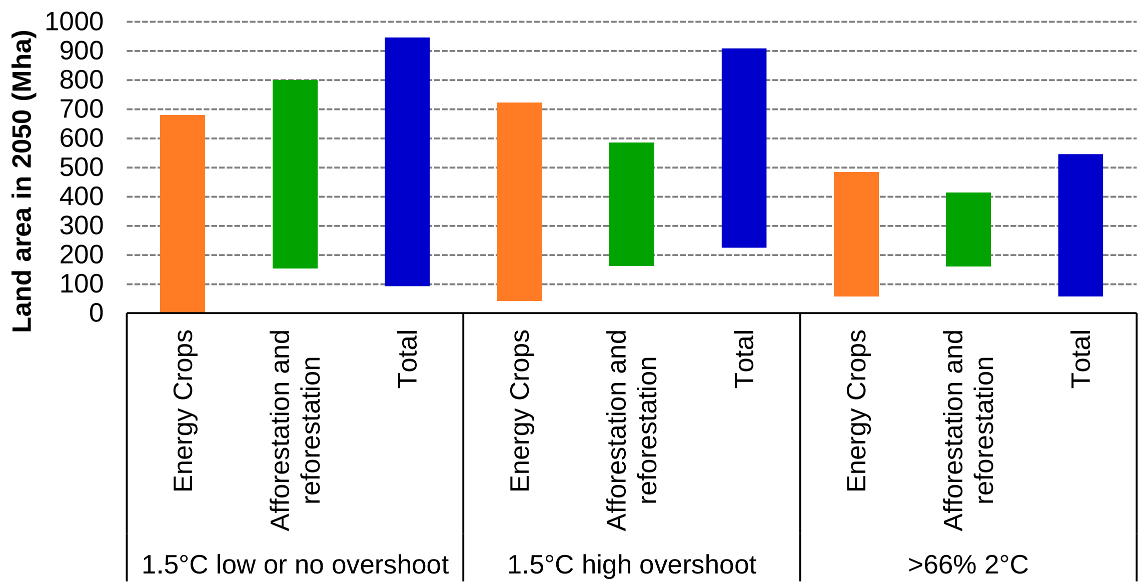
- Reducing deforestation and, in many cases, achieving net afforestation can help to make land a net sink of carbon, providing an offset to residual emissions elsewhere in the economy. This can help to restore the carbon content of the land surface which has been depleted by past management of land. The amount of carbon sequestered through afforestation and other land-use in 2050 can be as large as 6.5 $GtCO_2$/yr for 2°C pathways and up to 10 $GtCO_2$/yr for 1.5°C pathways, requiring between 160-410 Mha and 150-800 Mha.
- The total land-use footprint for afforestation can be larger than for energy crops in some scenarios.
- Large-scale land-use change is therefore a core element of many ambitious global mitigation scenarios (Figure B1.4). This utilisation of land may bring substantial trade-offs with other aspects of sustainability (e.g. biodiversity, land rights etc.) that are generally not explicitly considered within the formulation of these scenarios.

Box 1.4. The role of land-use, biomass and BECCS in meeting global climate change mitigation goals

Recent research has shown that pathways with a >50% chance of limiting warming to beneath 1.5℃ could be met **without large-scale deployment of BECCS** to provide negative emissions.

- This is conditional on the rapid implementation of **ambitious demand-side measures** that substantially reduce energy demand and carbon emissions over the near-term. These measures include substantial improvements in energy efficiency, shifts in diet, rapid electrification and low population growth. If many of these measures can be combined together, then the use of large amounts of **bioenergy without CCS may also be avoidable.**
- These measures are still combined with large-scale afforestation activities to offset any residual emissions from other sectors.

Figure B1.4. 2050 land-use for land-based mitigation in integrated assessment models



Source: IPCC SR1.5 database.
Notes: Global land area used in 2050 for energy crops, afforestation and reforestation, and their combined total in scenario groupings from IPCC SR1.5. The vertical extent of the bars indicates the range across the scenario set. High overshoot is defined as scenarios that have greater than 0.1℃ overshoot at the 50th percentile of the projected warming distribution.

Source: CCC, IPCC SR1.5, Bauer et al. (2018) *Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison;* Boysen et al. (2017) *Trade-offs for food production, nature conservation and climate limit the terrestrial carbon dioxide removal potential;*
Grubler et al. (2018) *A low energy demand scenario for meeting the 1.5 ℃ target and sustainable development goals without negative emission technologies.*

Box 1.5. Summary of potential GHG removal technologies

Greenhouse gas removal (GGR) is the process of deliberately removing GHGs (mainly CO_2) from the atmosphere and its near-permanent storage without re-entering the atmosphere. Proposed methods include the creation of new artificial sinks (such as direct air capture of CO_2 with geological storage) as well as the enhancement of existing natural carbon sinks (such as growing vegetation).

Many proposed methods involve the use of land to achieve net removal at scale:

- **Bioenergy with carbon capture and storage (BECCS):** The use of biomass in energy applications where the biogenic carbon content is prevented from entering the atmosphere and is stored in long-term geological storage sites.
- **Soil carbon sequestration:** Increasing the amount of carbon stored in soils through improved agricultural practice.
- **Afforestation and reforestation**: The planting of new forests on land not currently under forest cover. The forests remove carbon from the atmosphere as they grow.
- **Biochar:** The thermal decomposition of biomass in the absence of oxygen forms a charcoal known as biochar. This can be added to soils to improve soil fertility and to act as a stable long-term store of carbon.
- **Enhanced weathering:** Silicate rocks naturally fix carbon out of the air over geological timescales. This process can be speeded up by grinding up rocks (in order to vastly increase the exposed surface area) which can be dispersed over cropland.
- **Wood in construction:** Harvested wood can be used in as a construction material, creating an additional pool of carbon in the built environment as forest regrowth sequesters additional carbon.
- **Habitat restoration:** Restoring carbon dense habitats such as peatlands can sequester carbon from the atmosphere into the land surface.

As land is a finite resource the use of large land areas to remove carbon from the atmosphere may conflict with other land-uses, which include feeding a growing population, ecosystem services and wildlife conservation.

Additional artificial sinks (such as direct air capture) may be needed in the long-term to replace saturating natural sinks.

- Some land-based carbon sinks will be temporary, for instance soil carbon sequestration will increase soil carbon stocks until they reach an equilibrium with the atmosphere at which point no more additional carbon will be sequestered. This saturation may be expected soon after 2050.
- For land-based GGR methods that store carbon in the landscape, eventual loss of removed carbon stocks may occur if effective land-management methods are not maintained. Effective policies to preserve the land and its carbon stores in the long-term (hundreds of years) against both future anthropogenic activities and risks of disturbances (such as fires and pests), accounting for how these risks might be expected to evolve in a future climate.

Source: CCC and Royal Society/Royal Academy of Engineering (2018) *Greenhouse Gas Removal;* Heck et al (2018) Biomass-based negative emissions difficult to reconcile with planetary boundaries
Notes: Challenges in relation to large-scale BECCS are discussed in Heck et al (2018). Challenges for other removal options with large land-footprints may also be large.

3. Global biomass supply and use

Global forestry[17]

Forests cover around 30% of the world's land area. They store large amounts of carbon and provide vital ecosystem services as well as habitats for a vast range of fungi, plants and animals. They also provide timber and fuel for human consumption. In some parts of the world - including Central and South America and Africa - deforestation remains a prevailing trend, principally due to conversion for agricultural land. In contrast the area of forest in Europe, the USA, Russia, China and India is increasing.

Around 3 billion m^3 of wood is harvested from forests every year. The way in which wood harvested from forests is used varies around the world. In general terms larger proportions of harvested wood are used for energy production in countries with less developed energy infrastructure and distribution systems. For example, 97% of wood harvested in Ethiopia and 89% of wood harvested in India is used as fuel.

Most global production of industrial roundwood from forests (a category that includes sawlogs, veneer logs and pulpwood but excludes materials used for energy) comes from North America, Russia, China and Brazil. Sawn timber is one of the key products produced from this industrial roundwood. It includes planks, beams and boards and is a key construction material used worldwide. Global production of sawn wood is increasing over time to meet rising demand.

Global bioenergy supply and use[18]

Today, bioenergy provides around 9% of global primary energy demand. Much of this is 'traditional' bioenergy in the form of charcoal from unsustainable deforestation, used by some of the world's poorest people to produce heat for cooking (Box 1.6). 'Modern' forms of bioenergy using wastes, residues and purpose grown crops (Box 1.7) make up around 4% of global primary energy demand and are increasingly being used in both developed and developing countries to displace fossil fuels and deliver energy services.

Box 1.6. 'Traditional' bioenergy

'Traditional' bioenergy is solid fuel used for direct combustion. The fuel used can be wood, charcoal, manure or other organic wastes and residues. One-third of traditional bioenergy use is reported to be trees from forests, while two-thirds is trees outside forests and other wastes. It is used by around three billion people worldwide for heating and cooking. These tend to be poorer people in developing countries who often do not have access to electricity or modern fuels.

Traditional bioenergy can have a number of negative impacts on sustainability. For this reason it is excluded from our review.

[17] The information in this section is derived from a technical annex on sustainable forestry management (published as part of the supporting materials to this report) and FAO (2016) *Global forest products: Facts and figures 2016*.
[18] This section draws on recent work by the International Energy Agency, IEA (2017) *Technology Roadmap - Delivering Sustainable Bioenergy*; IEA (2018) *Renewables Market Report*.

Box 1.6. 'Traditional' bioenergy

- Traditional bioenergy has negative impacts on human health. It is combusted on open fires and in traditional stoves. These are inefficient and poorly ventilated, leading to indoor air pollution. This results in respiratory illness which causes almost 1.6 million deaths per year.
- Negative socioeconomic impacts are also attributed to the use of traditional bioenergy. These impacts disproportionately affect women and children. Children and young women collect fuel instead of going to school. Women are unable to work due to the labour demands of collecting fuel.
- Harvesting of traditional bioenergy is also reported to be environmentally unsustainable in some cases. Charcoal harvests exceed regeneration rates. Collection of forest biomass is reported to be contributing to deforestation in some developing regions.

Demand for traditional bioenergy is predicted to decrease through to 2050 as improved access to modern cooking fuels and stoves leads to a decrease in demand.

Sources: IPCC (2014) Appendix Bioenergy: Climate effects, mitigation options, potential and sustainability implications, to Chapter 11 (AFOLU) *Final Draft. IPCC WGIII AR5*.
SCOPE (2015) *Bioenergy & Sustainability: bridging the gaps*, http://bioenfapesp.org/scopebioenergy/index.php

Box 1.7. Bioenergy feedstocks and conversion processes

The main currently available bioenergy feedstocks are:

- **Energy crops:** Crops grown for energy production can be divided into the following categories:
  - 'First generation' crops are crops that are otherwise normally grown for food and typically require agricultural land of a reasonable quality. Examples include maize and sugarcane.
  - 'Second generation' crops are non-food lignocellulosic crops that have the potential to be grown on more marginal types of land. Examples include miscanthus and willow.
- **Forestry residues:** Definitions of forestry residue vary but generally this term includes small branches, bark and thinnings left over from forestry operations and residues from wood processing industries (e.g. sawmills). Some residues should be left in the forest for soil health. High-quality timber suitable for the production of sawn wood is not considered a residue.
- **Agricultural residues:** These fall into two broad categories:
  - Primary agricultural residues are materials left in the field/farm after a crop has been harvested. Examples include straw, rice husks and sugarcane bagasse. A substantial proportion of primary residues should be left in the field to support soil health.
  - Secondary agricultural residues are left-over materials from the processing of crops for food or fibre.
- **Biogenic wastes:** This category includes solid, liquid or gaseous biomass left over from other activities or from the disposal of other products. It does not include forestry or agricultural residues, but does include:
  - Food waste in the domestic and commercial sectors. Food waste is a wet waste resource and likely only suitable for use in an anaerobic digestion plant.

Box 1.7. Bioenergy feedstocks and conversion processes

- – Waste wood comes primarily from the construction and demolition sector. It is a dry solid biomass resource that would be suitable for a variety of end uses.
- – Municipal solid waste is collected from the commercial, industrial and domestic sectors. It currently includes a mix of biogenic and non-biogenic waste.
- – Livestock manures include wet cattle and pig slurries, predominantly suitable for anaerobic digestion or land spreading.
- – Sewage sludge consists of human excreta and is suitable for anaerobic digestion.
- – Tallow and UCO: tallow consists of fat harvested from livestock carcasses, and UCO is used cooking oil collected from both the domestic and commercial sectors. These are both liquid resources most likely used to produce liquid biofuels.

Whilst bioenergy feedstocks can be combusted directly for heat and power, there are also a wide variety of conversion processes to convert feedstocks into fuels (Figure 1.2).

For the purposes of this report we identify two general types of conversion process:

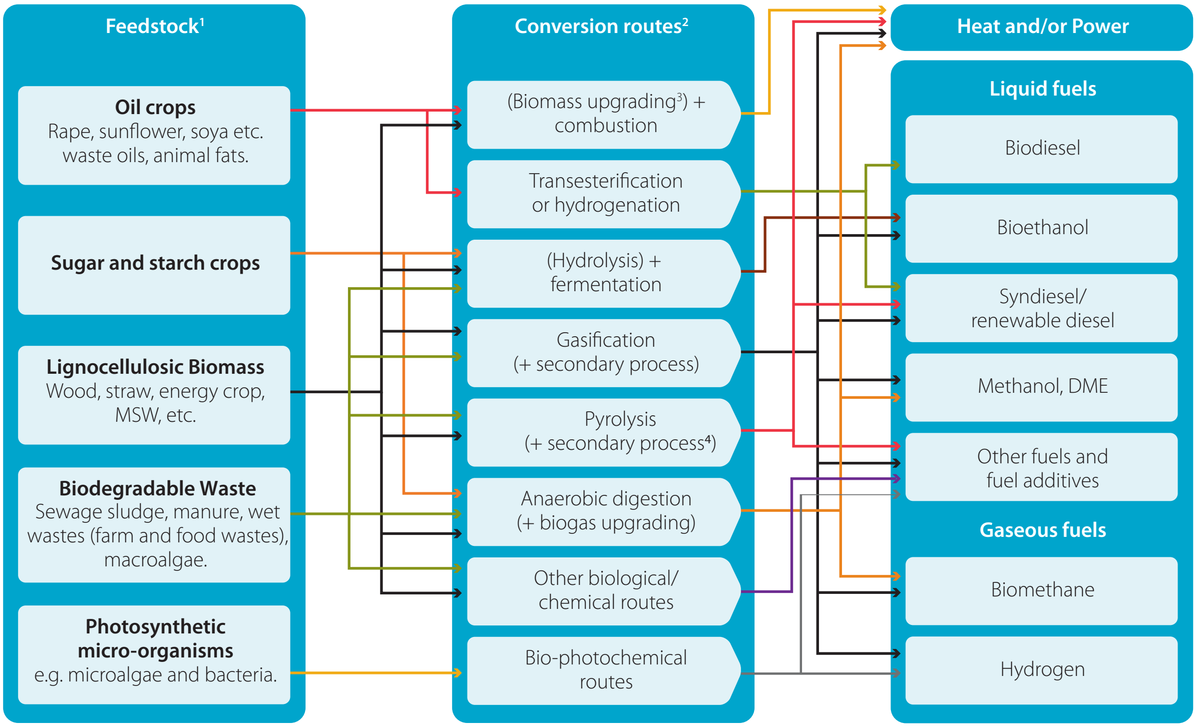
- **Current conversion processes** are mature technologies which are already being widely used to produce biofuels on industrial scales, including fermentation and anaerobic digestion (AD).
- **Advanced conversion processes** are the subject of current research, with some demonstration plants in operation, however they are not yet widely deployed. Examples include cellulosic ethanol production, Fischer-Tropsch synthesis, and pyrolysis.

Research and development is under way to create new and improved fuels from biomass. Much of this is devoted to methods for creating liquid fuels from alternative feedstocks. We therefore refer to two types of liquid biofuel signifying their stages of development:

- **Conventional biofuels** are derived from crops and waste using current conversion processes. Examples include bioethanol from sugar cane and biodiesel from cooking oil.
- **Advanced biofuels** incorporate a range of less developed methods. Many of these apply advanced conversion processes to the dedicated energy crops and the lignocellulosic parts of residues. Others use novel feedstocks such as algae and bacteria.

We also make a distinction between biomethane and biosynthetic natural gas (bio-SNG). Whilst both products are chemically identical (CH_4), biomethane refers to methane produced through AD and bio-SNG refers to methane produced from gasification. In both cases the initial output (sometimes referred to as syngas or biogas) requires cleaning up before it can substitute for natural gas.

Figure 1.2. Bioenergy feedstock conversion chains



Source: The original source is Bauen et al. (2009) Bioenergy - A reliable and sustainable energy source: A review of status and prospects, IEA Bioenergy, International Energy Agency, Paris, 2009. It has been updated.

Notes:

1 Parts of each feedstock, e.g. crop residues, could also be used in other routes.

2 Each route also gives co-products.

3 Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.).

4 Secondary processing routes include catalytic processes such as Fischer Tropsch.

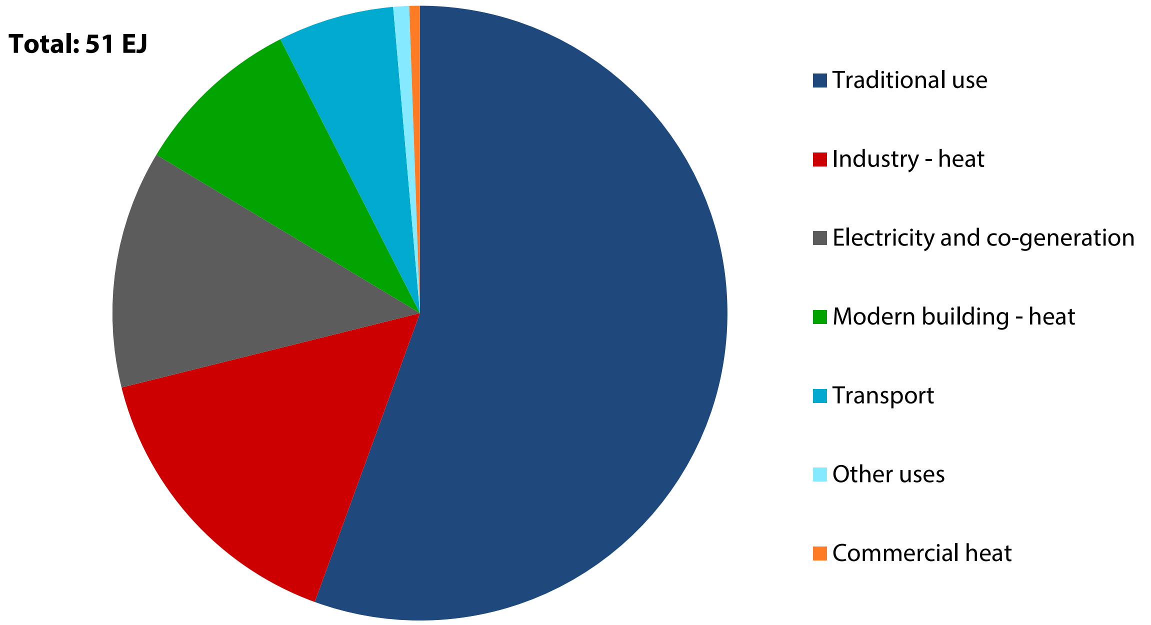
The use of modern forms of bioenergy has increased over the last decade and is currently focussed on four main sectors (Figure 1.3).

- Around 4% of the world's liquid **surface transport** fuels are biofuels, with usage occurring principally in the United States, Brazil and Europe. Despite rapid improvements to Electric Vehicle technologies, the IEA estimates that biofuels will continue to dominate renewable transport fuels over the next five years, contributing around 90% of the growth in this area to 2023.
- **Electricity** from biomass reached around 500 TWh/yr in 2015, around 2% of total global electricity generation. Whilst the IEA expects this to continue increasing over the next five years, other established low-cost renewables such as wind and solar are expected to contribute significantly more. This highlights that bioenergy is just one of a number of viable low-carbon options in the power sector.
- Biomass is currently the main route to renewable **heat in industry** globally and industrial heat is currently the largest end-use sector for modern bioenergy. Much of this is in industries that produce biomass as a residue, for example, pulp and paper. The share of

bioenergy in industry is expected to increase only slightly over the next five years as bioenergy growth in this area only marginally outpaces the growth in industry energy demand overall.

- Modern bioenergy currently provides over half of all renewable **heat for buildings** worldwide, both through on-site combustion and district heat networks. Whilst the IEA expects the use of bioenergy in buildings to increase over the next five years, its share will decrease as other sources of renewable heat are increasingly deployed (e.g. geothermal).

Figure 1.3. Global consumption of biomass and wastes by end-use in 2015



Source: Adapted from IEA (2017) *Technology Roadmap - Delivering Sustainable Bioenergy*.
Notes: This chart quantifies consumption of biomass and wastes in primary energy terms. EJ=Exajoules.

The expansion in modern bioenergy use has been driven by a proliferation of renewable energy support policies globally. By 2017 over 120 countries had adopted auction or Feed-in-Tariff policies for renewable electricity and almost 100 countries had introduced mandates for renewable biofuels in transport.

The IEA estimates that the share of renewable energy in global energy consumption will increase from 10.4% to 12.4% in 2023, with bioenergy contributing a larger share of this increase than any other renewable source. Over time however, the share of bioenergy in renewables is expected to decline as growth from solar and wind accelerates.

4. UK biomass supply and use

UK forestry supply and forest product use[19]

Around 5.5 million over dried tonnes (Modt) of wood is harvested from UK forests and woodlands each year. Over half (60%) is used in sawmills to produce sawn timber with the rest used for woodfuel (20%), wood-based panels (10%), pulp and paper (3%), and other uses (7%).

UK wood production has increased over the last decade. Softwood (from conifers) accounts for 94% of all removals from UK woodlands and total softwood production has increased by around a quarter since 2008. Hardwood production (from broadleaf trees) has increased by over 50%, however this still contributes a small proportion of the overall total.

There is potential for increases in UK wood production over the coming decades as more trees are planted in line with Government targets and as existing poor quality woodlands are brought back into management. However the time-lag between new planting and trees reaching maturity means that increases in production of construction quality sawlogs will be limited until after 2050. Future wood production from UK forests is explored as part of the Committee's land-use report and feeds into the biomass supply scenarios developed in this report (Chapter 4).

The UK is one of the world's largest importers of wood products and currently imports over half of the forestry materials it consumes each year. Imports of sawn wood exceed quantities produced domestically, and in recent years wood imports for bioenergy in the form of wood pellets have increased substatially in response to subsidies in the energy sector.

The construction industry uses most (around 60%) of the sawn wood consumed in the UK each year. This has increased over the last decade as an increasing amount of structural timber is now used in new buildings. The remaining sawn wood consumption is accounted for by the pallet, wood packaging, fencing and furniture markets.

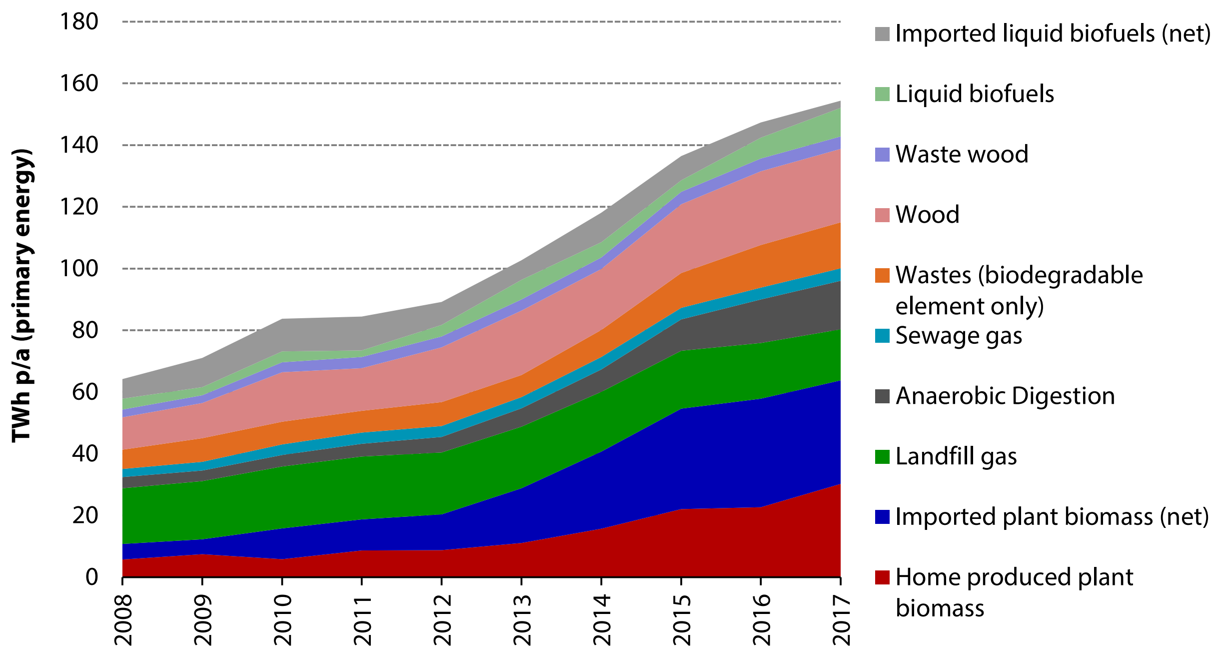
Bioenergy in the UK

The amount of bioenergy used in the UK has more than doubled over the last ten years (Figure 1.4) and it now provides around 7% of total primary energy demand (Figure 1.5):

- Over one-third of this comes from organic wastes, with increases in the amount of municipal solid waste incineration and anaerobic digestion of food and farm wastes over the last decade. Landfill gas continues to be a substantial source of biogas for heat and power.
- Domestic production of plant-based biomass products (such as wood pellets) and the use of straw for energy has increased substantially. Combined with wood burnt in homes, these domestic sources provide around one-third of the UK's bioenergy.
- Net imports have increased more than threefold from around 11 TWh in 2008 to 40 TWh in 2017, driven by wood pellet imports from North America for use in Drax power plant. This means the UK now imports over one-quarter of its bioenergy feedstocks.

[19] Forest Research Statistics were used to inform this section. See: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2018/uk-grown-timber/. Also see: Moore (2015) *Timber utilisation statistics 2014 & 2015 estimates for the Forestry Commission*.

Figure 1.4. Bioenergy supply to the UK from 2008-2017



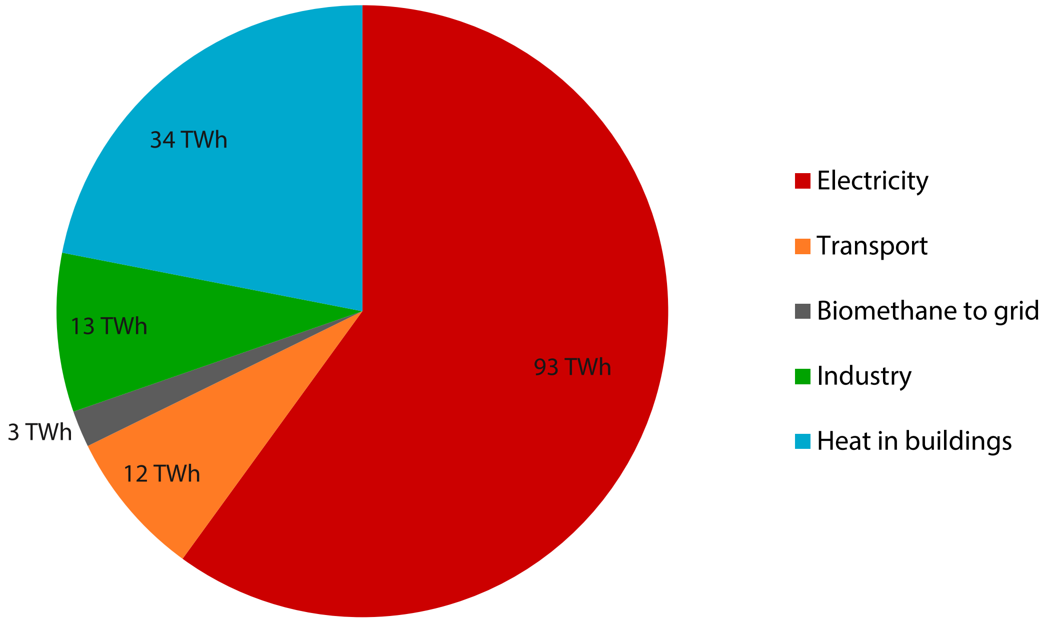
Source: Based on BEIS (2018) *Digest of UK Energy Statistics*.
Notes: The 'plant biomass' category includes straw, energy crops, short rotation forestry, other plant-based biomass and wood pellets. It excludes domestic wood combustion for heat unless supported by the Renewable Heat Incentive.

This increase in bioenergy has been driven by Government policies which have incentivised the use of bioenergy across a range of sectors since 2009:

- The Renewable Transport Fuel Obligation (RTFO) has increased the amount of liquid biofuels required in surface transport over time so that it now stands at around 3%. This is projected to increase to 8% in 2030. When the RTFO was first introduced there were a number of negative sustainability impacts associated with biofuel feedstocks (often food crops), however standards have tightened and now half of all biofuels are made from wastes.
- The Renewables Obligation (RO) and subsequently the Contracts for Difference (CfD) scheme, have incentivised the use of biomass for electricity generation. This has led to four of the six units at Drax power plant converting from coal to biomass. Drax currently generates around 4% of the UK's electricity.
- The Renewable Heat Incentive (RHI) has increased the amount of bioenergy used to heat homes and businesses. The UK is now the third largest market in the world for biomethane injection into the gas grid (2 TWh in 2016), and over 13,000 homes use biomass boilers.

There is variation in levels of bioenergy production and use throughout the UK (Box 1.8). Almost half of the UK's forestry output is derived from Scotland, and bioenergy use is proportionately higher in the devolved administrations than it is in England.

Figure 1.5. Bioenergy use in the UK in 2017 (measured in primary energy)



Source: CCC analysis based on BEIS (2018) *Digest of UK Energy Statistics*.
Notes: Numbers here represent primary energy measured in TWh/yr. By this measure most of the primary bioenergy resource is currently used to generate electricity. However biomass power plants have efficiencies around 35% or lower, meaning that electricity from biomass will be a lower percentage when measured in final energy terms. Biomethane is measured in terms of the energy content of the gas itself rather than the original biomass feedstocks.

Box 1.8. Bioenergy in the devolved administrations

The main areas of devolved responsibilities relating to biomass and bioenergy in the UK are agriculture, land use, waste, planning, local government and housing, as well as energy policy in Northern Ireland. The devolved administrations also have an important role in implementing reserved UK policy through the provision of additional incentives and their approach in areas such as planning.

The devolved administrations consume more energy from biomass and waste, and have a significantly higher proportion of UK woodland and agricultural area relative to their populations and economic output (Table B1.8). This implies that future biomass use may be more concentrated in the devolved administrations or that devolved administrations could be net exporters to the rest of the UK.

Table B1.8. Devolved administrations indicators as proportion of UK total

	Scotland	Wales	Northern Ireland	Total devolved administrations
Population	8%	5%	3%	16%

Box 1.8. Bioenergy in the devolved administrations

GVA	8%	3%	2%	13%
Final energy consumption from bioenergy and waste	11%	12%	6%	29%
Woodland area	46%	10%	4%	59%
Agricultural area	34%	10%	6%	49%

Source: ONS (2018) *Population estimates for the UK, England and Wales, Scotland and Northern Ireland*; ONS (2018) *Regional Gross Value Added (Balanced)*; BEIS (2018) *Sub-national total final energy consumption in the United Kingdom*; Forestry Commission (2018) *Forestry Statistics 2018*; Scottish Government (2018) *Economic Report on Scottish Agriculture, Table C2.*

The devolved administrations currently have varying levels of policy in place to support bioenergy production, although the reserved nature of energy policy in Scotland and Wales means this is largely restricted to the consenting of generating stations and support of bioenergy for renewable heat. There is more scope to influence the supply of biomass through land-use, agriculture and waste policy.

Scotland

The Scottish Government identified bioenergy as one of its strategic priorities in its 2018 *Energy Strategy*, and has committed to developing a bioenergy action plan that is consistent with its 2018 *Climate Change Plan* and 2016 *Land Use Strategy*. A guiding principle of the action plan will be that biomass should be used for energy in heat-only or combined heat and power schemes to exploit available heat and local supply.

In May 2018, Scotland had four biomass or waste power plants operated by major power producers, with an installed capacity of 130 MW.

Scotland participates in the GB-wide RHI scheme with additional interest-free loans provided by the Scottish Government for RHI-eligible installations. Over 90% of all low-carbon heat in Scotland is provided by biomass and biogas.

In 2017-18, Scotland's 7,100 hectares of new tree planting accounted for 78% of all new planting in the UK. The Scottish Government has set a target of 15,000 ha per year by 2025. The National Forest Inventory 50-year forecast predicts that in 2047-2051, Scotland will account for 69% of all available softwood and 26% of available hardwood in Great Britain.

In 2017, Scotland contained 53 of the UK's 164 active sawmills, but produced 52% (1.9 million cubic metres) of all sawn softwood. Almost all (97%) softwood sawlogs processed by Scottish mills in 2017 came from Scotland.

Wales

Wales' 2010 *Bioenergy Action Plan* identified actions to increase the supply of and demand for bioenergy, including supporting a biomass supply chain, increasing woodland planting, diverting wood from landfill, and raising awareness of bioenergy.

Box 1.8. Bioenergy in the devolved administrations

The Welsh Government consultation on a low-carbon pathway to 2030 did not assume significant levels of bioenergy in the Welsh power sector in future.

The Cardiff Energy Recovery Facility is Wales' only operational biomass or waste power station operated by a major power producer. Aberthaw B coal plant has potential to co-fire with 55 MW of biomass, and Shotton Paper Mill uses a biomass CHP system to provide 90 MW of heat capacity and 25 MW of electricity for on-site processes.

In 2016 there were 3,000 biomass heat projects in Wales, with deployment highest in areas with buildings off the gas grid. Many of these are supported by the domestic and non-domestic RHI schemes, the regulation of which is not devolved to Wales.

Northern Ireland

The power sector is a devolved issue in Northern Ireland so there is more scope for Northern Ireland to influence how bioenergy is used than elsewhere. However Northern Ireland shares an all-island network with the Republic of Ireland and has interconnectors to mainland Britain so policies must be compatible with these two markets.

At the end of May 2018, there were no biomass or waste fuelled power plants operated by Major Power Producers in Northern Ireland.

There is currently no policy in place to support the deployment of low-carbon heat, including biomass or biogas, following the closure of the Northern Irish RHI scheme to new applications in 2016. The scheme is currently subject to a public inquiry.

Chapter 2: When is biomass production low-carbon and sustainable?

1. Overview

This chapter reviews the evidence for two key questions:

- **When is biomass production low-carbon?** We start by setting out the evidence for the conditions under which biomass derived from forestry, agricultural production and wastes can be considered low-carbon.
- **When is biomass production sustainable?** We then extend the scope to include other elements of sustainability (biodiversity, ecosystem benefits, social impacts including food security) and assess implications for low-regrets planting strategies in the UK together with sustainability trade-offs.

In Chapter 3, we examine what would be required from policy to ensure that any biomass harvested and used is both low-carbon and sustainable, building on a review of what constitutes effective international governance.[20] The long-term role of biomass imports to the UK should depend on the success of these efforts. Chapter 4 then develops a set of scenarios for future sustainable biomass supply incorporating uncertainty about the strength of future governance, alongside other technological, social and economic uncertainties.

2. When is biomass production low-carbon?

2.1. Introduction and approach

This section summarises the latest evidence regarding how and when biomass production can be low-carbon. A key finding is that there can be substantial variation between crop types, locations and supply chains which leads to a wide range of possible greenhouse gas (GHG) lifecycle emissions associated with biomass growth, production and use.

Managing land for carbon stocks

When **biomass is left in the landscape**, the associated carbon storage varies as a function of climate, crop, management, land-use history, and disturbances such as pests or diseases:

- Planting can disturb soil carbon stocks and lead to temporary losses of carbon.
- Biomass growth rates are driven by climate (e.g. sunlight, temperatures, rain and irrigation, atmospheric CO_2) along with soil quality, crop type and the prevalence of external natural disturbances (e.g. fires, diseases, animal activity).
- Effective use of abandoned and marginal land will be critical for ensuring that land-use contributes to the sustainable mitigation of climate change.

Land carbon stocks averaged over the globe are currently growing,[21] but past human use of land has depleted them relative to their potential for storing carbon.[22] Concerted efforts can help to maximise carbon storage in the land surface:

- **Afforestation and reforestation** (creating new forests and replacing old ones) build up a large stock of biomass, both in vegetation and soils.

[20] Annex 2. What Works: International Sustainability Governance.
[21] Le Quéré, C.L. et al. (2018) Global Carbon Budget 2017. *Earth System Science Data*, 10 (1), 405-448.
[22] Erb, K.H. et al. (2018) Unexpectedly large impact of forest management and grazing on global vegetation biomass. *Nature*, 553 (7686), 73.

– Over time, **sequestration rates slow** as forest carbon stocks approach equilibrium. It may take a large number of decades for carbon stocks to fully equilibriate, particularly whilst atmospheric carbon dioxide concentrations are still rising.

– Unharvested, the maintenance of these carbon stocks **in perpetuity** is essential to ensure that the sequestered carbon does not re-enter the atmosphere. The biomass stock also needs to be resilient against changes in future climatic conditions, natural disturbances and threats from pests and diseases.

– Sustainable forest management, with regular thinnings, enables optimal growth and sequestration. This is because over time, the strongest and healthiest trees are selected to grow to their full height.[23] Achieving current forest planting targets (20,000 hectares p.a. by 2020 and 27,000 hectares p.a. by 2030) will be essential to maximise the potential of emissions sinks over UK land.

- Managed **harvesting and replanting** of afforested land enables both land carbon stocks and long-lived product stores to be increased, allows the substitution of fossil fuel emissions elsewhere in the economy, and offers a hedging strategy against current uncertainty over the evolution of future forest carbon sinks.

  – Uncertainties exist over the long-term future of land carbon sinks due to climate change, and therefore the permanence of carbon stored in unharvested afforested land.[24]

  – Harvesting may, in many cases, reduce the total carbon stored in the forest and wood products compared to an unharvested forest that is resilient to future climate changes.[25] However, if mature forests begin to become sources of emissions to the atmosphere, harvesting wood from afforested land may provide a more resilient long-term carbon store.[26]

  – Harvesting also provides wood products which store carbon and have the potential to displace fossil fuel emissions elsewhere in the economy. When these benefits of long-lived wood products are taken into account along with any displacement of fossilf fuels through bioenergy, sustainable management of afforested land can offers the largest sustained mitigation potential in the long-term.[27]

  – **Land used for energy crops** has a much lower equilibrium carbon content than forested land, but can provide higher average annual biomass yields. If this biomass is utilised with limited supply chain emissions, and with long-term geological storage (BECCS), then energy crops can provide greater cumulative long-term sequestration of carbon than afforestation. This arises due to their potential for continual increases in geologically stored carbon with ongoing BECCS usage, eventually outweighing the finite store of carbon within an afforested landscape and its products.

[23] Annex 1. Sustainable Forestry Management.

[24] Cias, P. et al. (2013) Carbon and other biogeochemical cycles. In: Climate Change 2013: The Physical Science Basis

[25] Ter-Mikaelian, M.T., Colombo, S.J. and Chen, J. (2013) Effects of harvesting on spatial and temporal diversity of carbon stocks in a boreal forest landscape. *Ecology and evolution*, 3 (11), 3738-3750.

[26] Bellassen, V. and Luyssaert, S. (2014) Carbon sequestration: Managing forests in uncertain times. *Nature*, 506 (7487), 153-155.

[27] Lippke, B. (2011) Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns. *Carbon Management*, 2 (3), 303-333.

The optimal use of land from a climate change mitigation perspective is likely to vary from location to location and will be determined, in part, by additional factors such as costs and incentives for land owners:

- Exploring these trade-offs within integrated frameworks that include both the land carbon-cycle and the energy system will be an important area of further research to understand better how to use land most efficiently.[28]
- An essential part of this will be a full consideration of the effects of land-use on climate change, including effects from changed surface albedo and short-lived climate forcing agents such as aerosols.[29]

Where **carbon-rich environments** such as peatlands exist, preventing further degradation and restoring these environments can prevent substantial sources of emissions and help to provide a number of ecosystem services:

- Peatlands in the UK are currently a substantial source of emissions and cover around 12% of UK land-area. Peatlands will be fully included within the UK emissions inventory by 2022.
- Restoring bare peatland with vegetation can help restrict the run-off from high precipitation upland areas, helping to manage flood related risks to population centres.
- Peatland also has an important role to play in the natural cycling of water, with knock-on effects for the quality of drinking water.

Harvesting biomass for use

When biomass is harvested and used, the potential range of GHG impacts increases.

- The use of some biomass for energy production or products can lead to substantial net GHG savings relative to high-carbon alternatives - particularly where it eliminates potent greenhouse gas emissions. For example, it can avoid emissions from biological wastes that would instead be left to decay, and where the carbon in the biomass enters long-term stores (e.g. buildings and geological storage).
- Alternatively, the production of some biomass feedstocks could lead to larger net GHG emissions than fossil fuel alternatives. This can occur where the carbon contained within the feedstock is released into the atmosphere and the same amount of carbon is not replaced back into the landscape (through regrowing the harvested crop or tree whilst maintaining soil carbon stocks), for example through deforestation.

Producing an equivalent amount of useable energy from biomass feedstocks releases more GHG emissions, **at the point of combustion**, than from fossil fuels: fossil fuels have a greater carbon content than biomass (60-80% for coal, ~50% for biomass), but are significantly more energy dense (26-28 MJ/kg for coal, compared to 18-20 MJ/kg for dry wood). Additionally, biomass feedstocks have a greater water content, reducing their combustion efficiency (~10% compared to fossil fuels).

---

[28] Harper, A. B. et al. (2018) Land-use emissions play a critical role in land-based mitigation for Paris climate targets. *Nature Communications*, 9 (1), 2938.
[29] Luyssaert et al. (2018) Trade-offs in using European forests to meet climate objectives. *Nature*, 562, 259–262.

However, calculating the net GHG from biomass-based energy production is **more complex than simply counting emissions at the point of combustion**:

- Unlike for fossil fuels, carbon released when the biomass is burnt can be re-sequestered from the atmosphere as the source of the biomass feedstock regrows.
- Additional GHG emissions are associated with the production and processing of biomass feedstocks. These may be different to those associated with the production and processing of fossil fuels.
- The long-term amount of carbon stored in the land biosphere (averaged over cycles of harvest and regrowth) can be decreased, or possibly increased, by the production of harvestable biomass. It needs to be assessed relative to a **counterfactual** 'world that might have been' without increases in biomass production.

Approach

The following three subsections focus on different contributions to the overall net GHG emissions from biomass production:

- **Direct land-use emissions**: Changes in the land carbon stock on the site of bioenergy production, including where a *land use transition* does *not* occur, such as may be the case for biomass sourced from existing managed forests.
- **Indirect land-use change emissions**: Changes in the land carbon stock at locations separate to the site of production, if the use of biomass for energy displaces existing uses of biomass such as food, fibre and wood products.
- **Emissions from the cultivation of biomass** (e.g. GHG emissions released from soils due to fertilizer application) and from **processing** and **transporting** the biomass feedstock.

2.2. Direct land-use emissions

Biomass production can change land carbon stocks through changes in:

- The stock of carbon in living vegetation (e.g. the carbon in trees growing in a forest).
- The stock of carbon as dead and decaying biomass in soils or litter.

These changes can occur when land-use changes (e.g. converting grasslands to dedicated bioenergy crop plantations) and with changes in land management that do not involve a change in land-use, such as changing forest management practices to produce additional fuel wood.

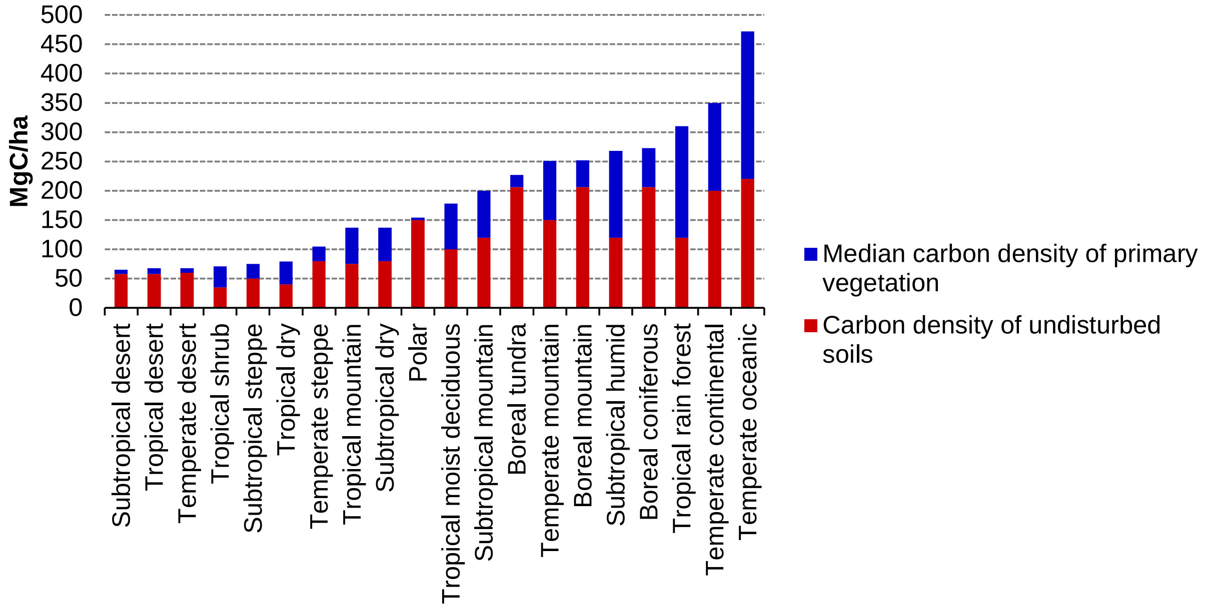
Land-use changes

Preventing the conversion of high-carbon land is critical to ensuring low-carbon biomass supply. This means excluding the conversion to cropland of **forest, peatland and other high-carbon content lands**, particularly those in a primary (natural) state:[30]

[30] Elshout, P. M. F. et a.l (2015) Greenhouse-gas payback times for crop-based biofuels. *Nature Climate Change*, 5, 604–610.

- The total land carbon stocks can be very different between different categories of land cover in natural states (Figure 2.1) and under human use. Cropland often represents a state of low-carbon stock relative to other uses.
- **Old-growth woodlands** are large stores of carbon. Over all but the longest timescales, harvesting these stores will lead to large losses in forest carbon that will outweigh any benefits from avoided fossil fuel emissions in the energy system.[31]
- **Peatlands** contain layers of partially decomposed organic material preserved in waterlogged environments. They contain a large fraction of the world's terrestrial carbon stock and when damaged or destroyed can become large sources of GHG emissions.

Figure 2.1. Carbon content of different natural land-cover zones



Source: Houghton, R.A. and Nassikas, A.A. (2017) Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochemical Cycles*, 31 (3), 456-472.
Notes: Peat layers are not included in this figure but are generally the largest store of carbon in land-cover types where they exist.

Both **perennial bioenergy crops** (such as miscanthus or short rotation coppice - SRC) and **short rotation forestry** (SRF) planted on arable or marginal land can increase land carbon stocks:

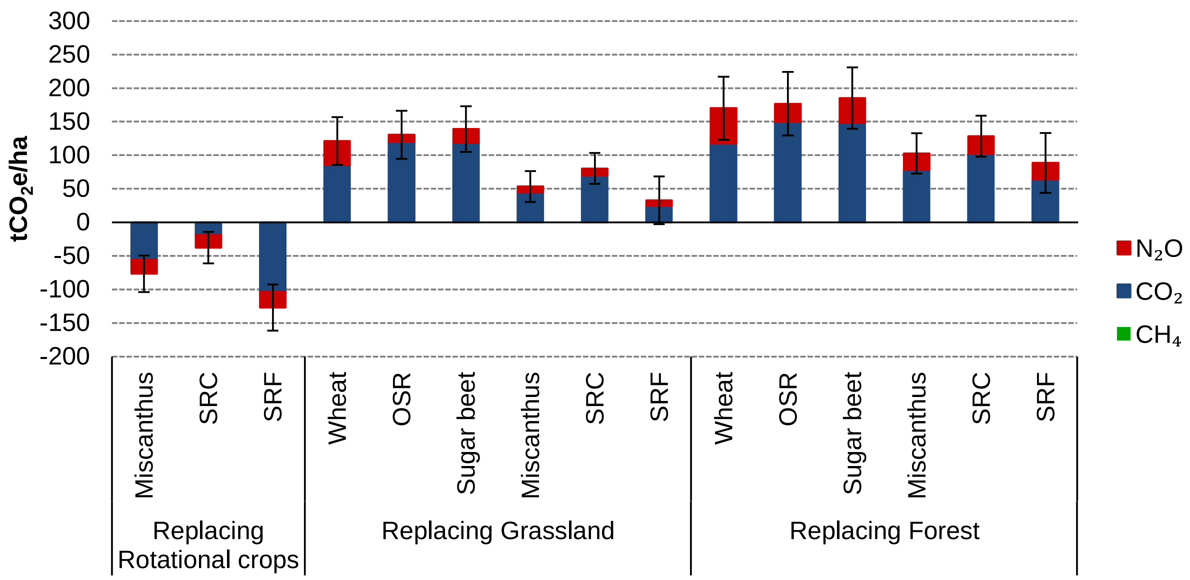
- **Perennial bioenrgy crops**, which do not need to be replanted every year, can lead to a net increase in the total soil carbon stocks when planted on marginal and degraded agricultural land or land currently used for annual crops (Figure 2.2).[32] Planting perennial crops on

[31] Mitchell, S.R., Harmon, M.E. and O'Connell, K.E. (2012) Carbon debt and carbon sequestration parity in forest bioenergy production. *GCB Bioenergy*, 4 (6), 818-827; Harmon, M.E., Ferrell, W.K. and Franklin, J.F. (1990) Effects on carbon storage of conversion of old-growth forests to young forests. *Science*, 247 (4943), 699-702.
[32] McCalmont, J.P. et al. (2017) Environmental costs and benefits of growing Miscanthus for bioenergy in the UK. *GCB Bioenergy*, 9 (3), 489-507.

agricultural land may however create risks associated with indirect land-use change – see section 2.3 - as these lands could otherwise be used for food production.

- **Short rotation forestry** leads to long-term increases in the land carbon stock when not planted on existing high-carbon lands. Creating new woodland for both harvest wood products and fuel can be compatible with increased land carbon stocks provided that indirect land-use change emissions are limited by avoiding conflicts with food products. Recent and on-going research efforts are substantially improving our understanding of the effects of land-use change in the UK on GHG emissions associated with biomass production (Box 2.1).

Figure 2.2. Simulated cumulative greenhouse gas emissions to the atmosphere from soil after 35 years following a land-use transition



Source: Richards, M. et al. (2017) High-resolution spatial modelling of greenhouse gas emissions from land-use change to energy crops in the United Kingdom. *GCB Bioenergy*, 9 (3), 627-644.
Notes: Median (50th percentile) values are shown across all simulated land-use changes at different locations across the UK. Cumulative CH_4 emissions associated with these transitions are generally very small relative to the CO_2 and N_2O contributions and are barely visible in the above figure. Above-ground biomass is also critical to the total change in land-carbon stocks where short-rotation forestry or existing forest cover is involved (not shown). Error bars show standard deviation in total soil GHG emissions across UK transitions considered.

Box 2.1 Land-use change emissions in the UK

Recent research efforts (Harris et al., 2014; Whitaker et al., 2018) have substantially advanced the understanding of land-use change emissions associated with biomass production in the UK, through a set of detailed measurement campaigns. Key findings include:

- Changes in soil carbon stocks were the primary determinant of whether a given land-use change to energy crops was beneficial or negative in terms of a site's net soil GHG emissions (which also include smaller contributions from changes in N_2O and CH_4 emissions - Figure 2.2).

Box 2.1 Land-use change emissions in the UK

- Across the UK, all assessed transitions from arable to second generation bioenergy crops delivered GHG savings.
- Transitions from grassland to first generation crops (wheat, oilseed rape and sugar beet), showed significantly greater net increases in soil GHG emissions than grassland to second generation bioenergy crops (middle partition of Figure 2.2).
- Transitions from forest to any other crop generally resulted in increased soil GHG emissions, as a result of reductions in soil carbon and increased CO_2 fluxes.

Source: ELUM Project (2018), elum.ac.uk; Harris, Z. M. et al. (2014) Research Spotlight: The ELUM project: Ecosystem Land-Use Modelling and Soil Carbon GHG Flux Trial. *Biofuels*, 5 (2), 111-116; Whitaker, J. et al. (2018) Consensus, uncertainties and challenges for perennial bioenergy crops and land use. *GCB Bioenergy*, 10 (3), 150-164.

Land carbon stocks for forest biomass from existing managed forests

The effect of changes in management practices for **existing managed forests** will depend on the specific circumstances and timescale considered:

- Evaluating the net GHG impact of biomass production from forests always needs to be done relative to what would have happened if the biomass had not been utilised for energy purposes (the 'counterfactual'). This includes recognising that harvesting patterns may be different in the absence of the use of the biomass for energy, affecting the composition and age distribution of stands within a forest. Because the growth rate of a forest varies depending on the age of its stands, forest carbon stocks will naturally evolve over time even without any change in management practice.
- Changes in forest management practice can have positive and negative effects on forest carbon stocks. Certain changes, such as an increase in harvesting frequency within a forest, will affect the evolution of the total forest carbon stock (including both the soil carbon stocks, which can hold around half of the total carbon stored within forests, and the stock of carbon within harvested wood products).
- The net impacts of a change in forest management on GHG emissions are highly dependent on the specific management change, the counterfactual evolution of the forest, and the end-use of the wood (Box 2.2).

Box 2.2 Assessing GHG emissions from forest biomass

The net cumulative emissions of CO_2 associated with forest biomass utilisation depends on the **supply chain emissions, the forest carbon stock counterfactual, the end-use application** and will vary over time.

- The appropriate counterfactual forest carbon stock **depends on the economic drivers underlying forest management**.
  - Existing managed forests are managed for a number of products, including the production of high-value sawn timber (Matthews et al., 2014). These high-value products are at present more important economic drivers of forest management than biomass production for energy uses. As such, a continuation of current forest management practice may, in many

Box 2.2 Assessing GHG emissions from forest biomass

cases, be an appropriate counterfactual against which the production of additional biomass from managed woodlands can be compared.

  - Some management changes to provide additional wood harvest may reduce the level of carbon stored within the forest landscape (averaged over the cycle of harvest and regrowth) and its long-lived products relative to the counterfactual. This provides a net source of cumulative emissions to the atmosphere (green line in left panel of Figure B2.2).
  - However, if the demand for additional biomass creates incentives to enhance the time-average carbon content and productive capacity of existing forests then total land carbon stocks may instead be increased relative to the counterfactual (green line in right panel of Figure B2.2), resulting in a net sink of cumulative emissions to the atmosphere.

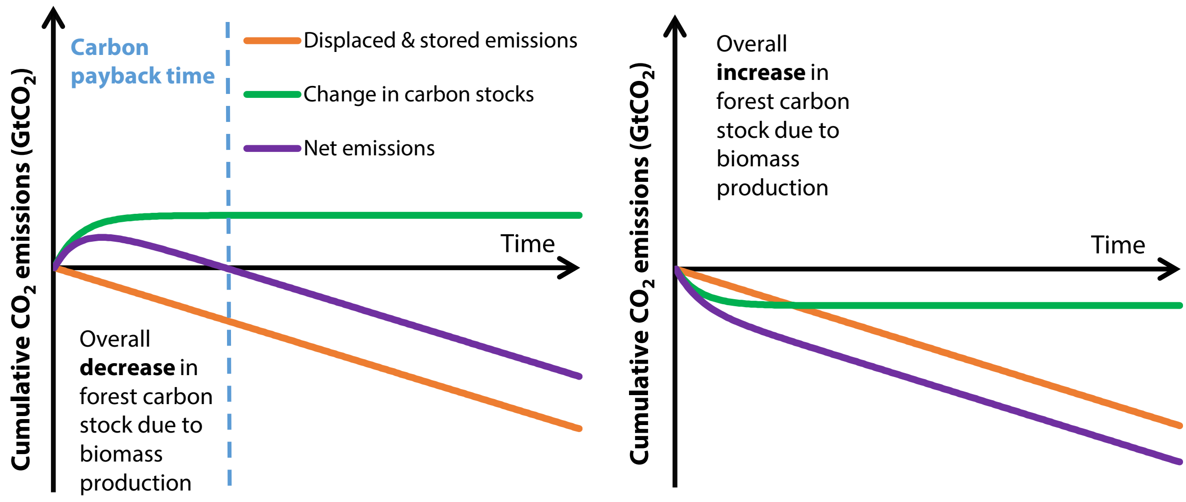
- The total **net avoided fossil fuel emissions** and **stored biogenic carbon** associated with the use of forest biomass for energy (orange lines in Figure B2.2) will vary depending on the end-use application.
  - One key contributor to the potential to displace emissions elsewhere in the economy is the rate of forest growth. Faster growing forests provide wood products and wood fuel more rapidly than slower growing forests, enabling more cumulative emissions to be displaced from the energy system over a given time period.
- The combined effect of changes in forest carbon stocks and avoided fossil fuel emissions can lead to a **complex shape** in the net cumulative emissions to the atmosphere (purple lines in Figure B2.2) when utilising forest biomass for energy.

When biomass production reduces forest carbon stocks relative to the counterfactual (left hand panel of Figure B2.2), it takes a finite length of time for the use of this biomass to become beneficial for the climate (**the carbon payback time**).

- Within the scientific literature, there are multiple definitions of carbon payback time. For carbon payback times to be truly representative of the timings of climate benefits, it is essential that all emissions and carbon pools from the forest, stores of harvested wood products, and energy system emissions are included in both the bioenergy and counterfactual scenarios.
- It is only when total cumulative emissions across both the forest and economy are **lower** in the bioenergy scenario than in the counterfactual (purple lines below x-axis in Figure B2.2) that utilising forest bioenergy contributes to climate change mitigation.

Box 2.2 Assessing GHG emissions from forest biomass

Figure B2.2. Schematic of carbon payback time for forest bioenergy sources



Source: CCC analysis.
Notes: Loss of land carbon stocks are shown averaged over the spatial scale of the forest and over the harvest and regrowth cycle of forest stands. Displaced and stored emissions (inclusive of any biomass supply emissions) and changes in carbon stocks (shown as emissions to the atmosphere) are both expressed relative to the counterfactual.

Source: Matthews et al. (2014) *Review of literature on biogenic carbon and life cycle assessment of forest bioenergy*, https://ec.europa.eu/energy/sites/ener/files/documents/2014_05_review_of_literature_on_biogenic_carbon_report.pdf
Notes: A continuation of the current forest management practice counterfactual is also to be used in new EU Land-use Land-use change and Forestry (LULUCF) regulation for accounting for emissions from the forest management sector as part of national emissions reduction targets.

Biomass production from existing managed forests covers a wide range of possible GHG emissions, depending on the forest management change and the appropriate counterfactual (Figure 2.3).[33]

Several possible forest-based biomass production pathways could lead to the long-term reduction of total land carbon stocks and, even when that biomass is used optimally (Chapter 5), could lead to carbon payback periods of many decades:

- **Harvesting of currently unmanaged mature forests (with high carbon stocks) for biomass** could lead to the reduction of very large carbon stocks that have been built up over

[33] This section summarises some sources of systematic variation between different sources of forest bioenergy and draws heavily on recent assessments conducted by Forest Research. Matthews et al (2018) *Carbon Impacts of biomass consumed in the EU: Supplementary analysis and interpretation for the European Climate Foundation*, https://europeanclimate.org/wp-content/uploads/2018/05/CIB-Summary-report-for-ECF-v10.5-May-20181.pdf

decades to centuries, including negative impacts on the soil carbon stock, even if replaced by rapidly growing short rotation forests.[34]

- **Harvesting of stemwood** (which is mainly used for high-value harvested wood products) *entirely* for energy use, where this would eliminate an effective use of wood in long-lived products, may lead to indirect emissions as a result of the need to continue to meet the demand for existing high-value stemwood products.[35] Small thinnings (not suitable for producing sawn wood) that are extracted as part of sustainable forest management, in order to improve the growing stock of the remaining trees, may be suitable for utilisation for bioenergy. This is because the thinning of stands does not frequently entail a change in forest management and helps to ensure that wood harvested in later years is suitable for high-quality and long-lived products.
- **Using roots and stumps** to produce energy can be associated with very high GHG emissions as stumps and roots decay in the forest in nearly all counterfactual scenarios and are essential to maintain forest soil carbon stocks and soil nutrients.[36] Some exceptions may exist when the removal of stumps and roots is necessary to aid disease control.
- **A reduction in harvest rotation periods** (relative to the counterfactual) reduces the average level of carbon stocks in a forest over the harvest cycle, unless there are other associated changes in forest management (e.g. restocking with more productive trees). The overall GHG emissions and carbon payback times depend critically on how the harvested wood is used (e.g. the balance between use for construction and/or bioenergy) and on the counterfactual products that are displaced by the wood products.

The effect of the **extraction of harvest residues that would otherwise be left in the forest** to decompose also creates a long-term reduction in average forest carbon stocks, but may offer net carbon benefits if used in applications with the potential to displace large amounts of fossil fuel emissions and/or when geological storage is available:

- Whilst most carbon in the harvest residues will decompose and enter the atmosphere on timescales of decades, some will also be retained in soil and litter carbon stocks over multi-decadal time periods. Ensuring that a sufficient fraction of residues remains in the forest can be important for maintaining the future productivity of the forest.
- Residues decay at different rates depending on climatic conditions and their size. Residues decay faster in warmer and wetter climatic conditions, and fine residues decay faster than coarse ones. Therefore the contribution of fast-decaying residues on the forest floor to time-average total forest carbon stocks is small. The contribution can be significant for slowly decaying residues (e.g. from boreal forests in Canada and Northern Europe).
- Particularly when biomass use applications with long-term storage are available (for example BECCS applications), utilising some fast decaying residues as biomass resources can offer

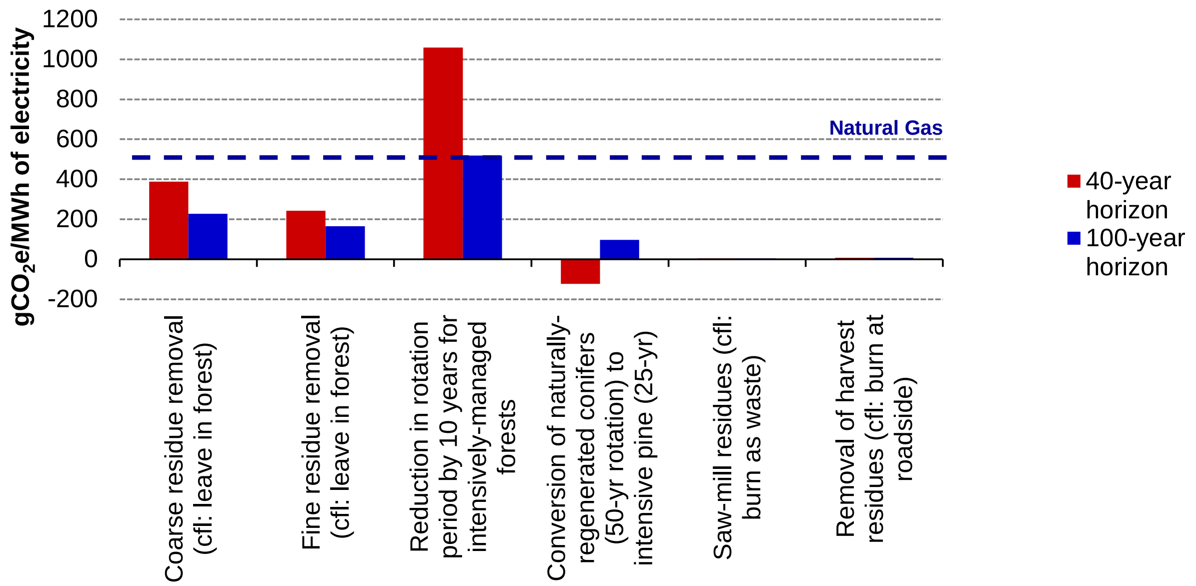
[34] Pukkala, T. (2017) Does management improve the carbon balance of forestry? *Forestry: An International Journal of Forest Research*, 90(1), 125-135; Harmon, M.E., Ferrell, W.K. and Franklin, J.F. (1990) Effects on carbon storage of conversion of old-growth forests to young forests. *Science*, 247 (4943), 699-702.
[35] Matthews et al. (2014) *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/282812/DECC_carbon_impacts_final_report30th_January_2014.pdf
[36] Walmsley, J.D. and Godbold, D.L. (2009) Stump harvesting for bioenergy–a review of the environmental impacts. *Forestry*, 83 (1), 17-38.

overall carbon benefits as a larger fraction of biogenic carbon is permanently stored in the geological sink than within forest soils.

Other sources of forest biomass are likely to be associated with short or negligible carbon payback times and low GHG emissions as they do not create significant decreases in the forest carbon stock:

- **Sources that do not result in any change in forest management**, such as the utilisation of residues from sawmills for energy use, do not deplete forest carbon stocks and therefore have payback times of essentially zero. Some sawmill residues are already used for producing MDF and pulp and paper, so large-scale utilisation for energy would come with risks of indirect land-use emissions if this demand is displaced.
- **Residues from harvesting, that would otherwise be burned within the forest without energy recovery**, are associated with negligible carbon payback periods as the combustion of residues in the counterfactual means that the carbon content of the residue wood would otherwise have rapidly entered the atmosphere.

Figure 2.3. GHG emissions associated with a subset of South-East USA biomass for electricity pathways from the BEAC study



Source: Stephenson, A.L. and MacKay, D.J.C. (2014) *Life Cycle Impacts of Biomass Electricity in 2020*, https://www.gov.uk/government/publications/life-cycle-impacts-of-biomass-electricity-in-2020

Notes: A subset of scenarios for forest biomass based electricity generation from South-East USA. The scenarios shown include several residue removal scenarios as well as a number of scenarios that were assessed to be possible high carbon responses to an increased demand for wood pellets in Ricardo (2017) *Use of North American woody biomass in UK electricity generation: Assessment of high carbon biomass fuel sourcing scenarios*, https://www.gov.uk/government/publications/use-of-high-carbon-north-american-woody-biomass-in-uk-electricity-generation. cfl = counterfactual. Emissions are shown for two different time horizons to indicate the sometimes large sensitivity of the associated emissions to the timeframe they are evaluated over.

2.3. Indirect land-use change emissions

Land, and products produced from land, have a number of uses including food, fuel and fibre. When existing productive land is used to provide biomass for an additional energy use there are risks that it may drive the conversion of land elsewhere in order to meet existing demand for products. This would result in indirect land-use change (iLUC) emissions.

iLUC can also be associated with any biomass source that has other existing uses:

- iLUC has been studied mostly in connection with the use of agricultural crops for biofuels, which may displace food production to other locations to meet existing food demand.
- Sawmill residues can be used for wood panelling and pulp, so large-scale production of energy from these residues may drive land-use changes as the pulp and panelling industries seek new sources of biomass.

iLUC GHG emissions occur at locations separate from the locations where biomass used for energy purposes is produced. These emissions therefore result from, and are mediated by, market effects. Due to uncertainties in how markets might respond to increases in demand for biomass for energy, iLUC emissions are challenging to estimate and have very broad uncertainty ranges (Box 2.3).

Box 2.3. Challenges in estimating iLUC emissions

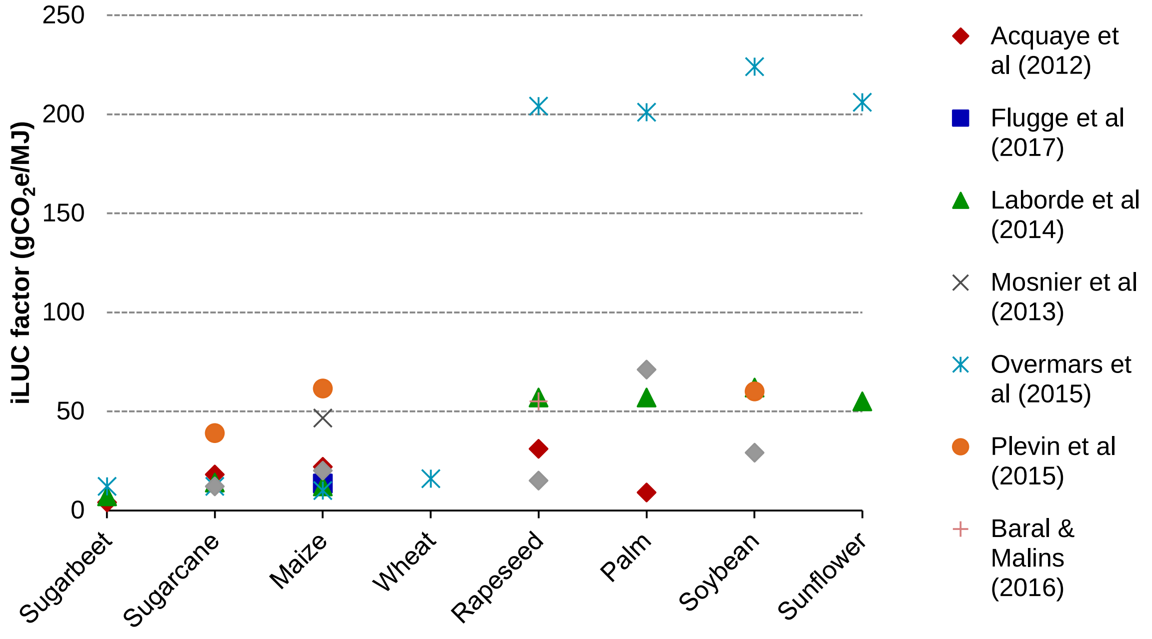
A number of factors underlie the large range of iLUC estimates between different studies:

- Models are always needed to assess the causal link between bioenergy deployment and changes in other land-use, making modelling uncertainty unavoidable, including for empirically-based studies (Overmars et al., 2015). Particular uncertainty exists regarding the elasticity of yields to crop prices and the carbon content of the additional land converted (Malins et al., 2014).
- iLUC effects may be experienced only with a substantial temporal delay.
- As iLUC effects are propagated through connected markets, which are often global in scale, they are not necessarily confined to locations close to the sites of bioenergy production.
- iLUC effects may not be linear in the amount of bioenergy required, so results may be sensitive to the amount of biomass used for energy.

Source: Overmars et al. (2015) *Estimates of indirect land- use change from biofuels based on historical data*, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC91339/eur26819_online.pdf; Malins et al. (2014) A *Guide for the Perplexed to the Indirect Effects of Biofuels Production*, https://www.theicct.org/publications/guide-perplexed-indirect-effects-biofuels-production.

Differences in estimates of iLUC factors more than span the difference between feedstocks under a single modelling framework (Figure 2.4). However, iLUC contributions are generally estimated to be substantial contributors to the overall GHG emissions associated with first generation feedstocks, requiring policy and regulation to be put in place to limit iLUC as much as possible.

Figure 2.4. Range of different iLUC estimates in the literature disaggregated by feedstock



Source: Woltjer et al. (2017) *Study report on reporting requirements on biofuels and bioliquids stemming from the Directive (EU) 2015/1513*, https://ec.europa.eu/energy/sites/ener/files/documents/20170816_iluc_finalstudyreport.pdf
Notes: Studies contributing to the wide spread in range for any feedstock are not necessarily directly comparable in their assumptions, scope and methodologies but give an indicative range of modelling uncertainty for each feedstock. Only post-2011 studies that separate out indirect from direct land-use change emissions contributions are included here, with all land-use change emissions harmonised to a 20-year amortization period.

Although estimating iLUC effects remains complex, contested,[37] and with wide uncertainties in iLUC factors, some features of relatively lower iLUC can be identified:

- **Second generation bioenergy crops that are grown on marginal or abandoned agricultural** land have very limited iLUC risks compared to biomass that is produced from crops that could otherwise be eaten.[38]
  - Within the category of first generation biofuel feedstocks, vegetable-oil based biofuels (such as palm oil, rapeseed, soybean and sunflower) typically have higher risks of large indirect land-use emissions compared to non-vegetable-oil based biofuels. This arises largely due to additional deforestation of very high carbon land, needed to meet existing demand from oil-based products (e.g. palm oil in South-East Asia).[39]
  - If bioenergy crops grown on marginal or abandoned land also create co-products that are useful elsewhere (e.g. in maintaining soil productivity), these crops could have beneficial indirect effects by increasing land carbon stocks elsewhere.

[37] Zilberman (2017) Indirect land-use change: much ado about (almost) nothing.
[38] Woltjer et al (2017). *Study report on reporting requirements on biofuels and bioliquids stemming from the Directive (EU) 2015/1513*, https://ec.europa.eu/energy/sites/ener/files/documents/20170816_iluc_finalstudyreport.pdf
[39] Valin et al. (2015) *The land-use change impact of biofuels consumed in the EU*, https://ec.europa.eu/energy/sites/ener/files/documents/Final%20Report_GLOBIOM_publication.pdf

- **Residues from food production that are currently discarded and do not have other economic uses** could be used as a feedstock without risks of the conversion of additional land. However, agricultural residues often have existing uses, such as application to soil to maintain soil productivity or animal bedding. Displacing existing uses of agricultural residues could lead to iLUC emissions in order to provide biomass for these displaced uses.

iLUC risk is associated with biomass use for energy at large-scales where this use **creates competition with other uses of biomass**. Policies and technologies that reduce competition, protect high carbon land and promote more efficient uses of land will help to ensure that this scale limit isn't breached.

- Due to the substantial uncertainty in the absolute value of iLUC factors, the robust inclusion of quantitative iLUC factors within sustainability schemes is likely to be challenging.
- However, policies can be put in place to help limit iLUC risks.
  - Preventing the conversion of high-carbon content land can help reduce the risks of high iLUC emissions, as can using bespoke tools such as the country- and operator-level food security tools developed by UN FAO.[40]
  - Policies and initiatives that aim to improve agricultural yields could also be effective. Other approaches include supporting mixed food-energy systems (Box 4.2), avoiding annual crops which use the same land as food crops and only planting on abandoned or marginal land.

2.4. Emissions from cultivation, processing and transportation

This section looks at emissions from the production of biomass and emissions resulting from specific processing steps that can be common across energy-use pathways. We do not look at processing emissions associated with other bioproducts, which may be important and should be considered by the Government as part of a wider bioeconomy strategy.

Emissions from cultivation

Cultivating biomass feedstocks can create several sources of emissions, such as the emissions of GHGs from soils associated with fertiliser application, and fossil fuel emissions from the use of farm machinery.

Fertilisers are applied to agricultural soils in order to boost crop yields, but can be a significant contributor to total cultivation emissions:

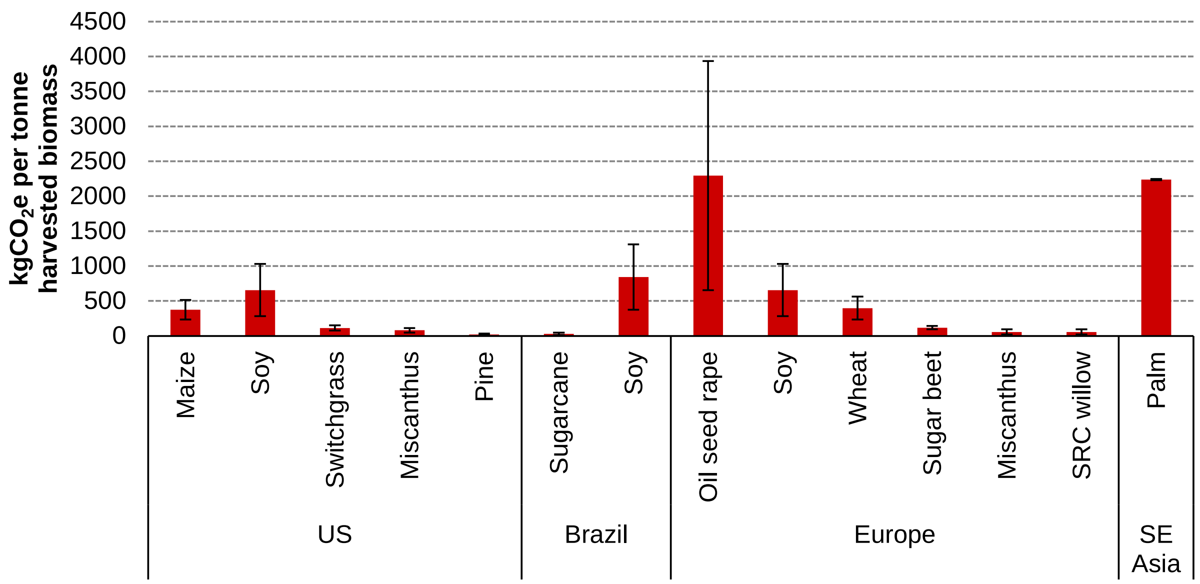
- Fertilisers contribute both through the GHG emissions from their production, which is highly energy-intensive, and additionally through the loss of N_2O from soils due to the activities of bacteria in the soil. N_2O is a very potent greenhouse gas with a global warming potential 298 times that of CO_2 (when aggregated using the GWP_{100} metric). Fertiliser application can vary according to crop type, climatic conditions and farming management practice (Figure 2.5).
- Perennial energy crops (such as miscanthus, switchgrass and short rotation coppice - SRC) generally have much lower fertiliser requirements compared to annual crops (e.g. corn, wheat, etc.). As such, the emissions of N_2O from their soils are much lower than for annual crops.

[40] UN FAO - Bioenergy and Food Security Operator Level Tool, http://www.fao.org/docs/up/easypol/947/befs_operator_level_tool_version_2_139en.pdf

- As perennial crops require a reduced frequency of harvesting compared to annual crops this can lead to reduced emissions from the use of farm machinery.

Agricultural management practices can also help to reduce the GHG emissions associated with cultivating biomass.[41] Practices such as cover cropping in fallow years can help to maintain soil carbon and nutrient stocks, reducing fertilizer input requirements, as can choices regarding the magnitude and timing of fertilizer application.

Figure 2.5. N_2O cultivation emissions from biomass feedstocks



Source: Del Grosso, S. et al. (2014) Sustainable energy crop production. *Current Opinion in Environmental Sustainability*, 9, 20-25.
Notes: N_2O emissions from fertilizer application. Crops are disaggregated by crop type and by region.

Waste and residue feedstocks

Food and agricultural wastes can present an accessible, low-GHG form of biomass. Using wastes for energy production can avoid emissions that would have resulted from the storage and disposal of these wastes (including potent methane emissions in some cases), providing an additional climate benefit from the utilisation of these biomass resources.[42]

Many agricultural residues do however have existing uses, which if displaced, may create additional emissions/land conversion to meet this demand (see section 2.3 on indirect land-use change emissions). This needs to be accounted for when considering the large-scale use of agricultural residues for energy.

[41] Davis, S.C. et al. (2013) Management swing potential for bioenergy crops. *GCB Bioenergy*, 5 (6), 623-638.
[42] Welfle, A. et al. (2017) Generating low-carbon heat from biomass: life cycle assessment of bioenergy scenarios. *Journal of Cleaner Production*, 149, 448-460.

Emissions from processing and transportation

Processing to turn raw biomass feedstocks into more useful and useable forms is often required before conversion to final energy. This includes processes such as the creation of wood chips or pellets for ease of storage, transportation and combustion, all of which can be associated with additional GHG emissions.

GHG emissions associated with **processing of biomass** are strongly dependent on the sources of energy used to complete the process:[43]

- Processing often involves the drying of biomass to reduce its moisture content in order to improve combustion efficiency. The carbon intensity of the heat supplied for drying drastically affects the emissions associated with this process. Heat supplied from waste heat, low-carbon fuels (including sustainable biomass) or natural drying can significantly reduce the contribution of any emissions from drying, relative to using heat generated from natural gas. However, the use of biomass as a fuel for drying reduces the overall processing efficiency (the fraction of harvested biomass that ends up in the final product).[44] Higher moisture content biomass, such as SRC Willow, is particularly sensitive to the choice of heat source in pathways where drying is undertaken.[45]
- The creation of biomass pellets is a particularly energy-intensive process. Its elimination from biomass supply chains, where possible, can help to substantially reduce supply chain emissions.[46]

Transporting biomass is likely to use similar methods to those used for fossil fuels. Overall transportation emissions will depend on the distances biomass is transported along the supply chain and the mode of transport (road, sea, rail):

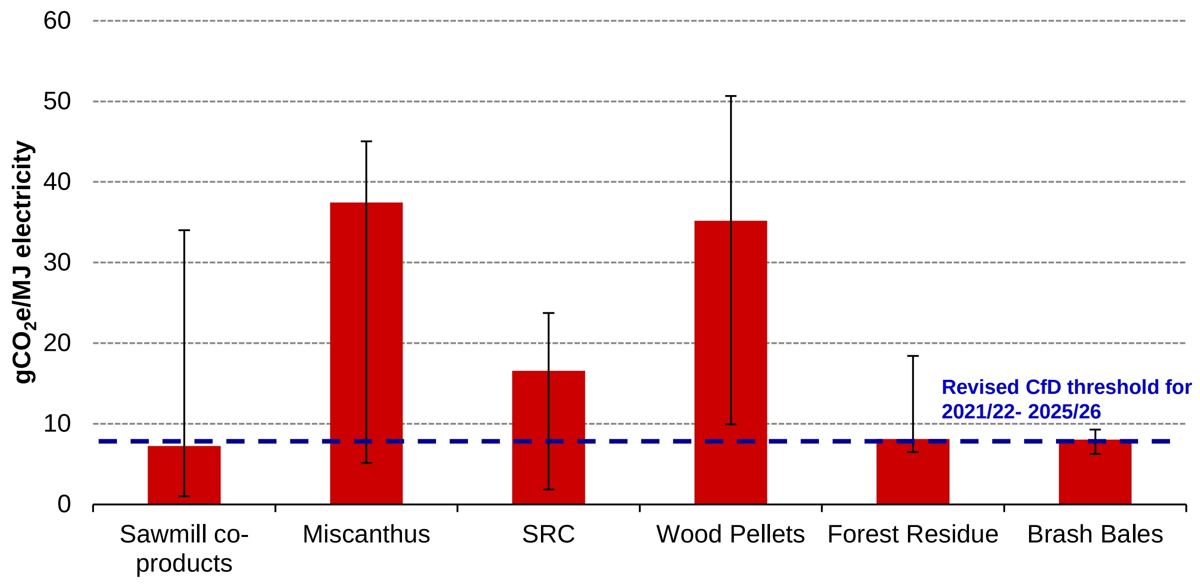
- For a given distance transported, transport by sea is expected to be more carbon efficient than road transportation, due to the use of different fuels.[47] This suggests that coastal feedstock locations for biomass imports may currently lead to lower transportation emissions, but this may change depending on the rates of future decarbonisation of the road freight and shipping sectors.
- Transportation is unlikely to be the dominant contributor to total supply chain emissions for most biomass feedstocks. Transport distance by itself is unlikely to be a good proxy for low GHG biomass.

Reported GHG emissions intensities under the Renewables Obligation (RO) show substantial variation of supply chain emissions between fuel categories used in electricity generation (Figure 2.6). The required sustainability threshold is currently 79.2 gCO_2e/MJ electricity for solid biomass stations. The government has announced that under future Contracts for Difference (CfDs) projects commissioning between 2021/22 and 2025/26, this threshold will be reduced to

[43] Mortimer et al. (2017) *Carbon life cycle assessment evidence analysis: Deliverable D4 – Bioenergy Life Cycle Assessment Report*, North Energy Associates.
[44] Röder, M., Whittaker, C. and Thornley, P. (2015) How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues. *Biomass and Bioenergy*, 79, 50-63.
[45] Fajardy, M. and Mac Dowell, N. (2017) Can BECCS deliver sustainable and resource efficient negative emissions? *Energy & Environmental Science*, 10 (6), 1389-1426.
[46] Welfle, A. et al. (2017) Generating low-carbon heat from biomass: life cycle assessment of bioenergy scenarios. *Journal of Cleaner Production*, 149, 448-460.
[47] Heavy fuel oil for sea transport has an emissions intensitiy of ~0.004$kgCO_2e$/(tonne km) as opposed to 0.077$kgCO_2$/(tonne km) for road transport diesel.

8 gCO_2e/MJ electricity,[48] in line with the median of current large-scale solid and gaseous biomass power plants.

Figure 2.6. Reported lifecycle emissions under the Renewables Obligation for electricity generation from a selection of fuel categories



Source: Ofgem (2018), Biomass Sustainability Dataset 2016-17, https://www.ofgem.gov.uk/publications-and-updates/biomass-sustainability-dataset-2016-17
Notes: Bars show a weighted average of reported lifecycle emissions from each reported fuel category shown, with the error bars indicating the maximum and minimum values reported. Contributions from cultivation, processing, transportation and direct land-use change are included in the calculation methodology, but indirect land-use change, and changes in land carbon stocks when no land-use change occurs, are excluded. Only a subset of fuel categories are shown to indicate variability across the reported emissions. Sawmill co-products include sawmill residues, sawmill chips and sawmill bark.

2.5. Overview

Whilst there is no universal answer to the question as to whether biomass is low-carbon, there is a sufficiently robust evidence base to identify contributing factors to both low- and high-GHG types:

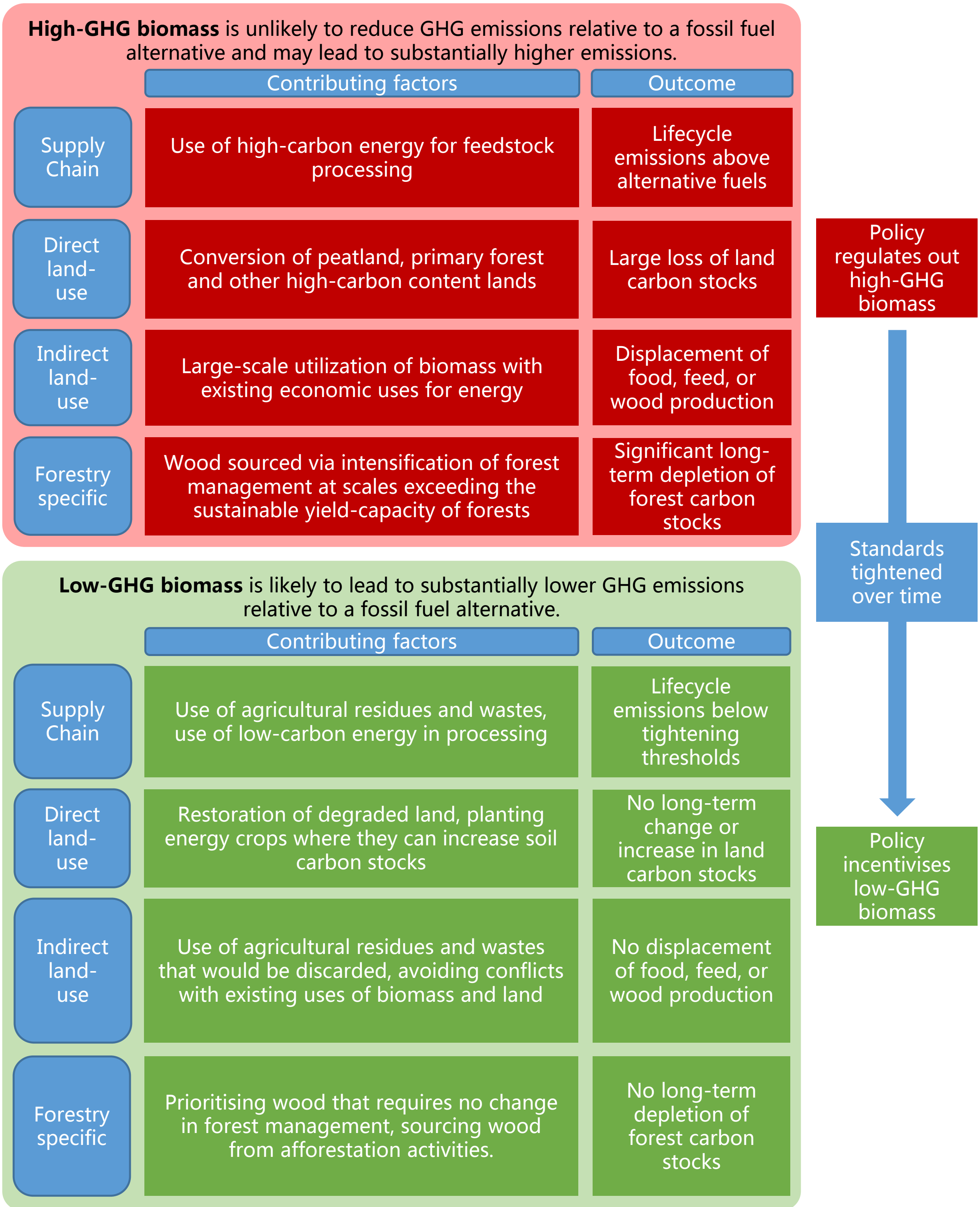
- Low-GHG biomass for energy depends on preventing losses of land carbon stocks both through direct and indirect effects, and minimizing the contributions from the cultivation and processing of biomass across the supply chain.

- At the other end of the spectrum, biomass used for energy can be associated with much higher GHG emissions than fossil-fuel alternatives, particularly when it drives large losses in land carbon stocks.

[48] BEIS (2017) *Contracts for difference scheme for renewable electricity generation, Government response to consultation on proposed amendments to the scheme - Part B*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/736640/Consultation_document.pdf

Effective policy is essential to ensure that low-GHG biomass is incentivised and high-GHG biomass is regulated out. It also has a role in incentivising best practice which could facilitate higher levels of low-GHG biomass supply. The role of policy in achieving this is picked up in Chapter 3.

Figure 2.7. High and low-GHG contributing factors as a basis for policy-making



Source: CCC analysis.

We can define outcomes that would be expected to be consistent with either low-GHG or high-GHG biomass with high confidence (Figure 2.7):

- Within each emissions category we list a number of contributing factors likely to be consistent with a high or low GHG outcome. Whilst these factors can serve as *guidelines* to low- and high-GHG biomass, due to the variability in GHG emissions from biomass and the many possible supply chain management decisions, it **is essential that sustainability frameworks assess the specifics of any particular pathway** with a comprehensive LCA for supply chain, direct land-use change and cultivation emissions.
- For forestry feedstocks, sustainability schemes **should explicitly consider the impacts of biomass production on the total carbon stored within the forest**. This remains an important gap in the current UK sustainability criteria. Modelling can help assign emissions factors associated with reductions or increases in the forest carbon stock for specific biomass feedstocks, but in the mid- to longer-term, governance should move towards requiring greater use of measurement of changes in land-carbon stock over time to help provide a robust evidence base.

Many sources of biomass may not fit clearly into these high- and low-GHG categories. This could include biomass associated with land-conversions where carbon stocks are reduced, for instance the conversions of some grasslands. Another example could be where using forestry materials for bioenergy leads to a limited short-term depletion of carbon stocks but significant climate benefits in the long-term. In such cases, if the resulting biomass is used in applications with large potential to displace fossil fuel emissions from the energy sector and/or store large amounts of biogenic carbon, then utilising these sources may be an effective climate change mitigation options. Our analysis of biomass is best used is addressed in Chapter 5.

Looking towards 2050, and a decarbonising wider domestic economy, emissions from land-use are likely to further increase their already dominant share of total GHG emissions from biomass production.[49] Ensuring that biomass supplies with no (or negative) land-use related emissions are developed and prioritised, and that policies exist to limit indirect land-use change risks, will be essential to ensuring that biomass supply can provide low-GHG sources of energy in the long-term.

The following section reviews the evidence on other aspects of sustainable biomass production, including low-regrets planting strategies for the UK and sustainability trade-offs. We then look at the extent to which the current governance framework manages these risks.

3. Biomass production as part of a system of sustainable land use

Overview

It is essential that the GHG mitigation potential of biomass is considered as part of a system of sustainable land use. This means recognising the importance of the range of ecosystem services provided by land and forests, and taking in to account the impacts of a changing climate.

This report is published alongside a report on land use which looks at both mitigation and adaptation potential for UK land (Box 2.4).

[49] Fajardy, M. and Mac Dowell, N. (2017) Can BECCS deliver sustainable and resource efficient negative emissions? *Energy & Environmental Science*, 10 (6), 1389-1426.

The broad concept of sustainability is central to our analysis and is used here to include biodiversity, soil health, ecosystem benefits and social issues such as impacts on food production and land tenure.

In some circumstances there could be trade-offs between GHG optimisation and other sustainability outcomes, such as supporting biodiversity. These may increase in more ambitious sequestration scenarios as large-scale afforestation and non-food crop systems put pressure on the natural environment and create the potential for competition with food.

Equally there can be important co-benefits in biomass production, for example by delivering social benefits, enhancing biodiversity, flood mitigation and soil carbon sequestration.

Box 2.4. The Committee's land use report (2018)

The report sets out why a new, integrated strategy on land use is needed to deliver our key objectives on climate change: achieving deep emissions reductions; and maintaining the goods and services provided by the land as the climate changes.

Mitigation: The way land is used and managed can have a significant influence on reducing GHG emissions and increasing carbon sequestration. However, based on a continuation of current policies and practices, emissions are expected to increase. It is against this background that the report explores how radically changing the use and management of land and livestock could deliver longer-term deeper emissions cuts and increased removals in the UK by 2050.

Our analysis indicates that:

- A significant amount of agricultural land could be released for alternative uses while maintaining existing per-capita levels of agricultural output. The measures that would allow for this relate to existing Government priorities e.g. improving sustainable agricultural productivity so that more can be produced with fewer inputs; meeting nutritional guidelines for healthy eating and reducing food waste. In addition to releasing agricultural land for alternative uses, these measures also impact non-CO2 emissions arising from changes in agricultural production.
- The alternative uses for released land are focused on options that increase the net carbon sink of land and/or provide fuel wood and timber to displace emissions elsewhere in the economy. These are increased woodland cover, including more trees on farms; the planting of bioenergy crops; peatland restoration; and the use of sustainable management practices on lowland peat that remains in agricultural production.

The report sets out illustrative scenarios to draw out key insights and implications for future land use. The results suggest that by 2050, net emissions in the agriculture and land sectors could fall by between 40-80% compared to current levels, based on the release of 20-30% of agricultural land for alternative uses.

Adaptation: Climate change will put increasing pressure on the long term ability of some land types to deliver the extent of benefits they currently provide. Unless addressed well in advance, some of the risks could be effectively irreversible and endanger the supply of ecosystem goods and services that support some current land use activities. We present findings from research that investigated the long-term impact on current land use activities of reaching specific climate hazard thresholds, and assessed the benefits and limitations of pursuing alternative land use strategies.

The analysis shows that through a structured approach to incorporating the potential impacts from a changing climate into long-term decisions on land use, land managers can identify appropriate adaptive actions to prevent or minimise the potential damage that results, or take advantage of opportunities that may arise. Furthermore, investment in adaptive actions at an earlier stage can lead

Box 2.4. The Committee's land use report (2018)

to greater net benefits over time, through enhancing the land's ability to maintain the delivery of key services, and reducing the risk of higher conservation costs or irreversible damage.

The report develops a framework for thinking about how land-use change can reduce net emissions and deliver greater resilience to the impacts of climate change. A second stage will provide an assessment of the most appropriate policy framework for agriculture and land use, and will be published in 2019.

Source: CCC (2018) *Land use: Reducing emissions and preparing for climate change.*

Factors which lead to positive and negative sustainability impacts

Whether biomass production delivers benefits against a range of sustainability objectives, or causes negative impacts, depends not just on the type of feedstock but also the type of land (including land-use change) and the management practices involved (Box 2.5).

In this section we summarise both the positive and negative impacts biomass production and use can have against a range of sustainability issues, and draw on the latest evidence to identify the specific context and conditions in which these occur (Table 2.1).

In the following sections, we examine what this suggests by way of low-regrets biomass production for the UK, along with the key trade-offs on biodiversity and air quality.

Box 2.5. Sustainable forestry management

The term 'sustainable forest management' is used to describe forests managed to provide social, environmental and economic benefits simultaneously. An internationally used definition reads: 'the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.'

Two sets of internationally accepted principles for sustainable forest management exist: Forest Europe and Montreal Process. Both cover:

- Maintenance of forest contribution to global carbon cycles
- Maintenance of forest ecosystem health and vitality
- Maintenance of productive capacity of forest ecosystems
- Conservation of biological diversity
- Conservation and maintenance of soil and water resources
- Maintenance of other socio-economic functions and conditions

Several different methods can be used to manage forests in accordance with Sustainable Forest Management:

- **Clearfelling:** Involves the dense planting of trees that are monocultures and even-aged. 'Thinnings' regularly occur to harvest trees with forked stems and other features which might

Box 2.5. Sustainable forestry management

reduce their ability to produce good quality sawlogs in future, whilst providing some income to the forest owner and improving the quality and productivity of the remaining trees.

- **Coppicing:** The regular cutting back of shoots attached to the coppice stump or stool. Harvesting may be every 10 – 20 years, depending on what stem dimensions are required by the local timber market. Coppice can provide several types of habitat from bare ground to areas of heavy shade beneath stems that are perhaps 15 m tall.
- **Continuous Cover Forestry** (CCF) is designed to maintain a tree canopy across the forest at all times. Converting to CCF has the potential to bring more diversity to the structure of the woodland, creating more ecological niches for plants and animals to exploit.
- **Short Rotation Forestry (SRF) and Short Rotation Coppice (SRC):** SRF is generally managed as a single stem crop and managed on a clearfell basis on a rotation of 20 years or less. SRC is generally managed on shorter rotations (typically 3 years) and each coppice stool produces multiple shoots. The yield of SRC and SRF is often much higher than that achieved by conventional forestry.

All of these approaches to forest management can provide long-term benefits to the environment, society and economy, but each have their pros and cons. Trade-offs can exist between the different aspects of sustainable forest management.

- Maximising short term carbon sequestration might involve creating new woodland or restocking existing woodland with fast growing conifers planted at close spacing with little open ground, but such a strategy would provide minimal benefits to wildlife, amenity and the landscape.
- Maintaining or improving biodiversity in broadleaved UK woodlands may require increasing the amount of light reaching the forest floor to encourage plant life that supports insects, birds and mammals. However, removing significant volumes of timber from these woodlands to restore habitats also reduces the carbon stock of that woodland.

Compliance with sustainable forest management criteria reduces the risk of harm to forest soils, water, biodiversity and long-term productivity but does not guarantee bioenergy supply chains reduce carbon emissions when used in place of fossil fuels. Additional dedicated principles focused specifically on ensuring low-carbon biomass supply from forests, such as those developed by Forest Research, can effectively complement sustainable forest management criteria.

In the future, the challenges for sustainable forest management are expected to continue to evolve. Protecting forests and their ecosystems against climate risks can be expected to play a more prominent role. There is some evidence that the behaviour of some pests is being influenced by the changing climate. As the climate changes and the impacts of pests and diseases vary over time, it is important that some flexibility is built into forest management planning so that functioning ecosystems can be maintained – and that their performance is monitored. Moving away from the practice of establishing commercial plantations with just one major timber producing species could help to provide some protection against pests and diseases in the future. Introducing new tree species that are not susceptible to diseases currently damaging woodlands can also help to ensure woodland cover is maintained in the long term.

Source: Annex 1. Sustainable Forestry Management, prepared by Ian Tubby at the Forestry Commission; Forest Europe (1993) Resolution H1, General Guidelines for the Sustainable Management of Forests in Europe, https://www.foresteurope.org/docs/MC/MC_helsinki_resolutionH1.pdf

Table 2.1. Factors that increase the likelihood of positive or negative sustainability outcomes

Dimension of sustainability	Factors that are likely to lead to negative sustainability impacts	Best practice: factors that are likely to lead to positive sustainability impacts
Biodiversity	Planting large-scale forest monocultures or non-native tree species (e.g. eucalyptus in Europe) Soil compaction due to use of heavy machinery in forests has negative impacts on soil biodiversity. This can affect the wider forest ecosystem. Planting crops in sensitive locations (e.g. annual crops on migratory bird routes, in areas of existing high biodiversity growing short rotation pine, corn or removing corn residues).	Thinning forests to improve growth and sequestration also allows more sunlight in, which can help support a wider range of species. Creating verge ecosystems works in the same way. There is some evidence that short rotation coppice willow and miscanthus are largely positive for biodiversity in the UK. Planting switchgrass on migratory bird routes can increase overall diversity.
Soil health and fertility	Some annual crops (e.g. corn, sugarcane, palm oil) are associated with soil erosion, especially when grown on slopes. This leads to negative impacts on soil health and fertility.	Leaving some residues on the fields is good practice, as it increases soil fertility. Some annual crops (e.g. legumes) have been shown to improve soil resilience. Willow makes efficient use of nitrogen, so willow plantations grown next to sources of biosolids or industrial or agricultural by-products are highly beneficial. Growth of switchgrass or miscanthus on pasture land or arable land that is no longer used for food improves soils. Forest-based feedstocks have lower requirements for fertiliser, pesticides and herbicides than agricultural feedstocks.

Table 2.1. Factors that increase the likelihood of positive or negative sustainability outcomes

Dimension of sustainability	Factors that are likely to lead to negative sustainability impacts	Best practice: factors that are likely to lead to positive sustainability impacts
Water availability and quality	Miscanthus, short rotation coppice and short rotation forestry can have negative effects on water availability, especially when grown on arable land. Water quality can be negatively impacted by soil erosion.	Sugar beet and wheat are relatively water efficient. Converting pasture or arable land to switchgrass improves water quality by reducing nutrient and sediment concentrations. Nitrate loss from miscanthus, short rotation coppice and short rotation forestry is lower, which has a positive impact on water quality. Mixed forestry stands can improve water quality.
Land remediation	-	Willow, poplar, corn or jatropha can sequester heavy metals (e.g. cadmium, lead, zinc). Growth of miscanthus, switchgrass, tall fescue or willow can remediate land contaminated with polycyclic aromatic hydrocarbons.
Other ecosystem services	Converting mature forest to perennial crops (e.g. miscanthus, short rotation coppice and short rotation forestry) can have negative impacts on flood regulation and soil erosion. Switchgrass and sorghum have much higher rates of eutrophication than forestry feedstocks.	Some perennial crops (e.g. miscanthus) have lower nutrient requirements compared to annual crops. Converting arable land or marginal land to miscanthus, short rotation coppice and short rotation forestry has positive impacts on flood regulation and disease. Converting arable land or grassland to miscanthus or short rotation coppice has positive impacts on disease. Converting arable land to perennials can benefit pollinator species.
Invasive species	Invasion risks are location-dependent. Poplar and eucalyptus have shown invasion. There is some evidence of invasion from glyphosate resistant crops (e.g. genetically-modified corn).	Miscanthus x giganteus is a sterile hybrid crop which has been shown not to be invasive in field trials.

Table 2.1. Factors that increase the likelihood of positive or negative sustainability outcomes		
Dimension of sustainability	**Factors that are likely to lead to negative sustainability impacts**	**Best practice: factors that are likely to lead to positive sustainability impacts**
Socio-economic impacts and food security in developing countries	Growing energy crops that displace food production, or make food less accessible or affordable, particularly for at-risk groups. 'Land grabs' for growing biomass from traditional land users. Unsafe working environments. Diverting residues or wastes from being used to fertilise soils. Health impacts from particulate matter when biomass is burnt, particularly for small-scale and domestic bioenergy for heat uses where no filters are fitted.	Using waste and residues to produce biogas and digestate, displacing traditional solid biomass and improving air quality. Integrated food and bioenergy crop systems help diversify and improve resilience. Respect for peoples' land rights and access to resources. Consultation with stakeholders, including leadership roles for women. Local jobs with established workers' rights, including collective bargaining.

Sources: Cambi, M. et al. (2015) The impact of heavy traffic on forest soils: A review. *Forest Ecology and Management*; Environment Agency (2015) *Energy crops and floodplain flows*, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/480799/Energy_crops_and_floodplain_flows_report.pdf; Evangelou, M. et al. (2012) Biomass Production on Trace Element-Contaminated Land: A Review. *Environmental Engineering Science*; Gasparatos, A. et al. (2013) Sustainability impacts of first-generation biofuels. *Animal Frontiers*; Haughton, A., et al. (2015) Dedicated biomass crops can enhance biodiversity in the arable landscape. *GCB Bioenergy*; Holland, R., et al. (2015) A synthesis of the ecosystem services impact of second generation bioenergy crop production. *Renewable and Sustainable Energy Reviews*; IEA (2017) *Technology Roadmap Delivering Sustainable Bioenergy*. https://webstore.iea.org/technology-roadmap-delivering-sustainable-bioenergy; Kline, K. et al. (2016) Reconciling food security and bioenergy: Priorities for action. *GCB Bioenergy*; McCalmont, J. et al. (2015) Environmental costs and benefits of growing Miscanthus for bioenergy in the UK. *GCB Bioenergy*; Naik, S. et al. (2010) Production of first and second generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews*; RAEng (2017) *Sustainable Liquid Biofuels*, https://www.raeng.org.uk/news/news-releases/2017/july/biofuels-made-from-waste-are-the-business,-says-ac; Rowe, R. et al. (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*; SCOPE (2015) *Bioenergy & Sustainability: bridging the gaps*, http://bioenfapesp.org/scopebioenergy/index.php

'Low-regrets' biomass production

Whilst risk-free biomass production is rare and mainly limited to biogenic wastes, the evidence supports the use of both perennial crops and sustainable forestry products in the UK under specific circumstances.

There are a range of positive roles for **perennial crops**, including improving soil quality, remediating contaminated land and - in certain cases - also enhancing biodiversity:

- Perennial crops such as willow and poplar can both improve soil carbon and wider soil health (increased nutrients, reduced erosion). They can also act as buffer crops to reduce run off. Some perennial grasses such as miscanthus also have a range of benefits, including high yields and low pesticide and nitrogen requirements.

- Willow and poplar present good opportunities for remediating land contaminated with heavy metals. Miscanthus can be used to remove polycyclic aromatic hydrocarbons. Post-combustion, contaminated ash must be disposed of safely. If economically feasible, the ash can be processed to recover valuable metals.
- In general, impacts on biodiversity can be positive or negative depending on the location, context and crop, but there is some evidence to suggest that willow and miscanthus may enhance biodiversity in a UK context.

As some perennial crops (e.g. willow and poplar) have higher water demands than some annual crops, they are likely to be less suited to areas which are water-stressed.

Some annual crops such as corn have a range of negative impacts, including increased soil erosion and decreased biodiversity, water quality and food security. Some of these environmental impacts can be mitigated by maintaining crop cover year round. These crops can have positive roles when used in integrated food and energy systems (Box 4.2) or to remediate land that is contaminated with heavy metals.

Sustainable forest management is a well-established practice within the UK which is embedded in forest standards and practices. There is good evidence that bringing forests back under active management can not only enhance sequestration but also improve the resilience of forests, reduce risks of pests and diseases and enhance biodiversity.[50] There is also some evidence to suggest these benefits can be associated with planting mixed-species woodland.[51]

Better use of **biogenic wastes** and **agricultural residues** is generally recognised as both GHG-efficient and sustainable, providing that a minimum of residues is left in the field. In the long term, uses which sequester greenhouse gases deliver the greatest abatement potential.

Risks and trade-offs

Biomass production

One of the main potential trade-offs arising from increased afforestation and biomass production, is the associated **biodiversity** impact, particularly in some regions of the world:[52]

- Some of the scenarios which make use of large-scale production of bioenergy feedstocks for use with CCS, are likely to lead to reductions in biodiversity - in the order of 25-35% for the more extreme scenarios for achieving net-zero emissions.[53]
- Our high scenario for biomass availability (Chapter 4) is based on a significantly lower total primary biomass use of around 100 EJ (compared to over three times that amount in the above modelling) but even at the lower level there are likely to be some local trade-offs which we do not fully mitigate.

[50] Forestry Commission (2010) *Managing ancient and native woodland in England - Forestry Commission England Practice Guide*, https://www.forestry.gov.uk/pdf/FCPG201.pdf/$FILE/FCPG201.pdf
[51] Felton et al. (2016) Replacing monocultures with mixed-species stands: Ecosystem service implications of two production forest alternatives in Sweden.
[52] Smith, P. et al. (2018) Impacts on terrestrial biodiversity of moving from a 2C to a 1.5C target.
[53] Heck, V. et al (2018) Biomass-based negative emissions difficult to reconcile with planetary boundaries. *Nature*.

- Such impacts need to be weighed against evidence which suggests that limiting temperature rises to 1.5 degrees could have biodiversity benefits of a similar order of magnitude relative to impacts of 2 or 3 degrees warming.[54]

If stronger sustainability governance can be established, this could help reduce the risks.

Food security risks can be managed to an extent by ensuring that land used for food production is not diverted to non-food crops. Using marginal and/or degraded land, integrating food and energy systems[55] and avoiding crops which require productive land can all help (Chapter 3). Bespoke tools such as the country- and operator-level food security tools developed by UN FAO have a role in limiting risks and minimising costs of certification.[56]

Socioeconomic impacts ranging from unsafe working conditions to human rights violations are particularly difficult to monitor for imports from developing countries. However if these can be mitigated there are opportunities for sustainable development and natural resources protection. Ensuring social sustainability criteria are embedded in UK policy and certification tools is a useful step, but needs to be considered as part of the broader strategic context around global markets and sovereignty concerns in producer countries (Chapter 3).

Sustainability of using biomass to produce energy

A second set of impacts occur when feedstocks are combusted, producing particulates (from woody biomass in particular) and nitrogen oxides (from woody biomass, biogases and bioliquids). These have a range of adverse effects on human health and the environment.

- Particulate matter, especially fine particular matter below 10 and 2.5 microns in diameter (PM_{10} and $PM_{2.5}$) causes respiratory illnesses and heart disease.

- Nitrogen oxides (NO_x gases) lead to ozone layer depletion, formation of acid rain and photochemical smog. Nitrogen dioxide (NO_2) causes respiratory diseases.

Particulate matter emissions from burning woody biomass can be much higher than fossil fuels, depending on the combusting technology and whether pellets are used, whereas NO_x emissions are comparable to gas and liquid fuel. This is particularly problematic for uses like residential heating where no abatement measures such as filters are fitted (Figure 2.8). Proposed measures under the draft Clean Air Strategy 2018 and the restriction to Defra-exempt ecodesign stoves in smoke control zones are positive developments.[57] NO_x emissions from biogas production are also an issue.[58] The combustion of E85 bioethanol in road vehicles tends to produce lower NO_x and $PM_{2.5}$ emissions than comparable petrol and diesel vehicles.

It is possible to manage these impacts for large point sources of emissions such as power stations and industrial sites, using stack technology such Selective Catalytic Reduction (SCR) for NO_x or Electrostatic Precipitators (ESP) for particulates.

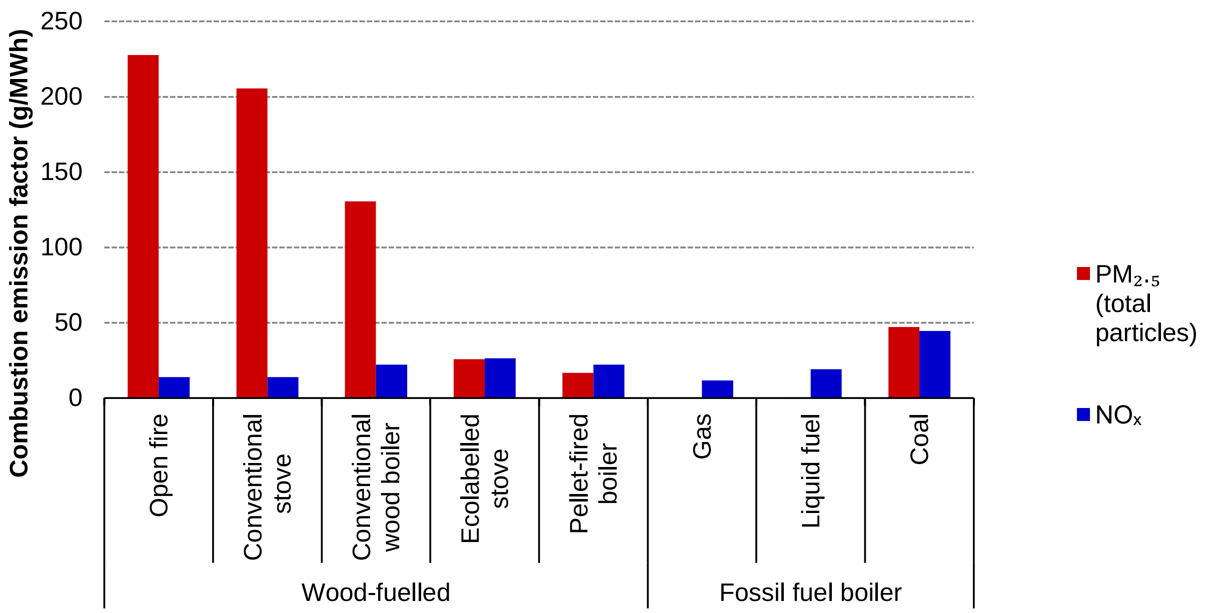
In small-scale uses such as heating homes, these options are not available. We therefore exclude these uses of bioenergy outside of low density rural areas where the pollutants are more easily dispersed.

---

54 Smith, P. et al. (2018) Impacts on terrestrial biodiversity of moving from a 2C to a 1.5C target.
55 See box 4.2.
56 UN FAO - Bioenergy and Food Security Operator Level Tool,
http://www.fao.org/docs/up/easypol/947/befs_operator_level_tool_version_2_139en.pdf
57 Defra (2018) *Draft Clean Air Strategy 2018.*
58 NAEI (2018) *National Atmospheric Emissions Inventory.*

We review the air quality impacts of different bioenergy uses further in Chapter 5, including for large scale bioenergy with carbon capture and storage.

Figure 2.8. Air quality emissions of bio-feedstocks and fossil fuels in residential heating - NO_x and particulates



Source: EEA (2016) 1.A.4 *Small combustion 2016; Tables 3.39, 3.40, 3.42, 3.43, 3.44, 3.16, 3.18, 3.20*
Notes: Emissions factors are for combustion only, and do not account for air quality emissions associated with fuel production. Coal emissions factors are for small (50 kw - 1 MW) non-residential boilers. The ecolabelled stove corresponds to a 'Defra-exempt' model. 'Defra-exempt' stoves are stoves that are cleared to burn specified fuels in smoke control areas - in this case, burning biomass.

Chapter 3: Sustainability governance for imported biomass

In this chapter we discuss the importance of international sustainability governance in facilitating imports of sustainable biomass, identifying measures the UK Government can take to help develop a robust governance framework over time.

It is structured in two sections:

1. How do the current accounting and sustainability frameworks manage risks?

2. International governance for sustainable imports - What Works

1. How do the current accounting and sustainability frameworks manage risks?

Having established that bioenergy can be low-carbon but only under certain conditions, this section considers whether the current accounting and governance rules ensure that these conditions are satisfied.

1.1. International accounting for biogenic GHG stocks and flows

The UN climate framework requires both reporting and accounting of greenhouse gas emissions.

Reporting refers to the need for Parties to the UNFCCC to provide a regular and comprehensive record of their territorial greenhouse gas emissions inventory to the UNFCCC.

Bioenergy is assumed to be 'carbon neutral' within reporting frameworks, representing a considerably simplified picture of the impact on actual emissions:

- Emissions of biogenic CO_2 from the combustion of biomass are reported as zero emissions within the energy sector according to IPCC guidelines, in order to avoiding double counting of emissions in both the energy and LULUCF sectors.
- However, any changes in land carbon stocks induced by the provision of bioenergy will be reported in the LULUCF sector.

International supply chains create additional complexity for the reporting of bioenergy related emissions. The biogenic carbon released on the combustion of imported biomass is not reported within the UK emissions inventory and any effect of its production on land carbon stocks is assumed to be reported by the exporting party as if it is fully oxidised upon harvest.

Accounting refers to rules for how reported emissions may be used to contribute towards a particular party's emissions reduction goal. During the Kyoto Protocol second commitment period (which ends in 2020), Annex 1 parties (including the UK) had to account for emissions resulting from forest management, but no emissions reduction commitments were required from non-Annex 1 parties.

The Paris Agreement was signed in 2016 and has since been ratified by 179 countries. All parties are now obliged to make commitments to mitigate their contribution to climate change. However, the existence of the Paris Agreement cannot, in of itself, be considered sufficient to ensure that parties have the necessary incentive to limit LULUCF emissions from biomass that is exported to the UK:

- Nationally Determined Contributions (NDCs) for emissions reductions in 2030 contain a wide diversity of different target frameworks and inclusion or exclusions of LULUCF within the targets for 2030.

- Many parties include LULUCF within mitigation commitments. About three quarters of these include LULUCF within an economy-wide GHG reduction, although limited detail is often available on the assumed accounting methodology.

Without additional monitoring, reporting and verification systems, the international accounting system does not, by itself, provide sufficient incentives for both individual importers and exporters of biomass feedstocks to ensure land carbon stocks are not reduced:

- Replacing fossil-fuel generation with imported biomass-based generation would reduce the reported emissions associated with the project and within the national jurisdiction irrespective of the consequence for land carbon stocks abroad.
- New and improved EU accounting rules to ensure the preservation of land-carbon stocks from imported biomass have been implemented at a national level, but it remains unclear the impact these will have at the level of individual supply chains.

In order to ensure sustainable biomass, it is therefore essential that international climate accounting structures are supplemented with additional sustainability criteria that address both risks of biomass production reducing land carbon stocks and wider sustainability risks.

1.2 How are sustainability risks managed and is the current approach working?

The current UK sustainability framework varies in terms of quality and coverage. It consists of:

- A comprehensive framework on **timber production and imports** (EU Forest Law Enforcement, Governance and Trade (FLEGT), and UK forestry rules).
- A set of criteria attached to subsidy schemes for **bioenergy**, based on EU Renewable Energy Directive (RED) framework.

There is comparatively little by way of policy to manage sustainability risks for **agricultural imports, which remain a lead cause of deforestation internationally.**[59,60]

EU **timber policy** (the FLEGT framework) aims to ensure that no illegal timber is sold on the EU market and to support international efforts to end illegal logging. It consists of an **integrated and holistic package of measures** under the 2003 FLEGT Action plan and the strong regulatory framework under the 2013 EU Timber Regulation (EU TR) (Box 3.1). At the UK-level, forestry regulations cover the import and export of wood materials, timber procurement, felling licences, species, habitat regulation and environmental impact assessment. They require detailed forest management plans which prevent change of use and deforestation.

---

[59] A 2013 study for the European Commission investigating the impact of EU consumption on deforestation found that, between 1990 and 2008, 53% of global forests have been cleared to produce agricultural commodities. Forest Trends (2014) estimated that some 71% of all tropical deforestation between 2000 and 2012 was driven by commercial agriculture. Similarly FAO's State of the World's Forests reported that nearly 70% of deforestation in Latin America was driven by commercial agriculture, with a lower fraction (one third) in Africa. Sources: European Commission (2013) *The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation*; Forest Trends (2014) *Consumer Goods and Deforestation: An Analysis of the Extent and Nature of Illegality in Forest Conversion for Agriculture and Timber Plantations*; FAO (2016) *State of the World's Forests*.

[60] These risks are partly addressed by accounting rules under international agreements, as far as GHG emissions are concerned. A number of international initiatives (such as those led by Forest Trends and REDD++) are aimed at improving sustainability of agricultural practices, including by reducing the clearing of forests to grow agricultural commodities. The UK Government has a number of international climate finance (ICF) initiatives supporting sustainable agricultural practices in exporting countries.

Box 3.1. FLEGT timber policy

The 2003 FLEGT Action plan sets out a **comprehensive package of measures** available to EU member states for tackling illegal logging globally. It is structured around key elements of international technical and financial assistance, trade agreements and multilateralism, public procurement, financing rules (for banks, institutions and export guarantee agencies), private-sector support and legislation:

- **Coordinated financial and technical support** to timber-producing countries is a central component. This includes helping countries build timber legality assurance systems, promoting transparency, building the capacity of governments, civil society, businesses and policy reform.
- A second key component is around **promoting international trade in legal timber**. This is about working towards a multilateral framework with major timber consuming-countries, whilst simultaneously working up a number of bilateral trade partnerships with producer countries. The bilateral agreements (Voluntary Partnership Agreements, or VPAs) each define 'legal timber' with input from the private sector and civil society, and set out a strong timber legality assurance system which is used to award a FLEGT licence, allowing access to the EU market.
- The remaining elements set out sustainable **public procurement** rules for large infrastructure projects, support for **private-sector initiatives** such as monitoring supply chains, financing and investment safeguards including for export credit agencies and financial institutions, use of existing or new legislation, and action to address the problem of **conflict timber**.
- The 2013 **EU Timber Regulation (EU TR)** emerged from work around standards and legislation under the FLEGT action plan. It covers all timber produced in the EU and timber imports. Businesses placing a timber product on the EU market must make every effort to ensure that it is legal ('due diligence'). Businesses selling or buying timber already on the market have to keep records that adequately trace the origin of the wood and wood products they buy or sell.

Whilst still needing improvement, overall EU FLEGT has contributed to improving forest governance globally, reducing demand for illegal timber:

- The 2016 independent evaluation of the first 11 years of the FLEGT highlights its **innovative, comprehensive and future-proofed approach** and concludes that **it has improved forest governance in all target countries, contributed to improved forest governance globally and helped to reduce demand for illegal timber in the EU**.
- However, fundamental governance challenges persist and require more effective tackling. The recommendations on how to improve the EU FLEGT system included in the evaluation focus on clarifying objectives, streamlining processes, improving communication - and over time, on shifting geographical focus to non-Voluntary Partnership Agreement countries and expending further effort on building international coalitions.

Sources: CCC; European Commission (2016) *Independent evaluation of the EU FLEGT Action Plan.*

The UK's bioenergy sustainability framework is based on the 2009 EU Renewable Energy directive (RED) and applies to all subsidies for biomass, bioliquids and biogas used in power, transport and heat (Box 3.2).

Both RED and related UK legislation set out trajectories for maximum GHG lifecycle emissions for different end uses. Wider environmental impacts on soils, biodiversity and water are managed in two ways: first, by ruling out unsustainable land conversions (including highly biodiverse or primary forests) and second, by requiring that scheme participants use certification schemes that are formally approved. The extent to which environmental and social impacts are managed varies amongst the approved certification routes, and often relies on local and national legislation in producer countries.

UK rules go further in managing broader sustainability risks related to woodfuel production. Woodfuel needs to be sourced in compliance with the Timber Standard, which requires alignment with internationally recognised criteria for sustainable forestry management. It includes a requirement to minimise harm to ecosystems (soil, water and biodiversity) and a specific requirement to ensure that biodiversity is maintained. The overarching framework for timber is set by the Timber Procurement Policy (UK-TPP) principles, which cover a range of social, economic and environmental issues building on internationally agreed criteria for sustainable forest management, and applies to all timber purchases.

Box 3.2. UK sustainability framework for managing risks around bioenergy feedstocks

The UK sustainability criteria for biomass build on the criteria established by the **EU Renewable Energy Directive** (RED, 2009).

- This set in law the EU renewable energy target for 20% renewable energy by 2020 across member states, and subtarget of 10% for renewable transport fuels.
- RED, now replaced by REDII (2018), sets renewable energy targets at EU level as well as specific targets for biofuels. The set of criteria it originally established covered biofuels and bioliquids only, leaving the option for Member States to extend to solid biomass and biogas by issuing non-binding recommendations on these.
- The underlying sustainability criteria were first transposed in to UK law in 2011 and they have since undergone several updates.

In transposing RED, the UK went beyond the mandatory EU rules, extending sustainability criteria to solid biomass and biogas and adding in a food crop cap.

The framework establishes a set of sustainability criteria:

- The mandatory **GHG criteria** sets limits on the lifecycle GHG emissions for bioliquids, biomass and biogases. GHG emissions thresholds vary according to fuel use and type and they are set to tighten over time. For solid biomass or biogas these are expressed as carbon intensity. They are currently set at 79.2 gCO_{2e}/MJ for electricity, decreasing to 8 gCO2e/MJ for projects comissioning between 2021/22 and 2025/26; for bioliquids and biofuels these are expressed as percentage savings compared to fossil fuels, currently set as 50%.
- The **mandatory land criteria** restrict the land that the feedstock can be sourced from. The legislation distinguishes land criteria for woody and non-woody biomass, setting out prohibited types of land for non-woody biomass, and forest management criteria tor the woody biomass as contained in the Timber Standard for Heat and Electricity.
  - Non-woody biomass must not be sourced from land that at or after Jan 2008 was primary forest, land designated for protecting nature, highly biodiverse grassland, peatland, continuously forested area, lightly forested area (unless forest cover is increased) and wetland.
  - Woody biomass or woodfuel must be grown in a way that is consistent with the Forest Europe Sustainable Forest Management criteria, or with another set of international principles that meet equivalent requirements. It must meet the '70/30 threshold' meaning that, whilst 100% of the woodfuel sourced must be legally harvested, only 70% need to comply with sustainability requirements.
  - The land criteria for woody biomass follows a regional risk-based approach which allows to seek evidence on sustainability at regional level rather than at producer level for producers located in low-risk areas. Whilst this does not in principle prevent sourcing from higher risk areas, it makes it harder to achieve in practice.
- The framework also includes **voluntary environmental** (e.g. soil, water) **and socio-economic** (e.g. land and workers' rights) **criteria**. Compliance can be demonstrated via the use of voluntary certification schemes, such as the Forest Stewardship Council (FSC) and the Sustainable Biomass Programme (SBP). Alternatively, operators need to collect bespoke evidence about the supplier which needs verifying by an independent auditor.

These criteria are reflected in the Renewable Transport Fuel Obligation (RTFO), the Renewables Obligation (RO) now replaced by Contracts for Difference (CfDs) and the Renewable Heat Incentive (RHI).

Box 3.2. UK sustainability framework for managing risks around bioenergy feedstocks

- The **RTFO** covers the transport sector and sets a trajectory for biofuel use, with a minimum percentage of biofuel increasing over time and exceeding 12% of total fuel for fuel and vehicle suppliers in 2032. Renewable Transport Fuel Certificates are awarded and subsidies provided to vehicles and vehicle-fuel suppliers for transport biofuels, upon demonstrating compliance with sustainability criteria. The RTFO was amended in April this year, including a specific target for advanced waste-based renewable fuels and a cap for crop biofuels which tightens over time.
- The **RO** was designed to incentivise large-scale renewable electricity generation in the UK. It sets an obligation for energy generators to source a part of their supply from renewable sources including biofuels, bioliquids, waste and solid biomass. It supports renewable electricity by providing Renewable Obligation Certificates (ROCs) to qualifying projects, replaced by Contracts for Difference (CfDs) since March 2017. As for the RTFO, ROCs and CfDs, are awarded conditional on meeting the biomass sustainability criteria.
- The **RHI** subsidies were put in place to incentivise energy users to switch to low-carbon energy sources. The RHI works as a feed-in-tariff, with direct payments available for biomass, biogas and biomethane injected in to the gas grid conditional on compliance with sustainability criteria. Choosing suppliers from the Biomass Suppliers List (for woody biomass) and the Sustainable Fuel Register (for non-woody biomass) allows participants to demonstrate compliance with no further evidence required.

REDII, approved in June this year, updates RED, extending its targets to 2030**:**

- **The new Directive, to replace the 2009 Directive, introduced several improvements , however important gaps remain**. Work by Forest Research (2018) has established 15 criteria required to ensure that forest bioenergy can deliver GHG savings. In reviewing the proposed REDII text against those criteria, Forest Research highlights that there is no specific provision for 9 criteria out of 15.
- In a number of areas, the UK framework is alerady in line with REDII, for instance it includes sustainability criteria for solid biomass and biogas and a cap on food-crop based biofuels. REDII however introduces additional requirements, most notably the requirement for biofuels and bioenergy from forest materials to be sourced from countries that are signatories to the Paris Agreement ('import rule'), and greater flexibility given to member states to go beyond EU-wide rules.

Depending on the timetable for EU Exit, REDII may or may not require transposing in to UK law.

Sources: Ofgem (2018) *Renewables Obligation: Sustainability Criteria; Forest Research (2018) Carbon impacts of biomass consumed in the EU. Supplementary analysis and interpretation for the European Climate Foundation;* DfT (2018) *Renewable Transport Fuel Obligation Guidance Part One Process Guidance;* Forest Europe (2016) *Sustainable Forest Management Criteria*; Gov.uk (April 2018); *New regulations to double the use of sustainable renewable fuels by 2020*; European Commission (2010) *Report from the Commission to the Council and the European Parliament on Sustainability Requirements for the Use of Solid and Gaseous Biomass Sources in Electricity, Heating and Cooling.*

Broadly, the evidence suggests that the UK's bioenergy sustainability rules are helping to limit the sustainability risks, although there is some evidence of negative local impacts (e.g. air quality), intensive forestry management practices, and disagreement around the use of some feedstocks (e.g. low-grade wood and 'thinnings') (Box 3.3). Using first generation food crops for energy remains controversial due to continued links to volatility in food prices; policy has responded by refocusing supply-chains on second-generation woody feedstocks, apart from where part of integrated food-energy systems (for example, through the food crop cap) (Box 3.4).

We have identified three key areas of gap in the current UK and EU governance framework, based on wide stakeholder consultation and literature review.

1. As a principle, high-risk feedstocks should be regulated out and best practice incentivised. Under the current framework, **risks are only partially managed**. This applies both to GHG emissions risks (e.g. around terrestial carbon stocks, soil carbon monitoring and accounting) as well as to broader sustainability issues (including indirect land-use change and social sustainability). There is a focus on **compliance with minimum standards, at the expense of best practice**.

- Changes in **terrestrial carbon stocks** are not counted if there is no change in land use category (Chapter 2). There is no strong safeguard against 'carbon mining' - where harvesting of biomass for energy acts to reduce carbon stocks long-term compared to what they would otherwise have been.
- The approach to dealing with **indirect land-use change emissions** varies depending on the certification route and could be improved.
- **Social sustainability** and broader environmental risks are only partly addressed by the current framework, particularly in countries with weaker governance. There is a risk that higher demand for bioenergy crops in the future could exacerbate those conditions.
- Current sustainability criteria are focussed on compliance, with no reward for going further. A greater focus on outcomes would also be an improvement (i.e. moving from 'is there is a policy in place' to 'is this supply chain actually protecting biodiversity').

2. **The current set of sustainability rules for bioenergy feedstocks are tied to subsidy-schemes and do not apply where use is not subsidy-dependent**. This means that sustainability risks may increase as a function of a rising carbon price. There are opportunities to adopt a more comprehensive and strategic approach to tackling risks, building on the example of EU timber governance.

- As bioenergy demand and policy move away from subsidies over time, this issue will become more important. As the carbon price on power and heavy-industry increases, there is likely to be more use of bioenergy driven by tax and carbon pricing alone, which would have no sustainability requirements attached.[61]
- The 2003 EU FLEGT action plan, which provided a set of measures to address illegal logging globally, can serve as example of an effective, integrated and strategic approach for broader biomass policy. The Renewables Obligation, Contracts for Difference and Renewables Heat Incentive already refer to the Forest Europe Sustainable Forest Management Criteria,[62] providing a potential basis for a more formal governance structure for sustainable woodfuel at a pan-European level.

3. Both **the EU and the UK are at risk of selecting the more sustainable feedstocks which otherwise might have been used elsewhere** and pushing the less sustainable feedstocks into other markets, with little overall benefit for the global climate.

---

[61] See discussion in Chapter 5 around the potential post-subsidy future for current coal to biomass power plant conversions.
[62] Forest Europe (2016) *Sustainable Forest Management Criteria*, https://foresteurope.org/sfm-criteria-indicators2/

- The EU sustainability framework and equivalent national and private sector schemes only cover a small portion of the global market for bioenergy feedstocks.
- Currently, there is not strong evidence to suggest that EU rules are driving up standards globally.

Effective policy is essential to ensure that low-GHG biomass is incentivised and high-GHG biomass is regulated out, incentivising best practice and creating a 'race to the top' to lift up the global average.

Box 3.3. Review of evidence around the sustainability of UK imports

Evidence on the **sustainability of the current supply chain is** reported in our Call for Evidence (Box 1.3) and related summary by Ricardo, as well as in other key studies and stakeholder consultation. Broadly, the evidence suggests that the UK's bioenergy sustainability rules are helping to limit the sustainability risks, although there is some evidence of negative local impacts (e.g. air quality), intensive forestry management practices, and disagreement around the use of some feedstocks (e.g. low-grade wood and 'thinnings').

- Using **low-grade wood for energy** is controversial. Current imports are largely made up of feedstocks classified as sawmill residues (40%), low-grade roundwood (24%), thinnings (18%), and forest residues (including branches and bark) (18%) (Drax, 2017).
  - Critics argue that roundwood and thinnings could be used for other purposes, particularly for larger trees which are part of the thinning process (Searchinger et al., 2018).
  - In other instances where the demand for pellets is creating incentives to remove any lower-grade trees left after the high-value timber has been extracted, there is a reasonable argument that this can make way for more sustainably-managed forests. However, there is no guarantee that will occur.
- There is conflicting evidence around **biodiversity impacts**. Negative impacts may be due to habitat loss or degradation. A number of studies have demonstrated no effect on biodiversity. Positive impacts may be due to clearing invasive species. However there is broad consensus that biomass should not be harvested from primary or virgin forests, land that is protected or land that has a high biodiversity value.
- There are concerns around local **noise and air quality** impacts in some cases of mills producing pellets for UK markets. These include air pollution produced by harvesting (dust) or by combustion (particulates, NOx).

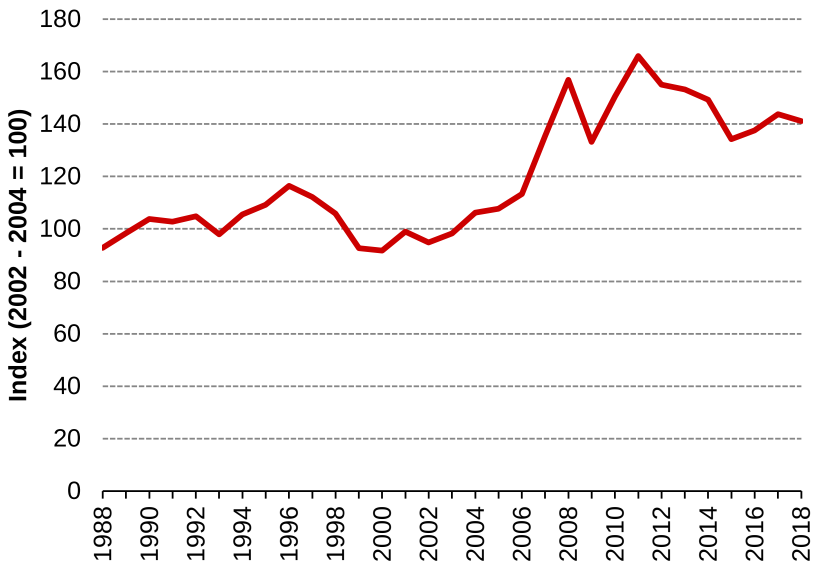
Sources: Searchinger, T. et. al. (2018) *Europe's renewable energy directive poised to harm global forests;* Drax (2017) *Sustainability* https://www.drax.com/sustainability/sourcing/; Ricardo (2018) *CCC Bioenergy Call for Evidence Summary of evidence submitted, final report*, published as supporting evidence for this report.
Notes: The removal of lower-grade trees left after high-value timber has been harvested is known as 'creaming the forest'.

Box 3.4. Biofuels and food security

The expansion of the biofuel industry over the last decade has triggered concerns over adverse effects on food prices, where increased demand for arable land to produce crop-based biofuels could cause food price inflation and increased price volatility:

- **Higher food prices.** After several decades of low and stable food prices, the price of many agricultural commodities has spiked twice in the last decade. Food prices began to rise sharply in 2006, initially peaking in 2008. Although they fell in 2009, they again rose sharply in 2010 and in 2011 and 2012 went even higher than the 2008 peak. In the last five years prices have remained above pre-crisis levels (Figure B3.4a).
- **Increased volatility.** After a period of relative stability for several decades, prices have been increasingly volatile in the last decade.

Figure B3.4a. Annual food prices from FAO Real Food Price Indices



Source: FAO (2018) *Real Food Price Index.*

In our 2011 Technical Paper, the Committee highlighted several studies that attempt to quantify the contribution biofuels consumption made to the food price spikes. The range of results was large, finding that biofuels may have contributed between 20-70% of the rise in maize price inflation in 2008.

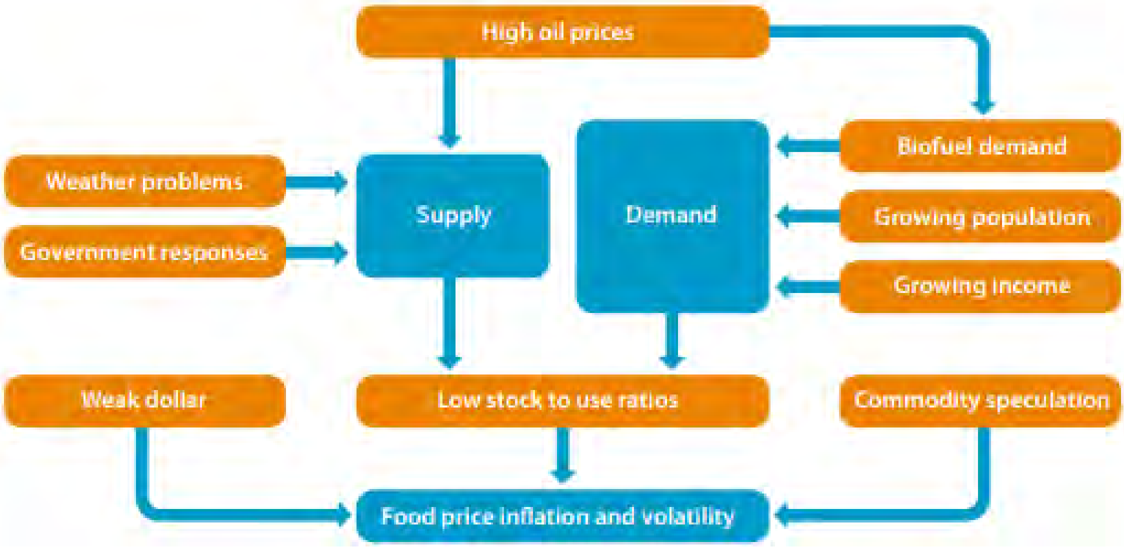
Since that publication, some additional evidence has been published on the contribution of biofuels to changes in global food prices:

- Roberts and Schlenker (2013) predict that the Renewable Fuel Standard will lead to a 30% increase in future food prices.
- Resources for the Future analysis showed a lower impact of biofuel mandates on global food prices, predicting a 17% increase by 2022.

There is a broad consensus that biofuel demand is one of a range of factors contributing to food price inflation and volatility (Figure B3.4b). Given this evidence, multilateral organisations have argued that the expansion of biofuels should be restricted to protect food security.

Box 3.4. Biofuels and food security

Figure B3.4b. Factors contributing to food price inflation and volatility



In April 2018, legislation took effect amending the UK Renewable Transport Fuel Obligation (RTFO). The legislation placed a limit on the contribution that renewable fuels produced from food crops can make to meeting targets, setting that limit at 4% in 2018, 3% in 2026 and 2% in 2032.

The primary aim of the cap was to reduce the risk of additional carbon emissions from indirect land-use change, but a shift away from crop-based biofuels under the RTFO may have a positive impact on global and UK food prices.

Sources: CCC (2011) *Bioenergy Review, Technical paper 2, Global and UK bioenergy supply scenarios;* Roberts, M. and Schlenker, W. (2013) *Identifying Supply and Demand Elasticities of Agricultural Commodities: Implications for the US Ethanol Mandate. American Economic Review*; Chakravorty, U.et al (2015) *Long-Run Impact of Biofuels on Food Prices. Resources for the Future, RFF DP*; OECD (2011) *Price Volatility in Food and Agricultural Markets: Policy Responses, Policy Report.*

2. International governance for sustainable imports - what works?

Governance will become more critical in the future as supply scales up and the value of biomass rises. Current consumer concerns around GHG benefits and any wider sustainability impacts are also likely to increase if supply is increased significantly without additional efforts to strengthen the framework.

It is also important to recognise that if the UK is participating in a growing global market for traded bioenergy resources, the benefits of UK actions will be the sum of the direct impacts and any indirect impacts - *not just indirect land-use change, but also any success in shaping markets and driving up standards internationally.*

A large range of governance solutions for sustainability of bioenergy have been implemented to date - varying in scope, coverage and approach. These initiatives differ in terms of geographic scale; whether they are mandatory or voluntary; in the area or sector to which they apply, and in their public, private or hybrid nature. Each of these may encompass one or more sustainability risks (i.e. reducing GHGs, environmental and social sustainability risks).

In the following sections, we draw on evidence from a technical annex on What Works in international governance for managing risks (Box 3.5).

The first section is focused on immediate steps which can be taken to improve the framework. The second focuses on the necessary elements of a strategy for dealing with the broader, evolving circumstances of participating in a global market - where success, ultimately, is defined at an international level.

Box 3.5. What we know of what works - local case studies and policy review

It is useful to consider practical lessons for insights on how to improve **governance for bioenergy**, particularly in the context of developing countries. There are international examples of governance mechanisms that have successfully addressed sustainability issues to date, including from wider biomass governance (e.g. timber). We take a broad view across the UK's current development, trade and climate finance initiatives in this (and closely-related) areas.

The analysis is based on a literature review and stakeholder interviews, including a workshop held in July 2018 with representatives from UK-based industry, academia, government, the NGO community and international experts. This box summarises findings that are written up in a technical What Works annex published alongside this report.

Certification schemes, which are used to demonstrate compliance with best-practice standards, are an effective governance tool but alone they are not sufficient to guarantee sustainability.

Certification has proved to be an efficient way to ensure standards are complied with along the entire supply chain, through different approaches such as chain of custody, mass-balance or segregation. Certification schemes have at times supplemented local or regional regulation, particularly in countries with weak governance structures; an increase in the number of schemes helped **stimulate competition amongst them.** However, certification schemes alone do not appear to be sufficient to ensure sustainability and can lead to negative outcomes including high administrative costs, the exclusion of small producers and limited transparency (e.g. around the auditing process).

- **Risk-based approaches** can provide an alternative to certification, particularly when the supply chain cannot be verified at a producer level. Risk-based approaches use regional risk assessments and do not require auditing at the individual producers' level, provided regional risk is deemed low, delivering greater efficiency and lower administrative costs (IEA, 2013). However their implementation needs to be targeted so as not to single out only a limited number of low-risk areas for biomass supply.
- **An independent monitoring system** based on robust indicators is critical for assessing the effectiveness of governance systems. Increased transparency and better data availability (i.e. through collating and publishing audit data) could be transformative, including via the use of modern technologies such as satellite and 'big data'.

As the concept of sustainability is very context-specific and dependent on local conditions, the ability to take these local conditions into account can determine the effectiveness of sustainability initiatives.

- A number of studies have shown that **multi-stakeholder** structures leads to more efficient governance outcomes and that participatory governance involving key stakeholders is required for public support of bioenergy (SCOPE, 2015). **'Roundtables'** such as the Roundtable for Sustainable Palm Oil (RSPO) and Roundtable for Sustainable Soy (RSS) have usually been set up by non-governmental bodies in partnership with industry. These provide examples of a multi-stakeholder structure, where all relevant stakeholders along the supply chain are involved in the various stages of the governance process (i.e. from standard setting to enforcement).
- Other ways to include local communities include forest concessions and local integrated food and energy systems (IFES):
  - **A well-evidenced example is that of Guatemala's forest concessions** within the Maya Biosphere Reserve (MBR), which were set up following civil war peace accords in 1996 as part of the national forest management plan. As reported by the Rainforest Alliance (2018), local communities were given the responsibility to manage around 660 thousand hectares of forest and were supported with capacity-building and technical tools. Forest concessions were coupled with the possibility of selling carbon credits on international

Box 3.5. What we know of what works - local case studies and policy review

markets. The system helped to support 26,000 new jobs in sustainable forestry and to improve gender equality by increasing the involvement of women in production activities. The forest concessions reached a near-zero deforestation rate, and kept the rate of forest fires remarkably low compared to nearby areas. These outcomes are much stronger than those achieved in national parks, which is linked to the impacts of corruption.

Successful governance requires continuously adaptating to changing circumstances and lessons learned, driving the gradual improvement of standards over time (IEA, 2018).

- Standards in the EU framework which regulates the sales and imports of forestry products, known as **EU FLEGT** Action Plan and EU TR (Timber Regulation), were initially set to be low, and then gradually improve over time. At the same time, coverage is extended gradually through a process for negotiating bilateral trade agreements, using a multi-stakeholder process to define outcomes under the licencing. In this way FLEGT has achieved both broad market coverage and high standards, while minimising administrative and transaction costs.
- The **Indonesian Sustainable Palm Oil (ISPO) standard** has been developed by the Indonesian government with foreign capacity-building support (including from the UK). It follows a similar principle of aiming to develop a properly-enforced minimum standard covering all domestic forest products, and then to tighten this subsequently, allowing it to increase the share of sustainable exports over time. If successful, it will allow market entry to producers currently excluded from international standards such as RSPO, while at the same time balancing this with issues of national sovereignty.

Sustainable outcomes in biomass governance also depend on the ability to integrate different and potentially competing uses of land, by adopting a more holistic landscape-based approach.

- A number of stakeholders suggested that such an approach can limit the negative impacts often implied by the somewhat artificial boundaries between the management of different land types, and can enable multiple objectives to be achieved simultaneously. Evidence suggests that there is scope for more efficient use of agricultural land today, for instance with the use of **multi-cropping** techniques (Box 4.2).
- **Integrated food and energy systems (IFES)** combine food production and energy services achieving synergies in otherwise potentially competing land uses. This helps limit sustainability risks, while at the same time empowering communities and minorities through the control of local natural resources, access to markets, diversification of revenues, reducing the gender gap and creating new jobs. International organisations such as FAO have supported IFES pilot programmes through finance and capacity-building, and they provide evidence of potential for scaling up beyond the pilot phase. Further examples of IFES can be found in Box 4.2 and Annex 2.

Source: IEA (2013) *Strategic Inter-Task Study: Monitoring Sustainability Certification of Bioenergy. Task 4: Recommendations for improvement of sustainability certified markets;* IEA Inter-Tasks Sustainability Project 2016-2018. Webinar (September 2018) *Approaches to creating trust in sustainability of bioenergy through effective governance;* Souza, G. M. et al (2015) *Bioenergy & Sustainability: Bridging the gaps*; Rainforest Alliance (2018) *Guatemala's Forest Concessions: A Global Conservation Model;* Lynd, L. et. al. *Biotechnology for Biofuels* (2015) *Bioenergy and African transformation.*

2.1. Immediate steps for improving the current framework

Areas of weakness and gaps in the current framework can be addressed in the near-term, to apply as a minimum to all future subsidies.

As a general rule, unsustainable or high-risk feedstocks should be regulated out and best practice encouraged. The current land criteria are a good first attempt to do the former, but BEIS and DfT should now update the criteria to reflect the growing evidence base in this area. This should draw on the Forest Research criteria and evidence summarised above.

BEIS and DfT should also address the current weakness in the criteria on preserving carbon stocks in existing forests by requiring that any long term changes in forest carbon stock at landscape scale are included in the calculation of the climate impacts of bioenergy systems. The general principle is to rule out feedstocks sourced from areas with falling carbon stocks. In applying the principle, account should be taken of appropriate spatial scales, the CO_2 fertilisation effect (i.e. the additional plant growth due to the higher atmospheric CO_2 concentrations) and relevant exclusions, for example in relation to diseased trees.

BEIS and DfT should also explicitly rule out the harvest of whole forest tracts exclusively for energy uses, in line with best practice as applied by the Green Investment Group:

- Green Investment Group (formerly UK Green Investment Bank, now part of Macquarie Group) requires funded projects not to include biomass from forest tracts harvested exclusively for energy uses (with certain exclusions, e.g. for diseased trees).
- The requirement aims to ensure that forest management (such as felling decisions and decisions regarding rotation lengths) continues to be driven by demand for higher value timber products rather than demand for bioenergy.[63]

This would also recognise the evidence that where used solely for energy, over 'climate policy relevant timescales (30 years, and in most cases significantly less)', using all of the stemwood from forest directly for energy leads to net increases in GHG emissions.[64] It does not rule out using all thinnings (including for example diseased trees, when removed as part of sustainable forest management).

Other areas for review include the approach to managing indirect land-use change risks and the coverage of social sustainability provisions:

- The approach to dealing with **indirect land-use change emissions** could be improved through better use of bespoke tools such as the country- and operator-level food security tools developed by UN FAO, by strategic coordination and use of 'flanking policies' to stop conversion of high-carbon and protected lands and by supporting mixed food-energy systems (Box 4.2).
- The coverage of social sustainability provisions under permitted certification routes should be reviewed to ensure that unsustainable practices (land expropriation, human rights abuses) are consistently ruled out.

Policy also has a role in incentivising best practice, to increase the supply of low-GHG biomass and create a 'race to the top'. BEIS should consider ways to incentivise best-practice not just minimum standards:

- More could be done on the GHG criteria to reward lower-carbon supply chains, drawing on the approach used in Belgium.

---

[63] Green Investment Group also have a requirement to source only from areas with stable or growing carbon stocks.
[64] Forest Research (2018) *Biomass Carbon Impacts*, and Matthews, R., et al (2014) *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*

- Reviewing eligible voluntary certification schemes on a regular basis would help to avoid a 'race to the bottom'.
- Ultimately, what is needed is a shift from relying on certification and audit as the main risk management tool towards focusing on better transparency of feedstock sources through use of modern technologies such as comprehensive publically-available datasets and satellite mapping.

The UK must show leadership through high quality independent monitoring and reporting of domestic UK biomass stocks and supply chains. This should be supported by improved monitoring techniques (e.g. satellite imaging, track and trace, improved soil carbon monitoring) and geographically-specific datasets:

- A robust monitoring process based on publicly available data could reduce reliance on third-party certification. This could lower administrative costs, open market access to small producers and increase overall trust in the system via greater transparency.
  - According to the IEA (2018)[65], there is relatively good data available from the forestry sector, for instance: the NepCon sourcing hub,[66] whose data can be used to show compliance with the EU Timber Regulation and other standards; data collected under the Sustainable Biomass Programme (SBP) Data Transfer System (DTS);[67] forest national inventories; and biodiversity data. Data are also available for the agricultural sector, though to a lesser extent.
  - Overall, data should be made more accessible, comprehensive (e.g. in terms of spatial coverage) and comparable (e.g. across sectors or products).
- There are several examples of how the use of the latest technologies has provided support to improved sustainability governance.
  - The US Forest Service uses remote sensing to track carbon stocks. Dale et. al. (2017)[68] have used a dataset of timber land variables to assess forest conditions in two South Eastern United States' fuelsheds. Their analysis enabled them to show that harvesting biomass for fuel did not lead to a decrease in carbon stock over the time frame considered.
  - The Swedish Forestry Board has national monitoring in place based on weekly Sentinel 2 data from Copernicus, to monitor the clearcut areas. This allows it to monitor each harvest permit granted, and to provide weekly updates of regenerated areas[69].
  - Kastens et. Al. (2017)[70] have used satellite data to estimate the impacts of the Brazil soy moratorium on deforestation rates, showing that the programme's benefit had originally been underestimated.

Aggregating and publishing datasets can not only help improve transparency and understanding of the impacts of supply-chains, but may also help to build public trust.

---

[65] See the IEA Inter-Tasks Sustainability Project 2016-2018 http://itp-sustainable.ieabioenergy.com/
[66] For further detail see the NepCon website: https://www.nepcon.org/sourcinghub
[67] For further detail see the SBP website: https://sbp-cert.org/data-transfer-system
[68] Parish, E., et. al. (2017). *Dataset of timberland variables used to assess forest conditions in two Southeastern United States' fuelsheds.*
[69] EARSC (2016). *Copernicus Sentinels' Products Economic Value: A Case Study of Forest Management in Sweden*
[70] Kastens, J., et. al. (2017). *Soy moratorium impacts on soybean and deforestation dynamics in Mato Grosso, Brazil*

2.2 Longer-term strategic approach

A second set of issues relate to how governance develops over time as markets scale up, policy evolves beyond the existing subsidy-driven markets, and how new international participants are given access to EU and UK markets.

Import standards should encourage new participants not simply to focus on 'low-risk' regions – this can be supported through wider trade and development activities, and through continued efforts to improve multi-lateral governance:

- Multi-level governance is the direction of travel for climate change governance more generally and underpins the system of Nationally Determined Contributions under the Paris Agreement. There would be benefits for bioenergy governance too, rather than aiming for a centralised approach (and issues of 'one-size-fits-all').
- However, there is a need to balance this against the potential for a multiplicity of schemes and related complexity.
- Ultimately, there is a need for transparent sustainability frameworks, but these are not enough in themselves. Governance strategy needs to expand beyond this to look at the range of drivers (finance, development activities, public procurement, trade agreements).

The UK Government already engages in a range of activities which have either direct or indirect impacts on sustainability governance for biomass imports, but currently these are not brought together in a public and transparent strategy.

Further strategic coordination, transparency and evaluation would replicate best practice in EU forestry governance. EU forestry governance is characterised by a holistic and integrated approach under the EU FLEGT action plan, including:

- Coordinated financial and technical support to timber-producing countries.
- The promotion of international trade in legal timber, building on a multilateral framework with major timber-consuming countries, and simultaneously on a number of bilateral trade partnerships with producer countries.
  - The EU FLEGT mechanism is an example of regulating out illegal logging through a combination of bilateral trade agreements and licencing.
  - Negotiating separate agreements with the involvement of stakeholders gives the flexibility to prioritise local considerations.
- Other incentive mechanisms, such as public procurement rules, support for private-sector initiatives, financing and investment safeguards, and action to address the problem of conflict timber.

Standards should be designed so as to ratchet up over time, with regular review and adaptive management, so that lessons can feed back in to decision-making. Various examples from international experience illustrate the strength of such an adaptive approach.

Ultimately, efforts are needed to evaluate progress on a regular basis. Success in doing so should determine the role of imports in the future economy.

Chapter 4: Future sustainable supply

In this chapter we explore potential future levels of sustainable biomass resource and set out the steps that need to be taken in order for higher levels of sustainable supply to be realised. We do this in two parts.

- First, we develop a range of supply scenarios for the UK from now to 2050, taking into account both domestic and imported biomass.
- Second, we set out the current barriers to producing domestic feedstocks and present a range of options for Government and industry to overcome these barriers and scale up UK supply.

The main focus of this chapter is biomass resources that are potentially suitable and available for bioenergy. In quantifying this resource we have taken account of future demand for established non-energy products such as wood in construction, pulp and paper and agricultural residues for soil health and animal bedding. However we have not accounted for potential new sources of future demand associated with the emerging 'bioeconomy' (discussed in Chapter 5). Future demand for products such as bio-based plastics is highly uncertain, but if it were to develop substantially there may be less resource available for bioenergy than we find here.

1. Future sustainable bioenergy supply scenarios

A technical annex covering our bioenergy supply scenarios is published alongside this report. This is supported by a paper produced by Forestry Research on global forest biomass resources, which is also published alongside this report.

1.1. Approach

There is significant uncertainty over the level of sustainable bioenergy resource that could be available to the UK in 2050:

- Future UK production of bioenergy resources from forestry and agriculture depends on decisions taken over the coming decades on tree planting, forestry management and the use of land for growing energy crops.
- Demand from competing uses will depend on factors such as levels of timber construction, paper and card usage for packaging, and new products such as bio-based plastics and bio-based chemicals.
- The availability of UK biogenic wastes (such as food waste, wood waste and some agricultural wastes) depends on broader trends in resource usage (e.g. the circular economy) and policy decisions on waste reduction, reuse and recycling.
- Whether substantial international biomass resources can be produced sustainably and made available for international trade depends on global developments including population growth, dietary habits and land availability as well as governance frameworks.
- Innovation in technology, agricultural strategies and crop genetics may mean that biomass production can increasingly be decoupled from productive land, potentially facilitating a scale up of supply that requires fewer trade-offs with other land-uses.

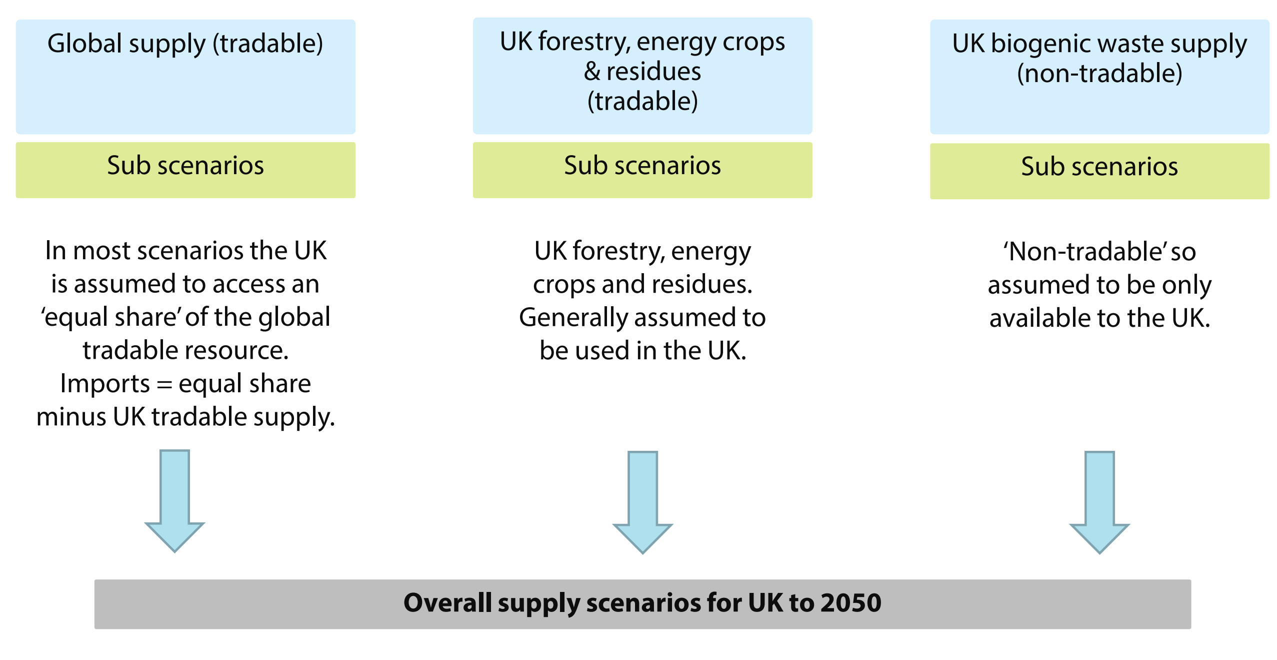
We have developed supply scenarios to reflect some of these uncertainties and represent different future pathways for the production and availability of sustainable bioenergy resource. They are stylised scenarios that allow us to explore what is required to achieve higher levels of supply and what the implications of different levels of sustainable bioenergy supply would be on strategies for meeting the UK's carbon budgets. While they are not predictions, they are intended to provide a indication of the range of sustainable supply that may be available to the UK in 2050.

Our supply scenarios are constructed from three core building blocks - a UK share of the global biomass resource, UK domestic production of agricultural and forestry biomass, and UK biogenic wastes (Figure 4.1):

- We make a distinction between tradable and non-tradable bioenergy feedstocks.
- Tradable feedstocks are those potentially suitable for international trade, including forestry and energy crop feedstocks and some agricultural residues. Our global resource estimates only include these tradable feedstocks.
- Non-tradable feedstocks are not suitable for long-distance trade due to low energy densities or other physical properties. We include biogenic wastes in this category and assume the UK can fully exploit its own waste resources.

For our scenarios which include imports we assume the UK accesses a share of the global tradable resource equivalent to its share of global primary energy consumption. This 'equal' share is estimated to be around 1.1% in 2050. We assume the UK utilises its own domestic tradable feedstocks and then imports additional resources until this equal share has been achieved.

Figure 4.1. Core building blocks of biomass supply scenarios



In quantifying the bioenergy resource available in our scenarios **we include only low-carbon, sustainable feedstocks that do not require further technological breakthroughs before they are commercially available**. Our estimates are derived from a review of the latest evidence and the Committee's UK land-use analysis, and aim to reflect the latest evidence on sustainable land-use management and biomass production (as summarised in Chapter 2).

- We explore levels of supply that are possible within an integrated land-use framework, considering interactions with biogeochemial, ecological and human systems.
- Our forestry supply estimates are based on sustainable forestry management and the latest evidence as to what constitutes a low risk, low-carbon forestry feedstock. For the UK, estimates were derived from assumptions about future tree planting rates and sustainable woodland management. Our global estimates were based on analysis undertaken for the Committee by Forest Research.[71] In this way, our estimates are intended to quantify only low-carbon forestry resources that provide significant GHG savings compared to fossil fuels once all land-use and carbon stock impacts have been taken into account. In our scenarios, the use of forestry resources for bioenergy requires stable or increasing forest carbon stocks and co-production with other harvested wood products such as sawn wood for construction.[72]
- Our energy crop estimates assume principally 'second generation' lignocellulosic crops (Box 4.1) grown on lower quality abandoned farming land, thus reducing the risk of displacing food production. We recognise that there may be potential for the production of biomass from 'first generation' food crops where this can be done sustainably (Box 4.2), although this is not assumed as part of our scenarios.
- Our agricultural residue estimates assume that half of all primary residues are not used for biomass production, but are instead retained for soil maintenance and animal bedding.
- We exclude biomass used for 'traditional' forms of bioenergy because this is often associated with unsustainable deforestation (e.g. charcoal production for use in low efficiency cooking stoves in developing countries).
- Our scenarios do not include biomass from algae or other potential innovative sources such as CAM crops (Box 4.4). If these feedstocks are successfully developed over the coming decades so that they are both sustainable and economically viable, then they could represent an alternative route to high levels of biomass supply.
- Our scenarios focus on the supply of solid biomass feedstocks to the UK. However in practice some of these are likely to have been processed into end-fuels (e.g. liquid biofuels) before being imported into the UK.

[71] The analysis carried out by Forest Research for the Committee is published as a technical annex to this report. It builds on work undertaken by Forest Research for the European Commission in 2014 (*Carbon impacts of biomass consumed in the EU*) and further developed for the European Climate Foundation in 2018 (*Carbon impacts of biomass consumed in the EU: Supplementary analysis and interpretation for the ECF*).

[72] Increased CO_2 fertilisation of plants from higher atmospheric levels of CO_2 is expected to increase carbon stocks in terrestrial ecosystems. The impact of biomass harvesting should be measured relative to this increasing baseline.

Box 4.1. Lignocellulosic energy crops - a UK case study

The Energy Technologies Institute (ETI) has reported on three case studies on farms in the UK that have successfully grown 'second generation' lignocellulosic energy crops including miscanthus and short rotation coppice (SRC) willow.

- Land was chosen that minimised or avoided impacts on food production.
    - Miscanthus was grown on land that had poor arable yields, displacing an average of 58.4 tonnes per year of food crops.
    - Miscanthus was also grown on grazing land freed up by increasing stocking densities of sheep on other pasture land and decreasing sheep numbers.
    - SRC willow was grown on surplus land.
- Initial investment costs are expected to be recouped in 7-10 years (without subsidy) and the crop lifetime was 23 years.
- Farms reported an annual net income increase of £139-£328/ha/year (without subsidies).
- The two farms growing miscanthus reported increases in wildlife numbers, particularly birds.
- An Environmental Impact Assessment was carried out on one site before the case study, but otherwise environmental impacts were not monitored.

Source: Energy Technologies Institute (2016) *Bioenergy crops in the UK: Case studies of successful whole farm integration evidence pack*, https://www.eti.co.uk/library/bioenergy-crops-in-the-uk-case-studies-on-successful-whole-farm-integration-evidence-pack. Photograph reproduced from the report with permission.

Box 4.2. Can 'first generation' crops be sustainably used for bioenergy?

There is some evidence that in certain circumstances crops normally grown for food can be grown for bioenergy in ways that deliver GHG emissions savings and minimise food security risks.

We present here two possible examples of this from the available literature: sugarcane production in Brazil and biogas production through sequential/seasonal cropping in Northern Italy. We have not undertaken a detailed review of the evidence relating to these two examples but highlight them here to illustrate the different approaches that can be taken to produce bioenergy crops, whilst acknowledging that both positive and negative impacts may be possible.

1. **Brazilian Sugarcane**

Sugarcane is widely grown in Brazil, which produced 40% of the world's sugarcane supply in 2016. It is processed to produce sugar for human consumption or used in the production of alcohol for consumption or bioethanol for fuel use. After the sugar is extracted the residue, bagasse, is combusted to produce electricity.

The rapid expansion of Brazil's bioethanol industry is largely due to a number of government policies that have promoted the production of bioethanol from sugarcane:

- Since 1993 it has been mandatory for petroleum in Brazil to include between 20% and 25% ethanol.
- The government is able to change the percentage to adapt to market pressures; in 2015 the mandatory requirement was increased to 27% bioethanol due to a market surplus.

The use of sugarcane ethanol has been estimated to reduce GHG emissions by 86% when compared to petrol, after taking land-use change into account. Selective breeding programmes have been used to increase yields and sugar content. Over the last 50 years, yield has doubled whilst unit costs have decreased by 67% in real terms. As sugarcane represents a food crop grown on agricultural land, risks of indirect land-use change emissions still exist with some evidence that indirect land-use change may be occuring in Brazil (Bergtold, 2017). However government initiatives such as agroecological zoning are in place which aim to prevent the indirect conversion of high carbon land (SCOPE, 2015).

The sugarcane does not require irrigation and residual water from the mills is used in times of shortage. The production of bioethanol is reported to improve economic resilience and food security, as crops can be diverted from bioethanol production to stabilise food prices. The electricity produced by bagasse can be used for heat and power and/or to provide an additional income. Traditionally, sugarcane fields in Brazil have been burned to aid harvesting. Although this practice is in decline, it causes atmospheric pollution that can be damaging to human health. Processing of sugarcane can have a substantial water demand, however research shows that there is the potential to reduce this through water efficiency strategies.

2. **Biogas production in Northern Italy - 'Biogas done right'**

A consortium of over 600 farmers in the Po River valley have used anaerobic digestion to produce biogas that is combusted on their farms to produce electricity.

Farmers used double-cropping, where a second crop is grown after the main food crop is harvested. The second crop, along with animal manure and other farm wastes and residues, is fed into an anaerobic digester to produce biogas. The biogas was then combusted to produce electricity that farmers sell to the national grid.

In addition to the biogas, the anaerobic digester produces two by-products. The liquid by-product was used for irrigation to provide water and mineral nutrients. The solid by-product was added to the soil

Box 4.2. Can 'first generation' crops be sustainably used for bioenergy?

to improve soil carbon and soil fertility. This led to a reduction in fertiliser costs and therefore an improvement in water quality.

Double-cropping reduced output of the summer crop to 92% of its original harvest. No land-use change was reported. The growth in the anaerobic digester industry is reported to be directly responsible for 12,000 new jobs in Italy. Income from food production did not change and fertiliser costs decreased. The production of biogas also adds economic resilience, as electricity production can be increased if crops fail or if there is a change in the relative prices of crops and electricity.

Estimates of GHG emissions savings were 79-86% (excluding credits for biogas production from manure). Double cropping did not increase water requirements as the Po River valley is very humid; however this may be an issue in other locations. Increased soil nutrients and soil compaction due to double cropping could lead to water quality and run-off impacts.

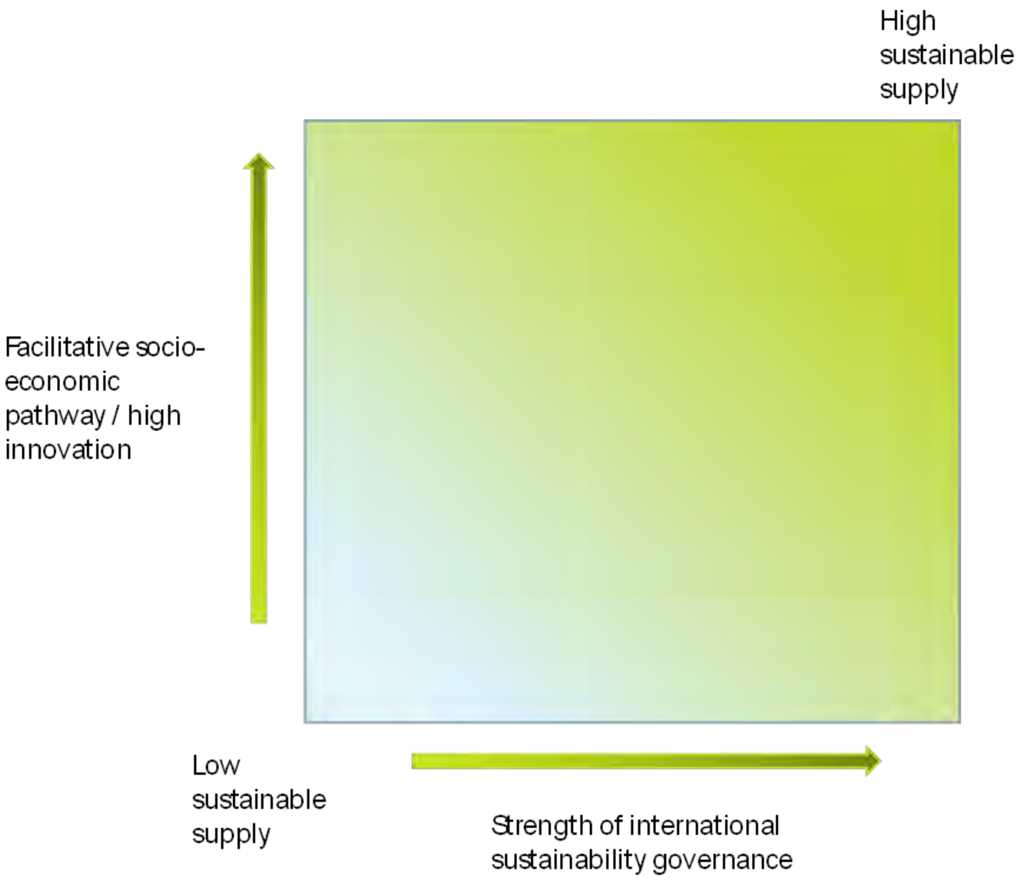
Source: Amorim, H.et al (2011) Scientific challenges of bioethanol production in Brazil; Bergtold, J.S. (2017) Indirect land-use change from ethanol production: the case of sugarcane expansion at the farm level on the Brazilian Cerrado; Buckeridge, M. et al (2012) Ethanol from sugarcane in Brazil: a 'midway' strategy for increasing ethanol production while maximizing environmental benefits. *GCB Bioenergy*; Chen, X. et al (2015) Explaining the reductions in Brazilian sugarcane ethanol production costs: importance of technological change. *GCB Bioenergy*; Dale, B. et al (2016). Biogasdoneright™: An innovative new system is commercialized in Italy. *Biofuels, Bioproducts and Biorefining*; Ecofys (2016) *Assessing the case for sequential cropping to produce low ILUC risk biomethane*, https://www.ecofys.com/files/files/ecofys-2016-assessing-benefits-sequential-cropping.pdf; Economia (2015) *Mistura de etanol na gasolina sobe hoje*, http://g1.globo.com/economia/noticia/2015/03/mistura-de-etanol-na-gasolina-sobe-hoje.html; FAOSTAT (2018) http://www.fao.org/faostat/en/#data/QC; Filoso, S. et al (2015) Reassessing the environmental impacts of sugarcane ethanol production in Brazil to help meet sustainability goals. Renewable and Sustainable Energy Reviews; RAEng (2017) *Sustainable Liquid Biofuels*, https://www.raeng.org.uk/news/news-releases/2017/july/biofuels-made-from-waste-are-the-business,-says-ac; SCOPE (2015) *Bioenergy & Sustainability: bridging the gaps*, http://bioenfapesp.org/scopebioenergy/index.php; Valenti, F. et al (2018). Evaluation of biomethane potential from by-products and agricultural residues co-digestion in southern Italy. *Journal of environmental management*; Wang, L. et al (2014) Economic and GHG emissions analyses for sugarcane ethanol in Brazil: Looking forward. *Renewable and Sustainable Energy Reviews*.

1.2. Global biomass supply

Our global supply scenarios are framed around two key axes (Figure 4.2):

- **Global socio-economic pathways** represent different possible futures for economic growth, trade and investment, innovation, consumption intensity and population growth. Our approach here is comparable to the Shared Socioeconomic Pathway (SSP) framework (Box 4.3) and allows us to explore the effect of key drivers such as land availability on the future sustainable supply of biomass.
- **International sustainability governance** represents the rules, processes and incentives that exist at the international level to ensure that biomass production is sustainable. The strength of future governance frameworks is likely to be a critical factor in whether sustainable biomass production is incentivised and the extent to which the UK can have confidence that imports are contributing to positive outcomes.

Figure 4.2. Framework for considering future global supply of bioenergy resources



Box 4.3. Shared Socioeconomic Pathways (SSPs)

The Shared Socioeconomic Pathways (SSPs) are **self-consistent sets of assumptions** regarding future changes in important development-related variables, such as GDP, population, agricultural and technological development (Riahi et. al., 2018).

- These variables fit within a given **narrative 'storyline'** for global development, such as green-growth, fossil-fuel based development, or a retreat from international co-operation and globalisation.
- The SSPs represent **normative** possible futures and are not intended to be predictions of how the real world will evolve. Importantly, the evolutions of GDP, population etc are assumed to be independent of impacts from climate change, which is unlikely to be the case in reality (Pretis et. al., 2018).

Biomass availability across the SSPs in the absence of climate policy is controlled by a number of assumptions.

- The **SSP1 'sustainability'** world assumes **low future population and strong improvements in agriculutural productivity**, enabling a significant fraction of existing agricultural land to be spared. Strong land-use regulation also exists to avoid adverse environmental trade-offs.
- **SSP2** represents a **'middle-of-the-road'** future broadly consistent with a **continuation of current development trends**.

Box 4.3. Shared Socioeconomic Pathways (SSPs)

- **SSP3** is a **'fragmentation'** world with **weak global institutions, barriers to trade and high challenges to implementing the rapid and deep mitigation** actions required to achieve the long-term temperature goal of the Paris Agreement.

For each SSP, integrated assessment models of the economy and climate can be used to describe the kinds of energy system transitions that would be required to meet a given climate objective (Box 1.4, Box 4.4), such as limiting warming to 'well-below' 2°C. This includes the compatible levels of low-carbon biomass supply.

- All scenarios compatible with ambitious climate mitigation **contain elements of strong global climate policy** independent of the background SSP narratives. This includes **a high and rapidly rising global carbon price**.

Our supply scenarios assume that stronger global governance and amenable socio-economic development characteristics from across the SSP narratives enable higher levels of sustainable biomass to be produced.

- Unlike in integrated assesment models, the sustainable biomass supply scenarios developed in this report are not explicitly tied to achieving a specific global temperature goal.
- Therefore the levels of sustainable biomass supply in our scenarios are more indicative of the different **underlying enabling conditions** for sustainable biomass across the SSP narratives.

Source: Riahi, K. et al. (2018) *The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change*, 42, 153-168; Pretis, F. et al. (2018) *Uncertain impacts on economic growth when stabilizing global temperatures at 1.5°C or 2°C warming. Phil. Trans. R. Soc. A*, 376 (2119), 20160460.

We have developed three global supply scenarios based on this framework. These scenarios result in a global tradable resource of 14-84 EJ per year / 4,000-23,500 TWh per year (Figure 4.3), reflecting a decrease compared to today at the low end and a substantial (three-fold) increase at the high end:[73]

- Our **low global supply scenario** reflects a fragmented world order with less international cooperation than today and low levels of international trade and investment, broadly in line with SSP3. The wider socio-economic context is poor for sustainable biomass production. High global population growth, high food demand, meat intensive diets and low levels of innovation mean that much more land is required in 2050 for agriculture and very little if any land at all is available for energy crops. Together these factors mean that **the global tradable bioenergy resource in 2050 falls to around half that of today**. This is reinforced by poor global governance meaning that the UK can have only very limited confidence that any imports are contributing to positive outcomes.
- Our **mid global supply scenario** reflects a world continuing along current global trends, broadly in line with SSP2. Buisness-as-usual (BAU) levels of investment lead to some further development of key markets and infrastructure, enabling some scale-up of supply. There is robust if incomplete governance in several key areas of the world and sufficient international cooperation to provide confidence that the trade of bioenergy feedstocks can contribute to positive outcomes. Population growth and a continuation of meat-intensive diets mean that

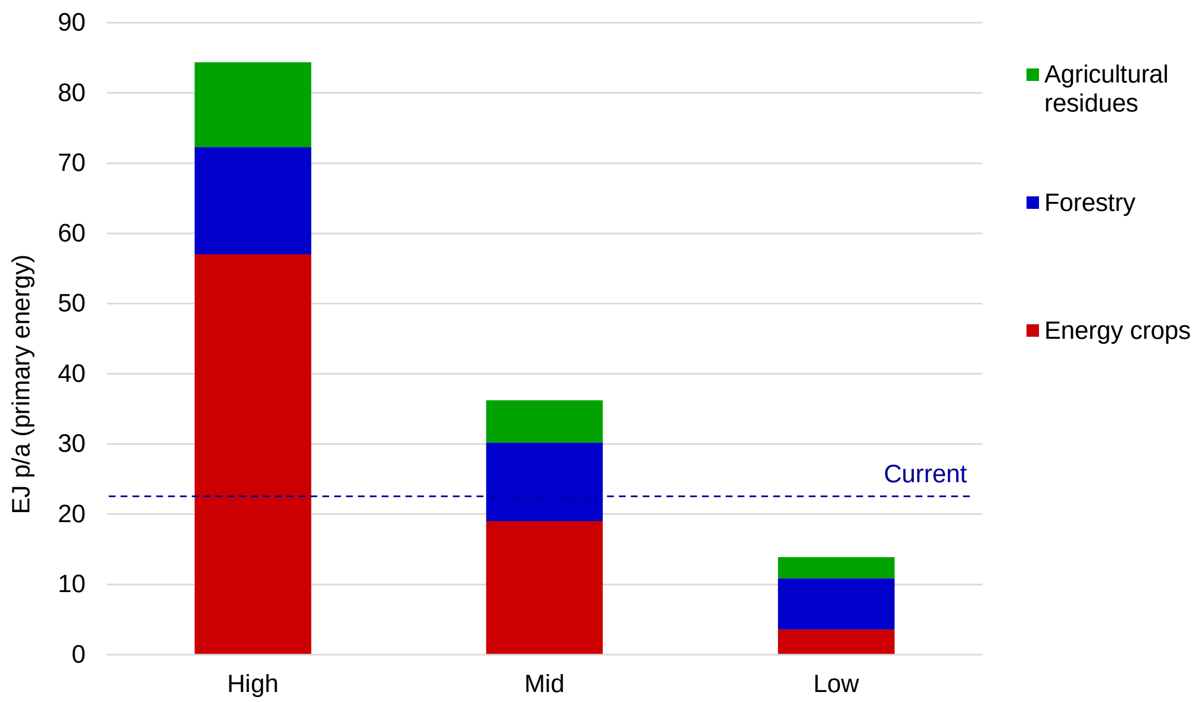
[73] We estimate that the current global tradable biomass resource is up to ~23 EJ p/a, based on IEA (2017) *Technology Roadmap - Delivering Sustainable Bioenergy*.

there is very little, if any, additional land available for bioenergy crops by 2050[74] (although bioenergy crops could still be produced in integrated agricultural food and energy systems). Overall, **the global tradable bioenergy resource increases by around 50% by 2050** compared to today.

- Our **high global supply scenario** reflects an interconnected 'green growth, investment and innovation' world broadly in line with SSP1. Increasing levels of market and infrastructure development are assumed over time, facilitating greater availability of sustainable biomass. Strong global governance ensures only sustainable biomass is produced and traded. A favourable socio-economic context with low global population growth and a shift to less meat intensive diets means less land is needed for food in 2050 compared to today, allowing an increased use of land for energy crops (~200 Mha in total) as well as increased afforestation and ecosystem restoration. Energy crop yields continue to improve over time, although break-through innovation is not assumed.[75] Overall, this drives a **three-fold increase in the global tradable resource by 2050**. A similar outcome could be achieved via innovations that result in high bioenergy supply without the use of substantial amounts of productive land (Box 4.4). Our high scenario is at the low end of biomass availability assumed in many global mitigation scenarios that achieve ambitious climate goals (Box 4.5).
- In all of these scenarios, forest bioenergy resource estimates assume that residues and thinnings come from forests that are managed to produce a range of products including high-quality saw logs for sawn wood production. The low and mid global supply scenarios assume growth in global demand for sawn timber, wood-based panels and pulp and paper in line with the historical average. The high scenario assumes higher levels of growth such that overall demand for these products, driven by increases in timber construction, doubles by 2050. In this way, forest bioenergy resource estimates are tied to wider economic trends and demand for a range of forestry products.

[74] It is estimated that between 50 Mha and 100 Mha land is currently used for bioenergy crop production.
[75] For our high global scenario we assumed an average global yield of 15 oven dried tonnes (odt) / ha for lignocellulosic energy crops grown on lower quality agricultural land. In reality we would expect large variation according to location, investment and management intensity.

Figure 4.3. 2050 global 'tradable' biomass resource scenarios



Source: CCC analysis.

Box 4.4. Can biomass production be decoupled from land?

There are a range of potential innovations in bioenergy feedstock production that could reduce bioenergy demand on land and/or reduce trade-offs with food production and other aspects of sustainability. Whilst the Committee is cautious about such future innovations and we have not included these in our bioenergy supply scenarios, we acknowledge the potential for game-changing developments in the future. Below we summarise some examples:

- **Algae** includes both microalgae and macroalgae (e.g. seaweeds). Some evidence suggests algae could reduce emissions by between 60% and 80% relative to fossil fuels.
  - **Microalgae** can be grown in open ponds or closed reactors in warm climates. These can be built on barren land, reducing competition for land. Microalgae can grow very rapidly and efficiently to produce greater energy per unit area than terrestrial crops. Their high oil content is used to make liquid biofuels. They can also utilise captured CO_2 (for example, from fossil fuel use). Microalgae have high water demands, however this can be met using seawater or waste water. Integrating production with wastewater treatment could meet microalgae's high nutrient demand, as well as treating the water, which could provide additional income. The main barrier is the current cost of microalgae production and harvesting. Genetic modification has been suggested as a way to increase yields and minimise other issues such as predation in open ponds. However, the environmental impacts of these modifications are unknown.
  - **Macroalgae** can be harvested from open water or grown in aquaculture systems, requiring no land for production. They can be used to produce biogas via anaerobic digestion. Macroalgae is already harvested for higher value products (for example food, nutritional

Box 4.4. Can biomass production be decoupled from land?

and chemical products). Their production is seasonal; additional feedstocks would be required to supplement biogas production.

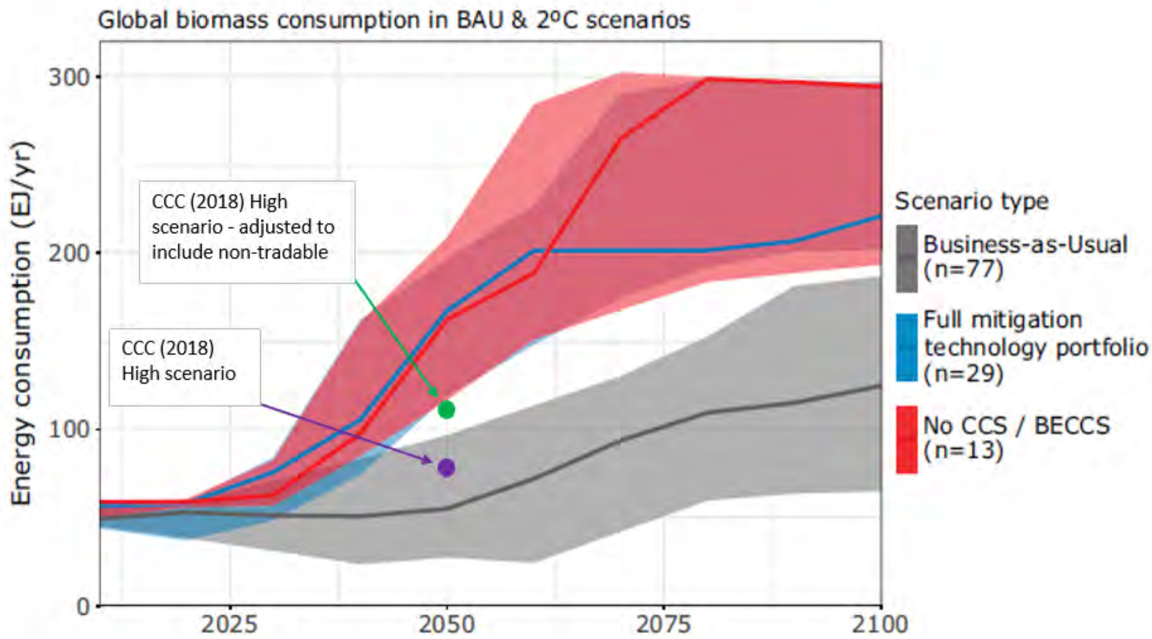
- **'CAM' crops** such as Agave and Opuntia use the Crassulacean Acid Metabolic (CAM) pathway as an adaptation to an arid environment. This allows them to maintain very high rates of water efficiency. They can be grown in areas where traditional agriculture is not profitable due to insufficient or irregular rainfall. They can be converted into biogas via anaerobic digestion. Agave plants cannot be mechanically harvested, which increases labour costs for these crops. There are over 200 species of Agave, many of which have not been field-tested. Some of these have desirable traits (for example, cold tolerance).
- **'Oily' crops** such as Camelina and Jatropha are characterised by seeds with a high oil content.
  - Large scale **jatropha** plantations exist in a number of African countries. It is traditionally used to make soap. The plant is toxic to humans and animals. It is also used as a hedge species to protect food crops from livestock. The seeds have an oil content of approximately 35%. Jatropha seed oil can be used to make biodiesel. Seedcake, kernels, fruit and seed husks are also produced in the processing of Jatropha. Seedcake can be used as fertiliser, however this may prove toxic. It is also made into briquettes and used as a fuel although this may affect human health. Estimates of GHG emissions savings range between 11-107% relative to fossil fuels. Exploitation of jatropha byproducts will be necessary to make it more profitable than soap production.
  - **Camelina** can be grown on marginal lands to make biodiesel. It has low water and nutrient requirements. Camelina is an annual crop and can be grown in rotation with winter crops (for example, winter wheat). It is also highly resistant to disease and pests. Camelina produces lower quality biodiesel which limits its applications. Reports suggest that genetic engineering could improve its quality.
- **Synthetic biology** developments can be applied to existing bioenergy crops to improve yields and make them more cost-effective. Research has been conducted into modifying plant genes that alter plant content and composition. This can increase the yield of the plant and make the feedstock easier to process into fuel.

Source: ARUP (2014) *Advanced biofuel feedstocks - an assessment of sustainability* http://www.e4tech.com/reports/advanced-biofuel-feedstocks-an-assessment-of-sustainability/; Bacenetti, J. et al. (2017) *Biodiesel production from unconventional oilseed crops (Linum usitatissimum L. and Camelina sativa L.) in Mediterranean conditions: Environmental sustainability assessment. Renewable Energy. 12, 444-456*; Ciubota-Rosie, C. et al. (2013) *Biodiesel from Camelina sativa: A comprehensive characterisation. Fuel. 105. 572–577*; IEA (2017) *State of Technology Review - Algae Bioenergy*, https://www.ieabioenergy.com/publications/state-of-technology-review-algae-bioenergy/;
Kagale, S. et al. (2014) *The emerging biofuel crop Camelina sativa retains a highly undifferentiated hexaploid genome structure. Nature communications. 5. 3706*; Mason, P. et al. (2015) *The Potential Of CAM Crops As A Globally Significant Bioenergy Resource: Moving From Fuel Or Food To Fuel And More Food. Energy Environ. Sci.* 8; Owen, N., et al. (2015) *Crassulacean acid metabolism (CAM) offers sustainable bioenergy production and resilience to climate change. GCB Bioenergy. 8, 737-749;* SCOPE (2015) *Bioenergy & Sustainability: bridging the gaps,* http://bioenfapesp.org/scopebioenergy/index.php; Shurin, J. et al. (2013) *Industrial-strength ecology: Trade-offs and opportunities in algal biofuel production. Ecology letters. 16, 1393-1404*; Su, Y. et al. (2017) *Progress of microalgae biofuel's commercialization. Renewable and Sustainable Energy Reviews. 74. 402-411.*
UNU-IAS (2012) *Biofuels in Africa Impacts on Ecosystem Services, Biodiversity and Human Well-being,* http://collections.unu.edu/eserv/UNU:2902/Biofuels_in_Africa1.pdf; Wang, P., Dudareva, N., Morgan, J. and Chapple, C. (2015) *Genetic manipulation of lignocellulosic biomass for bioenergy. Current Opinion in Chemical Biology. 29, 32-39.*

Box 4.5. A comparison with biomass requirements in Integrated Assessment Models

Figure B4.5 shows the Committee's high global bioenergy resource scenario compared to a range of biomass requirements in global mitigation scenarios. Our high estimate is at the low end of the range of resources required in many integrated assessment models that limit warming to below 2°C, when compared on a like-for-like basis. This reflects the Committee's approach to deriving resource estimates based on a comprehensive assessment incorporating the latest evidence on both GHG emissions and sustainability issues.

Figure B4.5. Global biomass requirements in Integrated Assessment Models



Source: Adapted from Minx, J.C et al. (2018) Negative emissions—Part 1: Research landscape and synthesis. *Environmental Research Letters*, 13 (6), 063001.
Notes: Biomass resource is measured here in primary energy terms. The Committee's high global biomass supply scenario (~84 EJ p/a) is shown relative to biomass consumption in global mitigation scenarios. We also show an adjusted high scenario which includes an estimate of 'non-tradable' biomass resources. These non-tradable resources are excluded from our supply scenarios but are included here to allow a like-for-like comparison. Integrated assessment model scenarios compatible with a 2°C warming are shown in blue (all technologies available) and red (CCS/BECCS excluded). Ingrated assessment models run without an explicit climate constraint (business-as-usual) are shown in grey.

Integrated assessment models (IAMs) are coupled models of the global energy system and physical climate. They can be used to provide **'cost-effective' energy system pathways** expected to be consistent with a particular climate outcome.

- IAMs require external assumptions such as future population, GDP, crop yields and relative prices of different technologies.
- Perfect foresight across all future years is often assumed in order to minimise the net present value of achieving the climate goal.

Box 4.5. A comparison with biomass requirements in Integrated Assessment Models

- Idealised climate policy implementations are often assumed (such **as a global carbon price applied to both fossil fuel and biogenic carbon emissions**) that are unlikely to be replicated in the real world.
- IAMs provide projections of pathways that would be **sufficient** to meet a climate goal (e.g. 66% chance of limiting warming to beneath 2°C). They do not provide predictions for future evolutions of the energy system.
- IAMs generally include a land-surface model which simulates any change in land carbon stocks associated with high-levels of biomass supply, **including indirect land-use change emissions**.

For ambitious climate goals such as that of the Paris Agreement, **high levels of future biomass use are simulated by many IAMs in order to achieve deep emissions reductions** (Box 1.4).

- **Traditional biomass use is phased out** in IAMs to be replaced by dedicated energy crops and sources of forest biomass.
- IAMs use biomass to provide **electricity** and/or **heat**, upgrade to **hydrogen**, and to produce **liquid fuels** (Bauer et. al., 2018).

In pursuit of ambitious climate goals, the amount of bioenergy deployed in IAMs can increase to well in excess of 100 EJ/yr by 2050, with further increases thereafter.

- A large contributor to the high levels of bioenergy deployment is projected future yield growth (both for bioenergy crops and for agricultural crops, allowing agricultural land to be freed up for bioenergy production) (Creutzig et al., 2012).

Enabling such **high-levels of sustainable biomass supply** depends on assuming elements **of strong global climate policy**. Such idealised conditions are unlikely to be seen in reality. These assumptions include:

- A global carbon price applied on all sources of biogenic carbon, disincentivising the conversion of high carbon content land.
- Restricting biomass for energy production to avoid existing arable land and the conversion of protected forest areas (in many IAMs).
- **Ecological studies** are generally **more sceptical** that such large amounts of sustainable biomass can be achieved in reality (Creutzig et al., 2012).
- This literature suggests that producing such large amount of bioenergy supply would require more land and therefore create greater sustainability challenges.
- Other sustainability dimensions (such as biodiversity) are not generally explicitly incorporated into IAM estimates of supply, and might be expected to reduce the magnitude of sustainable supply in reality (Dooley and Kartha, 2017).

Source: CCC; Bauer et al. (2018) Global energy sector emission reductions and bioenergy use: overview of the bioenergy demand phase of the EMF-33 model comparison. *Climatic Change*, 1-16; Creutzig et al. (2012) Reconciling top-down and bottom-up modelling on future bioenergy deployment. *Nature Climate Change*, 2 (5), 320; Creutzig et al. (2014) Economic and ecological views on climate change mitigation with bioenergy and negative emissions. *Nature Climate Change*, 2(5), 320; Dooley & Kartha (2017) Land-based negative emissions. Risks for climate mitigation and impacts on sustainable development. *International Environmental Agreements: Politics, Law and Economics*, 18(1), 79-98.

1.3. UK domestic bioenergy resource production

UK forestry, energy crops and agricultural residues ('non-waste' bioenergy resources)

Our scenarios for future UK production of bioenergy resources from forestry and energy crops are derived from the Committee's work on future UK land-use published alongside this report.

The land-use project assesses the potential for changes in UK land-use and land management to contribute towards more ambitious climate goals. It explores the impact of key drivers of land-use and assesses the extent to which current use of natural land can be improved to deliver deeper carbon reduction and sequestration and improve resilience of land to climate change. The project developes a series of *'what-if?'* scenarios to quantify the aggregate impacts of different levels of ambition for key measures (Box 4.6). The scenarios also quantify amounts of future UK biomass production that could be possible under different conditions.

Box 4.6. A summery of the Committee's UK land-use analysis (2018)

The CCC land-use project developed five 'what-if' scenarios for UK land-use in 2050. These scenarios do not result from a process of optimisation but are intended to explore how changes in land-use and land management could reduce emissions and increase sequestration from the UK's land, as well as take account of the effects on climate resilience.

The analysis looked at the potential release of land from current uses due to increases in agricultural productivity, reduced food waste and healthier diets. A number of constraints were applied, including protection of all national parks and natural habitats, allocation of land for expansions of settlement growth and the requirement to maintain current levels of per capita UK food production. This anlysis suggested that around 20-30% of agricultural land (an upper bound of just over 5 Mha) could be released from agricultural uses by 2050, allowing this land to be allocated to other uses including peatland restoration, afforestation and biomass production. In addition, better management of existing land-uses was explored, for example active management of degraded woodlands. This can increase biomass supply whilst also improving habitats for biodiversity, without requring any land-use change. The five scenarios explored were:

- Business as usual (BAU) - Existing trends in land use continue to 2050. Levels of agricultural productivity and innovation reflect past trends with little change on diets and food waste.
- High biomass/natural peatland (HBP) - Agricultural land released through higher agricultural productivity and some changes in behaviour on diets and food waste. Focus on high tree and bioenergy crops planting rates, productivity and peatland restoration.
- Innovation and behaviour focus (IBF) - Maximum ambition for agriculture innovation and technology, high levels of change in behaviour towards healthy eating guidelines and willingness to try novel food sources that could release more land. High tree planting and productivity rates helped by innovative techniques.
- Multi-functional land use (MFLU) - Medium levels of ambition on innovation and behaviour to release agricultural land for other uses. High levels of hedgerows and trees on farms and areas of afforestation leading to a more diverse agricultural landscape.
- Off-track - Land released through higher agricultural productivity and technology used mainly for growing more food in the context of increasing global food demand. Focus on maximising agriculture output and exports, with low levels of ambition for afforestation and bioenergy.

Source: CCC (2018) *Land Use: Reducing emissions and preparing for climate change.*

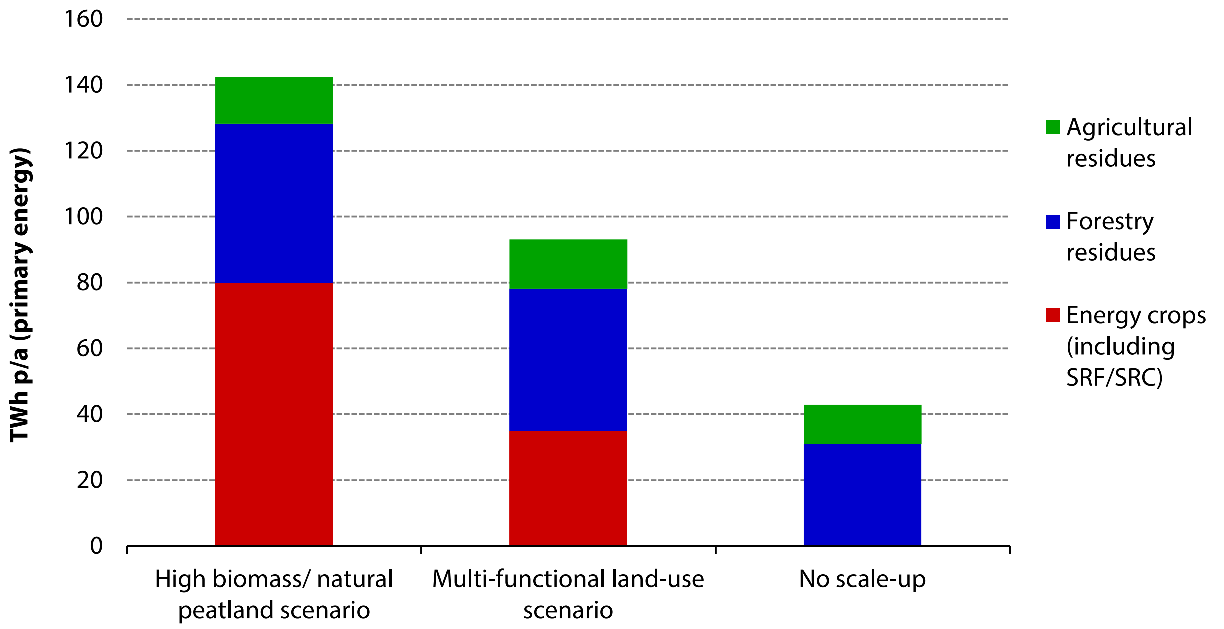
This land-use analysis has informed the development of three scenarios for UK production of bioenergy resources from non-waste biomass. Two of these scenarios would represent a significant increase in production by 2050 compared to today (Figure 4.4). They demonstrate the high levels of production that could be possible if steps are taken to increase UK supply. Whilst both of these scenarios assumes sustainable land-management practices, the desirability of these levels of long-term biomass supply will in practice depend on multiple factors including the extent to which potential trade-offs are avoided and food production prioritised:

- The **multi-functional land-use scenario** assumes a combined reforestation and afforestation rate of 30,000 ha p/a alongside increased levels of forestry management and 0.7 Mha land used for energy crops by 2050. **This results in UK production of non-waste bioenergy resources doubling to ~95 TWh p/a by 2050**.
- The **high biomass / natural peatland scenario** assumes a combined reforestation and afforestation rate of 50,000 ha p/a alongside increased levels of forestry management and over 1 Mha land used for energy crops in 2050 (around 7% of the UK's total agricultural land). **This results in UK production of non-waste bioenergy resources increasing three-fold to ~140 TWh p/a by 2050**.
- We have also included a scenario where there is **no scale-up** of UK non-waste bioenergy supply by 2050, implying low levels of afforestation and no significant amounts of energy crops production. This could reflect either a lack of action in these areas or a concerted effort to maximise UK food production. This results in supply stagnating at today's levels through to 2050 (~45 TWh p/a).

For our multi-functional and high biomass land-use scenarios, high levels of tree planting are achieved and maintained, leading to a substantial increase in wood production from UK woodlands. This is most pronounced for forestry residues and thinnings suitable for bioenergy, which increase from ~28 TW p/a (5.4 Modt) today to up to ~45-50 TWh p/a (9 Modt) in 2050. There is less of an increase in high quality sawlogs, from ~1.5 Modt today to ~1.7 Modt in 2050. This is because of the time-lag between tree planting and harvesting of mature trees, implying sawlog production would increase more substantially beyond 2050 in these scenarios. A similar measured level of growth is assumed for other non-energy products including wood for paper and wood-base panels. If demand for these increased (Chapter 5) there would be a further, relatively small, reduction in bioenergy supply.

Our domestic UK agricultural residue estimates include crop straw and seed husks. We assume around 50% of crop staw is left in the fields to maintain soil quality and crop yields. We also assume other non-energy uses (such as animal feed) are satisfied. **This results in a small increase in UK agricultural residues from around 12 TWh p/a today to around 15 TWh p/a by 2050.** This is included in the scenario totals given above. Clearly if more residues are required for competing uses or soil health then less would be available for bioenergy than we assume here.

Figure 4.4. Scenarios for 2050 UK biomass from forestry, energy crops and agricultural residues

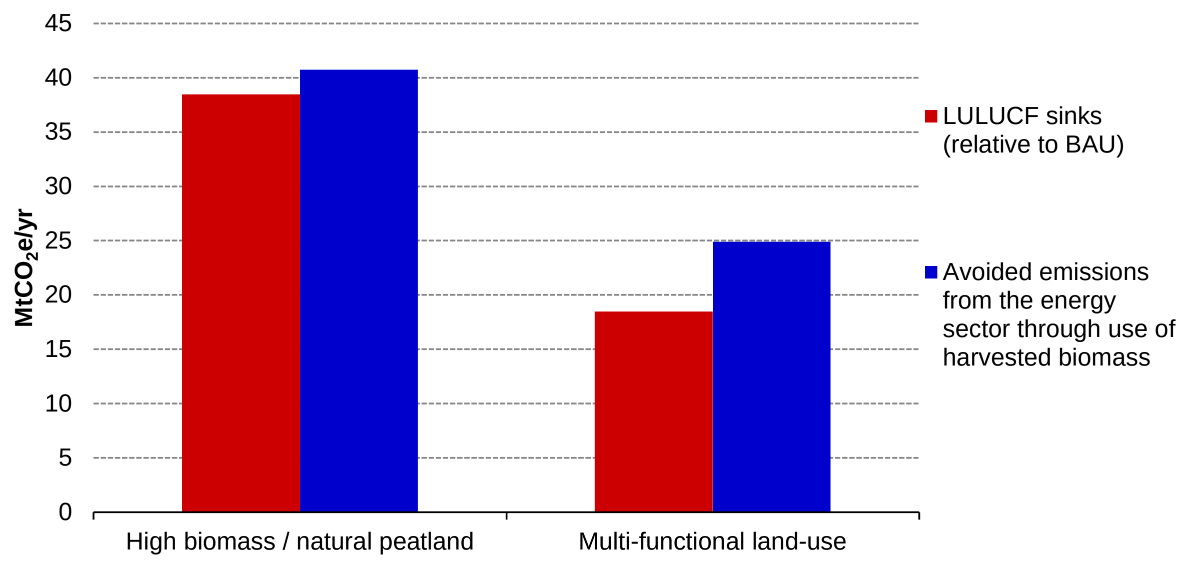


Source: CCC analysis.
Notes: The high biomass and multi-functional land-use scenarios are derived from the CCC's land-use report. The no-scale up scenario broadly maintains current levels of production.

Both the multi-functional and high biomass land-use scenarios are likely to deliver significantly greater levels of GHG abatement compared to a continuation of current trends (Figure 4.5):

- The amount of biomass in the landscape increases (absorbing and storing carbon from the atmosphere). This is alongside an increase in the amount of harvested biomass available for use in the energy system and bio-based products (displacing fossil fuel emissions as well as potentially storing carbon for long-periods). The amount of mitigation in the energy sector can vary substantially depending on how the harvested biomass is used.
- These scenarios do not result from an optimisation process and are not based on detailed bottom-up modelling. In reality there are a number of factors that impact how land is used, and different choices will impact the level of abatement achieved in any given situation.

Figure 4.5. Abatement in both land-use and energy sectors in 2050 for UK land-use scenarios



Source: CCC analysis.
Notes: Land-use, land-use change and forestry (LULUCF) sinks in 2050 from the UK Land-Use report scenarios (expressed relative to the business-as-usual scenario and without emissions from agriculture) and avoided emissions due to domestic harvested biomass use in the energy sector. Avoided emissions from the energy sector are calculated using the idealised assumption that harvested biomass for fuel is all used in power sector applications with carbon capture and storage; in reality the carbon displaced and stored from the use of sustainable harvested biomass for energy purposes will vary depending on the application (see Chapter 5 for our best-use hierarchy).

UK biogenic wastes

The UK currently produces substantial amounts of biogenic waste each year from sources such as waste wood, food waste and municipal solid waste (see Box 1.6 for descriptions of these categories of waste). When this waste is left to decompose (often in landfill sites) it produces methane which, unless captured, is emitted into the atmosphere, where it has a considerably greater warming effect than CO_2. These methane emissions have been falling over the last decade in the UK, partly as a result of the use of waste for energy. Further significant reductions will be needed by 2050 to meet the UK's carbon budgets.

UK waste policy adheres to the 'waste hierarchy' which ranks waste management options in line with what is consdered best for the environment:

- The waste heirarchy is a legal requirement of the revised EU Waste Framework Directive.
- It sets out that the first priority is to minimise the amount of waste produced, and then maximise the amount of waste recycled or re-used. Only after this should any residual waste be used for energy recovery.
- The waste hierarchy also makes sense from from a climate point of view. For example, avoiding waste will avoid upstream emissions in agriculture and food production, and potentially free up biomass resources and/or land.

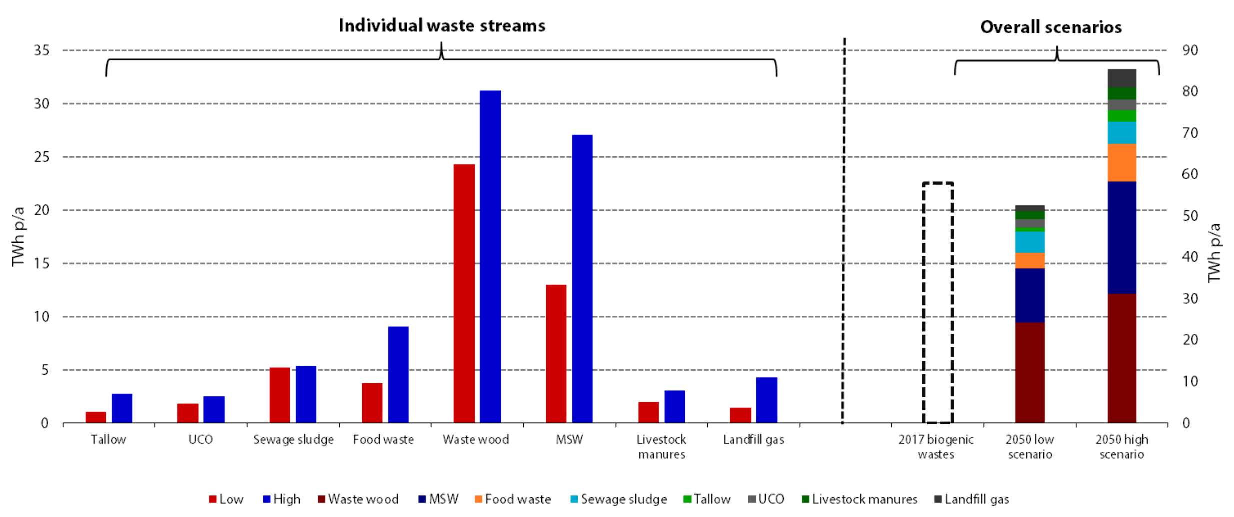
Based on these principles we have developed a high and low scenario for the level of biogenic waste available for use in the UK to 2050:

- These scenarios illustrate two different pathways for how waste may be reduced and biogenic waste collected, giving a lower and upper bound in 2050.
- They consider only the levels of biogenic waste in the economy, not non-biogenic waste.
- Even with ambitious waste reduction, reuse and recycling, we estimate that substantial biogenic waste resources will be available in 2050.

Our scenarios result in a total biogenic waste resource for bioenergy of between 50 TWh p a and 85 TWh p a in 2050, compared to around 60 TWh p a used today (Figure 4.6):

- **The 'low' scenario** is our preferred scenario and reflects a future where waste is minimised at source. For example, in this scenario less household food waste is generated - with around 60% of today's household food waste avoided by 2050. The residual waste resource is almost fully exploited with most barriers to waste seperation and use being overcome, potentially through future technological breakthroughs. The overall biogenic waste resource in 2050 is 53 TWh p/a, lower than that exploited today.
- **The 'high' scenario** reflects a future where there is more biogenic waste in the UK economy. Less waste is avoided or minimised at source with Government, households and businesses taking less action than in our low scenario. Waste arisings are therefore substantially higher, and higher collection rates for this residual waste resource are needed. The overall biogenic waste resource in 2050 is 85 TWh p/a, substantially higher than that exploited today.

Figure 4.6. 2050 biogenic waste scenarios



Source: CCC analysis.
Notes: The chart only includes estimates of biogenic wastes. All waste streams except landfill gas are estimates of primary energy. Landfill gas represent the energy in the capture landfill gas in 2050, and is not the primary energy in the landfilled waste.

1.4. Overall bioenergy resource supply scenarios

We have constructed four overarching UK biomass supply scenarios drawing on the above analysis and pulling together different assumptions about domestically produced and imported feedstocks (Table 4.1). These scenarios result in a total UK biomass resource in 2050 of around 100 TWh p/a to 300 TWh per year (Figure 4.7), indicating **biomass could provide 5-15% of UK primary energy consumption by 2050.**[76] In 2035 there is a narrower range of around 130 TWh per year to 240 TWh per year (Figure 4.8). This is because some of the key determinants of our supply scenarios (such as sustainability governance) are assumed to have cumulative impacts over time.

Achieving the higher end of this range in a sustainable way is likely to require a number of preconditions to be met, including:

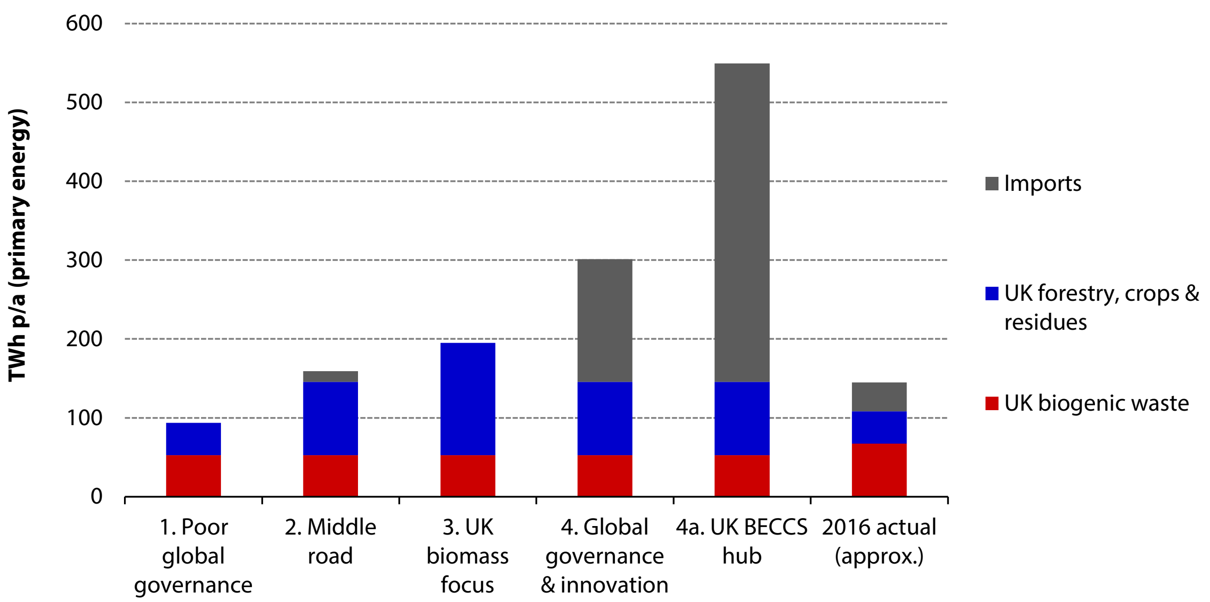
- Strong sustainability governance and international cooperation.
- Significant amounts of land for growing energy crops (in turn requiring a favourable socio-economic context) and/or high levels of innovation in technology and agricultural strategies.
- Significant amounts of investment and policy support.

We have also developed an additional 'UK BECCS hub' scenario. This assumes the same global supply picture as our 'global governance and innovation' scenario, but reflects a future in which the UK accesses a greater proportion of the global resource as part of a wider international effort to sequester and store carbon dioxide. In this scenario we assume the UK is well placed to play this global role due to its supply chains, infrastructure and geological storage capacity (Box 4.7). One implication of the UK acting as a 'BECCS hub' would be that it should deliver a greater share of global emissions reduction than currently assumed in the UK's long-term climate targets.

[76] This compares to ~150 TWh or ~7% of primary energy consumption today.

<table>
<caption>Table 4.1. Description of overall UK bioenergy resource supply scenarios</caption>
<tr><th>Scenario</th><th>Global narrative</th><th>UK narrative</th><th>Total UK resource to 2050</th></tr>
<tr><td>1. Poor global governance and UK supply fails to scale-up</td><td>An unfavourable global context for sustainable biomass production and supply (SSP3 'low' global supply world). Imports decline to zero by 2050 reflecting poor sustainability governance and the fact that domestic production exceeds the UK's 'equal share' of the small global resource.</td><td>A stagnating domestic picture where no significant land is used for energy crops in 2050 (this could imply a decision to focus on food security) and forestry resources fail to scale-up. Domestic biogenic wastes reduce, reflecting high ambition on waste reduction.</td><td>Remains at ~145 TWh to 2030, then reduces by 50% to ~100TWh by 2050.</td></tr>
<tr><td>2. Middle road: status quo globally & UK supply increases</td><td>A continuation of current trends globally (SSP2 'mid' global supply world). However whilst more biomass is available internationally we assume no net imports by 2050 because scaled-up domestic production exceeds the UK's 'equal share'.</td><td>UK production increases substantially over time as part of a broader multi-functional land use strategy that sequesters more carbon in soils and forests and produces more forestry and energy crops. Domestic biogenic wastes reduce as above.</td><td>Increases by around 10% from ~145 TWh today to ~160 TWh in 2050.</td></tr>
<tr><td>3. UK biomass focus</td><td colspan="2">This scenario reflects a future where the UK scales up domestic production of biomass to near the maximum sustainable level ('high biomass' land-use scenario) whilst imports decline to zero by 2035. The significant increase in biomass resorce is driven by energy crops with increased tree planting having less impact due to longer timescales involved. Domestic biogenic wastes reduce as in scenario 1.</td><td>Increases by around 40% from ~145 TWh today to ~200 TWh in 2050.</td></tr>
<tr><td>4: Global governance and innovation</td><td>A favourable global context for sustainable biomass production and supply (SSP1 'high' global supply world). This is accompanied by strong sustainability governance allowing imports to increase more than three-fold over time.</td><td>Domestic production in line with scenario 2.</td><td>Increases by around 100% from ~145 TWh today to ~300 TWh in 2050.</td></tr>
<tr><td>4a. UK BECCS hub</td><td colspan="2">This scenario is a variation on scenario 4. It assumes the same global and UK context except here the UK accesses double its 'equal share' of the global resource by 2050 (2.12%), with high levels of imports and substantial infrastructure requirements.</td><td>Increases more than three-fold to ~550 TWh in 2050</td></tr>
<tr><td colspan="4">Source: CCC.</td></tr>
</table>

Figure 4.7. Breakdown of overall UK bioenergy resource supply scenarios in 2050



Source: CCC analysis.
Notes: Scenario 2 shows low amounts of imports by 2050. This is because in this scenario the UK's domestic production is almost equivalent to the UK's 'equal share' of the tradable global resource, as defined in our methodology above. This scenario could also involve higher levels of imports that are in large part balanced by UK exports (resulting in low levels of *net* imports).

Box 4.7. UK BECCS hub scenario

The UK could be well placed to play a role as a global hub for carbon removal due to its supply chains, infrastructure and geological storage capacity. If 400 TWh of imported bioenergy were made available to the UK, this could be turned into up to 133 Mt of sequestered CO_2, with bioenergy with carbon capture and storage (BECCS) providing benefits both to the UK energy system (in the form of power or hydrogen) and in reducing atmospheric concentrations of CO_2. Acting as a BECCS hub at this scale would have significant - but potentially manageable – implications for UK infrastructure.

- The UK has ample CO_2 storage potential – around 80-90 $GtCO_2$ – almost 90% of which is within saline aquifers. This is sufficient to be able to capture 200 $MtCO_2$ per annum for over 400 years.
- Previous work for the Committee by Mott Macdonald in 2011 identified rail and port infrastructure as a potential constraint for the expansion of imported bioenergy in the UK.
  – Biomass has a lower mass to energy ratio than coal (1:1.2), limiting how much can pass through UK ports, and a lower volume ratio (1:1.8), limiting how much can be transported per train.
  – Converting all previous UK coal-handling ports to biomass would allow a fivefold increase in biomass imports compared to today (around 165 TWh). A BECCS hub scenario could require 2.5x this port capacity.

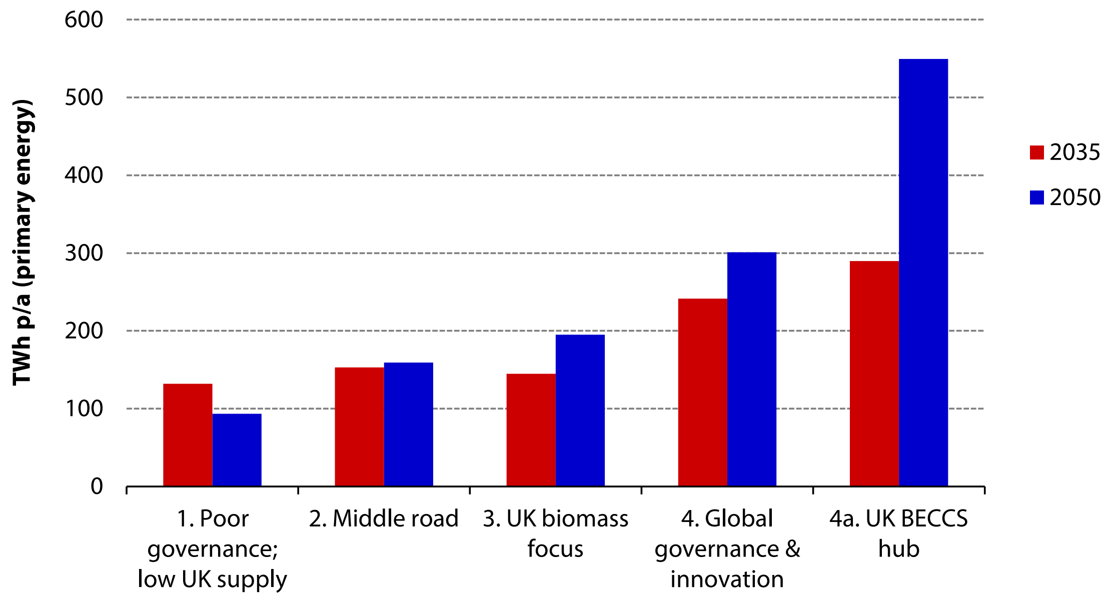
Box 4.7. UK BECCS hub scenario

- In the 1980s the UK transported around 90 Mt of coal per year around by rail, equivalent to around 50 TWh of primary bioenergy. A BECCS hub scenario could require a 60% increase on this.
- Although a BECCS hub scenario could imply a significant scaling up of infrastructure, building BECCS plant in coastal areas could allow new infrastructure to be built more easily.

- Converting 400 TWh of primary bioenergy into power or hydrogen could produce 140 or 240 TWh respectively. As hydrogen can be stored, and clear low-carbon alternatives exist for electricity generation, it may be preferable to gasify the biomass to produce hydrogen.
  - There are likely to be a range of demands for use of low-carbon hydrogen in the UK (see our parallel *Hydrogen Review*). In scenarios where UK demand for hydrogen is lower than might be produced in a BECCS hub scenario, there could be potential to export hydrogen or use some of the biomass in other ways.
  - Combustion of large volumes of bioenergy for power generation could require around 18 GW of bioelectricity generation in the power sector. Thermal electricity generation can be useful in providing essential electricity grid operation services (such as inertia and frequency response) in a low-carbon way, although if these plant were run at constant output, this could cause issues in a power system dominated by variable renewables.
- Transforming 400 TWh of bioenergy into energy and negative emissions has the potential to increase local air pollutant emissions (Box 5.5) - ensuring that it does not do so would require the fitting of mitigation technologies, at additional cost.
- Under this scenario, negative emissions from additional imports of bioenergy to the UK are assumed not count towards the UK emissions reduction targets, but rather than would be counted towards the decarbonisation efforts of other countries. However, production of energy from additional bioenergy may displace emissions from other energy sources in the UK. We will consider how such a scenario should be treated under the UK's emissions targets as part of our advice on the UK's long-term targets to be published in spring 2019.

Source: CCC analysis based on Mott Macdonald (2011) *Biomass conversion of coal plant*, ETI (2016) *Strategic UK CCS Storage Appraisal*, ORR (2018) National Rail Trends Portal.
Notes: Total CO_2 capture based on 400 TWh of primary bioenergy with a carbon intensity of 365 gCO_2/kWh, 90% CO_2 capture rate. Assuming process efficiency of 60% HHV for biogasification, and 35% for bioenergy combustion in power.

Figure 4.8. UK bioenergy resource scenarios over time



Source: CCC analysis.
Notes: These scenarios include both domestic and imported feedstocks. The range (excluding scenario 4a) in 2035 is ~130 TWh p/a at the low end (scenario 1) and ~240 TWh p/a at the high end (scenario 4).

2. Scaling up UK supply

In this section we set out the context and barriers to biomass production in the UK and present options for government and industry to scale-up supply over the next five to ten years.

This assessment has been informed by engagement with Government, industry and academic stakeholders.[77] More detail is provided in a technical annex on scaling up UK supply, published alongside this report. We also draw on the work of others, including the Energy Technologies Institute (ETI), who have explored this topic in recent years.[78]

2.1. Context and barriers

There has been a substantial increase in bioenergy use in the UK over the last decade, with most of this associated with increased exploitation of wastes and agricultural and forest residues, along with additional imports (Figure 1.4). In contrast there has been only a modest increase in

[77] This was undertaken in partnership with Dr Jeanette Whitaker, a Senior Research Scientist and NERC Knowledge Exchange Fellow at the Centre for Ecology & Hydrology, conducting research on the environmental costs and benefits of renewable energy in the terrestrial environment. Her role as NERC Knowledge Exchange Fellow for Bioenergy involves translating and communicating scientific evidence to policymakers and industry on the impacts of land-use change to bioenergy production and bioenergy sustainability more broadly. In July 2018, a stakeholder workshop was convened on "Steps to scaling up UK sustainable bioenergy supply" bringing together 35 stakeholders from academic, policy, NGO and commercial stakeholder communities.
[78] See ETI (2015) *Enabling UK biomass* and ETI (2016) *Bioenergy crops in the UK. Case studies of successful whole farm integration*.

the production of purpose grown biomass through the planting of energy crops and new woodland.[79]

- Production of dedicated 2nd generation energy crops such as Miscanthus has been relatively static with very little additional planting in the last decade and only around 10,000 hectares of land cultivated in total. The Government's previous Energy Crop Scheme suffered from low uptake and closed to new applicants in 2013.
- Around 120,000 hectares (2%) of agricultural land was used for growing 1st generation crops for energy in 2016, mostly maize and wheat. Whilst this has increased over time, there are sustainability concerns about the production of these crops for energy (see Chapter 2).
- Between 2007 and 2017 the area of newly created woodland in the UK was around ~9,000 hectares p/a. This is substantially lower than the stated ambition of England and the Devolved Authorities (DAs) to increase annual afforestation rates to 20,000 hectares p/a by 2020 and 27,000 hectares p/a by 2030, and only around one fifth of the 2050 planting rates explored in the Committee's UK land-use scenarios.
- The amount of biogenic waste landfilled in the UK has fallen since 2008, reflecting progress in waste minimisation and improved waste collection. This has been largely driven by the increase in the landfill tax.

This slow growth in biomass production from forestry and energy crops is associated with a range of regulatory, economic and technical barriers, as well as a lack of support and suitable incentives:

- High establishment costs and delayed revenues from harvestable biomass can discourage production of both energy crops and forestry.
- This combines with a lack of long-term policy certainty and low confidence in future market demand so that land managers often view biomass production as a high risk endeavour.
- The approvals processes for planting energy crops and forestry are seen by many stakeholders as bureaucratic, complex and time-consuming.
- There is a lack of relevant agronomic advice on energy crop establishment and a lack of guidance for farmers and landowners on tree planting and management.

2.2. Options for scaling up UK forestry and energy crops

Our UK land-use scenarios suggest that it may be possible to substantially scale up UK production of forestry and energy crops without reducing per person food production, due to improvements in agriculture and dietary shifts releasing land for other uses. However whether using significant amounts of land for bioenergy ultimately proves the most desirable option will depend on other priorities and the extent to which trade-offs can be mitigated. In the short to medium term (the next 5-10 years) the immediate objectives should be meeting ambitious tree planting targets and facilitating an appropriate scale up of bioenergy crop production to develop business models, incentvise innovation and build market confidence. This will allow the option of further scale-up in the future.

[79] See DEFRA (2017) *Crops grown for bioenergy in England and the UK in 2016* and Forest Research (2018) *Woodland statistics.*

There are a number of steps Government and Industry can take to overcome the barriers to biomass production from UK forestry and energy crops. These must be taken within the context of strategic land-use management and targeted at delivering a broad range of benefits:

- **There is an increasingly strong evidence base for the diverse environmental and socio-economic benefits that energy crops and forestry can provide.** Realising these benefits depends on factors such as location, site characteristics, feedstock choice and land management practices (Chapter 2). **This evidence base should underpin Government action and form the basis for any incentives offered to biomass production**.
- The UK's 25 year Environment Plan and planned exit from the Common Agricultural Policy (CAP) provide a new context for policies and strategies to scale up biomass production. **Rewards for carbon sequestration in forests and soils and other ecosystem services such as alleviation of flood risk should be built into the UK successor to the Common Agricultural Policy**. Energy crop production should be included in this rewards scheme where it delivers these wider sustainability benefits and provided it is not already incentivised through other subsidies.
- Building a self-sustaining industry in the UK should be the long-term goal, but in the short-term this **requires economic, policy and regulatory barriers to be addressed** through targeted action. Options include:
  - Streamlining the complex cross-agency responsibilities for planting approvals.
  - Removing inconsistencies in regulation, for example the significant differences in the approvals processes for changing land-use to forestry compared with energy crops planting.[80]
  - Creating a more compelling business case for growers by addressing the high establishment costs and delayed income from energy crop and tree-planting.
  - Establishing sources of robust advice for growers and landowners to develop knowledge and skills in planting and managing unfamiliar crops and forestry.
  - Supporting the development of new crop breeds and the scale-up of planting materials.
- **Clear signals of a long-term government commitment** to biomass production are needed to build confidence and trust across supply chains. Support should include planting rate targets for key feedstocks, building a pathway to further scaling up in the future. Progress and benefits should be monitored so that policy can evolve over time.
- The development of UK supply chains will require confidence in long-term market demand for sustainable biomass. There is a role for policy here in **providing greater certainty through carbon pricing, bioenergy incentives and developing new markets** as part of a wider bioeconomy strategy.

2.3 UK wastes

The Committee has previously made a number of recommendations to Government on reducing emissions from UK waste streams. Here we reiterate the need for action but also identify further measures to fully exploit the UK's biogenic waste resource.

[80] Changing land to forestry is considered a permanent land-use change in environmental impact assessments (EIAs). Short Rotation Coppice (SRC) needs an EIA whereas planting miscanthus does not.

Our previous recommendations on reducing emissions from waste centre on:

- **Banning landfill of bio-degradable waste streams, including food, by 2025**. This includes setting out a commitment to the ban alongside publishing and implementing specific strategies for each of the main biodegradable waste streams.
- **Maximising the amount of gas captured at existing landfill gas sites**, by exploring new and innovative ways to manage these. Scoping studies and research are required to assess the best methods for the management and aftercare of existing landfill sites. Having carried out this research, cost-effective policies for this should be developed and implemented.

However, in order to realise the 2050 future waste scenarios set out in this report, further action would need to be taken in a number of areas. These relate to both minimising waste and maximising exploitation of the remaining available resource:

- **Further action on improving recycling rates**: The UK is currently not on track to meet the EU target of 50% recycling by 2020, although Wales currently has recycling rates of around 56% and is on track to meet its target of 70% recycling by 2025. Our scenarios envisage between 70-85% recycling rates being achieved UK wide by 2050. Further policy effort is required to achieve this.
- **Reducing food waste**: Evidence suggests that around 60% of current household food waste is avoidable. Currently there are voluntary programs, such as 'Love food hate waste' campaign, that are targeted at reducing this. Whilst these are helpful, more action is needed to reduce food waste out to 2050.
- **Separation of waste streams**: There are currently no legal requirements on local authorities in England to introduce separate food waste collections, and many that do also mix this with garden waste. In order to best use the future UK waste resource, further action is required to separate out biogenic waste streams from non-biogenic waste streams.
- **Data collection**: Due to the distributed nature of wastes, data quality and coverage is low in some areas. For example, there is currently no data covering food waste that is generated on farms. Improving data quality is necessary in order to monitor and evaluate the UK's progress towards reducing emissions from waste and maximising the potential of any residual waste streams.

Chapter 5: What is the role of biomass in meeting UK carbon targets?

In this chapter we consider the role of biomass in decarbonising the UK's economy and set out how the uses of biomass should change over time. Our starting point (Section 1) is that there is likely to be a finite supply of sustainable biomass feedstocks available to the UK through to 2050, and that this scarce resource should be used where it delivers most value (i.e. where it is 'best used'). We then proceed in four parts:

- We set out the principles we use to assess best use of biomass over time.
- We identify the end-uses that we think are most likely to constitute best use in 2050, focusing on the energy system and construction sector.
- We set out how uses of bioenergy in key sectors of the economy need to change over time to maximise GHG abatement, develop technologies and align with long-term best use.
- We consider the emerging 'bioeconomy' (in particular bio-based plastics) to explore the circumstances in which new sources of potential long-term demand might also constitute best use.

1. Sustainable low-carbon biomass is a flexible and finite resource

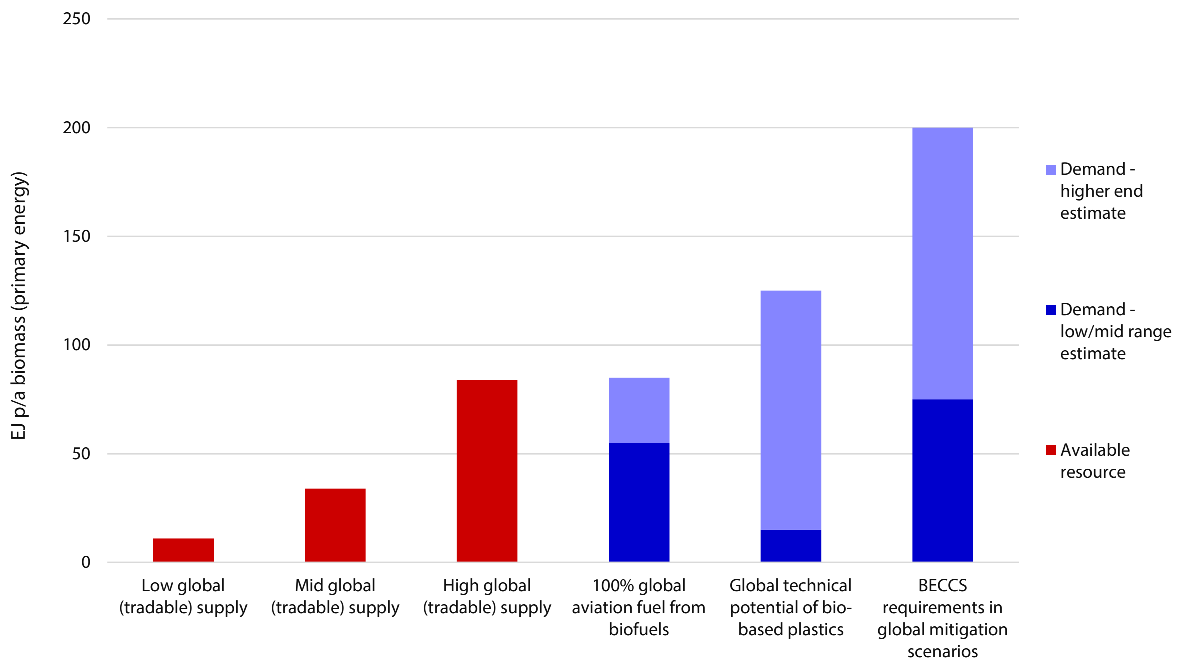
Biomass is a flexible resource that has the potential to contribute towards decarbonisation activities across multiple sectors of the economy:

- The growth of biomass is one of the few established routes to absorbing large quantities of carbon from the atmosphere and storing it for long periods of time. In some circumstances this will be best achieved by leaving living biomass in the landscape. In other circumstances more carbon can be stored (and more abatement delivered) by harvesting biomass for use in the economy and allowing regrowth of biomass in the landscape (Chapter 2).
- Within the energy sector biomass can be converted into a number of different energy carriers and used for a wide variety of applications:
  - Energy carriers include wood pellets/chips, biomethane, liquid biofuels, electricity and hydrogen. In some cases biomass can be converted into 'drop-in' fuels that require few changes to existing end-use infrastructure and technologies.
  - Applications where biomass can displace fossil fuels include electricity generation, liquid fuels for transport, and heat for buildings and industrial processes.
  - In the future we anticipate that it will be possible to deploy bioenergy with carbon capture and storage (BECCS) to produce power, heat, hydrogen and/or biofuels. This will provide a route for long-term carbon storage and as well as providing important services within the energy system (e.g. by providing baseload power or storable hydrogen).
- Within the construction sector, wood-based products and timber-frame construction are well established with significant levels of deployment in the UK and elsewhere. Using wood in construction has the potential to be scaled-up in the UK and contribute towards GHG abatement through storing carbon and displacing fossil fuels.
- Within the emerging bioeconomy new products such as bio-based plastics are being developed that use biomass as a production material, often as a route to replacing fossil fuel feedstocks.

1.1. Potential uses for biomass are likely to exceed sustainable supply

The wide range of possible end-uses for low-carbon sustainable biomass mean that potential demand is likely to be substantially greater than supply. This is illustrated at the global level in Figure 5.1, focussing on just some of the potential uses of biomass in 2050. This means decisions will need to be made as to where this finite biomass resource is best used across the economy.

Figure 5.1. Potential global demand for sustainable biomass by key end-use applications in 2050



Source: CCC analysis.

Notes: The low, mid and high global supply scenarios are described in Chapter 4 of this report. They present global *tradable* supply. Demand for the end-uses shown is uncertain and mid-range/higher-end estimates of *potential* demand are shown, based on CCC analysis and drawing on publicly available sources. The end-uses shown are not exhaustive. The bar on aviation biomass demand is derived using ICAO estimates of potential total global aviation fuel demand in 2050 (ICAO 2017 *Trends and scenarios on alternative fuels*) and reflects uncertainties about the conversion efficiencies of aviation biofuel production. A range of efficiencies of 30% to 47% was used here. The bar on BECCS biomass demand is based on the amount of biomass required under different global mitigation scenarios taken from the IPCC 2018 *Special report on global warming of 1.5C*. Some scenarios meet 1.5C or 2C without any biomass, other 2C scenarios use more than 100 EJ p/a biomass with BECCS and some 1.5C scenario use more than 200 EJ p/a. The range shown in the chart is indicative only. The bar on bio-based plastics shows potential demand if the full technical potential of bio-based plastics were realised. The range reflects uncertainties over future technical potential and uncertainty / variability as to the amount of biomass needed to produce a given quantity of plastics. The lower end of the range assumes bio-based plastics can replace 50% of all plastics and require ~4 over dried tonnes (odt) biomass for every 1 tonne of plastic produced. The higher end assumes 90% bio-based plastics and ~12 odt biomass for every 1 tonne plastics produced. These figures are highly uncertain. References for bio-based plastics are provided in the bioeconomy section of this report.

1.2. The high value of sustainable biomass in a low-carbon world

Over time, as emissions targets tighten and the costs of alternative means of reducing emissions increases, the value of biomass is likely to rise significantly:

- Since additional sustainable biomass will always be able to provide additional opportunities for carbon reduction or sequestration, its value will be affected by the value of carbon reductions more generally.
- For example, in the UK the Government's published carbon values increase from £35/tCO_2e in 2017 (the midpoint of values in the traded and non-traded sectors)[81] to £113-340/tCO_2e in 2050 in order to meet an 80% reduction in emissions as required by the Climate Change Act. By 2050, these carbon values imply an increase in the value of biomass of between £10/GJ and £33/GJ by 2050.[82] The current price of wood pellets is around £7/GJ.

How rises in carbon values feed through to prices of traded biomass will depend on policy arrangements across the world and market dynamics between producers, suppliers and users of biomass. However we would expect biomass prices to rise to levels that substantially exceed future costs of production in many locations:

- Costs of biomass production (excluding land values) are expected to remain stable or at least to increase less rapidly over time due to innovation (for example, in crop types and practices, driving up yields), due to learning and potentially also economies of scale for more significant supply-chains.
- Strengthened governance may increase costs due to additional sustainability requirements and monitoring - equally, innovation in use of satellite data and track and trace may help keep costs increases down.
- Overall, these supply and demand dynamics imply that there could be significant pressure to increase supply beyond sustainable levels over time.

This emphasises the importance of strong global governance and the need for careful policy design in the UK to avoid incentivising unsustainable supplies. This could in turn require **quantity-based limits** on the amount of biomass used in particular applications or across the economy, based on robust assessments of the amount of sustainable resource available.

2. Principles and approach to analysing 'best use'

The fundamental principle guiding our analysis of best-use is that a finite supply of sustainable biomass should be used where it can deliver the greatest overall value to the UK's economy as we reduce emissions over time to meet increasingly stringent carbon budgets:

- The value of using biomass in a particular application will depend on the cost of its use (including conversion of the feedstock, transportation and equipment required to turn it into a useful end-product) relative to the cost of the alternative low-carbon option.
- As we move towards 2050 and abatement activities are required in more expensive and difficult areas, this points to biomass being used in applications that give the greatest overall levels of GHG abatement.

[81] The non-traded carbon value is £4/tCO_2e, traded carbon value £65/tCO_2e.

[82] These 2050 values assume the use of biomass in BECCS applications. If used to displace fossil fuels with a lower carbon intensity then these values would be lower.

- Some biomass feedstocks (e.g. some biogenic wastes) have characterstics that mean they may be most appropriately used for specific end-uses. We take this into account in our assessment of best-use, and identify some of these 'niche' end-uses below.

2.1. Why does using biomass for sequestration generally deliver more GHG abatement?

Our analysis suggests that more GHG abatement will generally be achieved by using a unit of harvested biomass as a route to storing carbon (alongside producing a useful energy service or product) than by using it only to displace fossil fuels. This conclusion rests on assumptions about CCS capture rates, the longevity of CO_2 storage and the carbon intensity of the fossil fuel potentially displaced:

- Biomass contains more carbon per unit of stored energy than most fossil fuels. This means that if just the combustion phase of bioenergy use is considered, biomass normally emits significantly more CO_2 per unit of energy generated than fossil fuels.
- The amount of atmospheric carbon stored in a unit of biomass used for construction or energy generation with CCS will generally be greater than the amount of fossil carbon emissions displaced by using a unit of biomass instead of fossil fuels.
- The exception to this is if biomass displaces coal, which has a very high emissions intensity. In this case, once conversion efficiencies are taken into account, storing away the carbon in the biomass or using biomass to displace coal emissions are likely to be broadly comparable - although clearly displacing the coal *and* storing the emissions would be preferable.

As a result, **in the long-term harvested biomass should generally be used to sequester atmospheric carbon, where this also displaces other emissions**. Should available options for doing this be exhausted (for example if there are limits to feasible BECCS deployment) then the greatest abatement would be delivered by using biomass to displace high-carbon fossil fuels where there are no other viable low-carbon alternatives.

2.2. How should biomass be used in a transition to long-term best use?

In the short term there are only limited options for using harvested biomass as part of carbon storage strategies in the UK, principally through the use of wood in construction. We have therefore identified the following 'transitions' principles to guide how sustainable biomass should be used through the 2020s and 2030s where more extensive sequestration and use is not a widely available option. Biomass should be used where:

a) It can deliver cost-effective GHG abatement compared to the next-best low-carbon alternative whilst avoiding 'lock-in' to sub-optimal uses, *and/or*

b) It develops key technologies and sustainable supply chains.

2.3. Approach to modelling best use in the energy system

To inform our view on the best use of sustainable biomass across the energy system, we have carried out modelling using the Energy System Catapult's (ESC) Energy System Modelling Environment (ESME).[83] A summary is provided in Box 5.1.

[83] An annex to this report provides a comprehensive description of the ESME model, details of how we produced the results in this report plus changes we made to the ESC's version of ESME, Annex 5. Energy System Modelling for the Biomass and Hydrogen Reviews.

Box 5.1. ESME energy system modelling

ESME is a cost optimisation, policy neutral tool which models the whole UK energy system including the power, transport, buildings and industry sectors from 2010 to 2050. It indicates the optimal energy system design that minimises total cost whilst meeting user-defined CO_2 emissions limits.

In running ESME, we have also pushed the model beyond the emissions reductions required by the current 2050 target, in order to understand the implications of biomass use under more stringent constraints on emissions, whether by 2050 or subsequently. For all model runs, unless otherwise stated, we have applied an emissions limit corresponding to a greenhouse gas reduction on 1990 levels of 90% by 2050 (or as near to this as the model can achieve under any given set of constraints).

The model uses primary energy resources (e.g. biomass, fossil fuels, nuclear, wind) to meet demands for energy services (e.g. vehicle kilometres or heat for a specified number of buildings), often via an energy carrier such as electricity or hydrogen. The use of resources for purposes other than energy are not represented (for example low-grade wood for building materials, where this overlaps with bioenergy feedstocks). To account for this we first deducted demands for other uses of biomass.

The primary resources defined in ESME with wholly or partly biogenic content are:

- Biomass, which includes energy crops and agricultural and forest residues. The volumes of UK-grown and imported biomass available are both defined as inputs.
- Dry waste, composed of municipal, commercial and industrial waste.
- Wet waste, representing food waste and agricultural and sewage slurries.

These resources can be used in a number of ways by the model:

- Biomass and dry waste can be used to produce hydrogen, synthetic natural gas or electricity. They can also be used to produce biokerosene or a general liquid biofuel, via gasification and Fischer-Tropsch or fermentation processes. They can be burnt directly for heat in homes or industry.
- Wet waste has fewer potential conversion routes: it can be anaerobically digested to produce biogas either for biomethane, or combusted directly to produce heat and power.

The model has the option to deploy BECCS in all of the conversion processes above except where biomass is burnt for buildings heat or fermented to produce biofuels. For each process, the percentage of CO_2 assumed to be captured and stored (the 'capture rate') is defined by the user. We investigated how the volume of biomass used in BECCS processes depends on the capture rate (Figure 5.5).

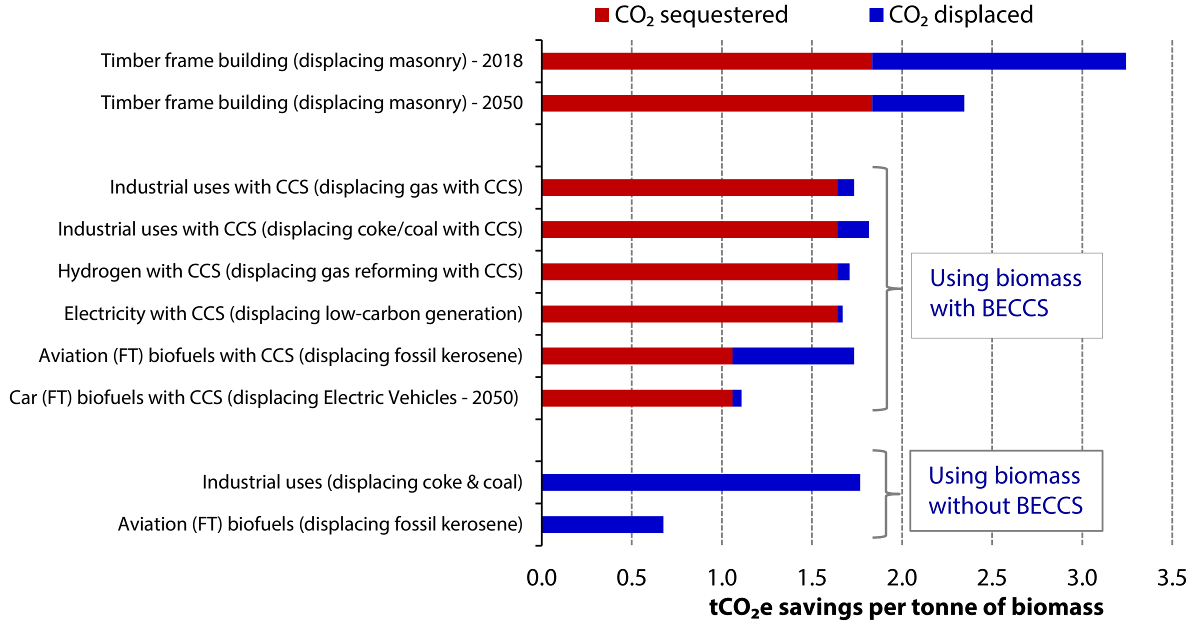
We have provided ESME with the volumes of each biogenic resource as defined in our future sustainable supply scenarios (Chapter 4). This has allowed us to investigate how the availability of biomass affects both best use and the overall level of emissions reductions that can be achieved.

Notes: ESME was originally developed by the Energy Technologies Institute (ETI) and ownership passed to the ESC in 2018. A detailed overview of ESME, covering the approach and the key technical features of the model is available in: ETI (2014) *Modelling Low-carbon energy system designs with the ETI ESME model* at the link below. We have made comprehensive updates to the ESME (v4.4) input dataset, as detailed in the annex to this report on *Energy System Modelling for the Biomass and Hydrogen Reviews*. For all model runs we have applied a constraining trajectory for CO_2 emissions consistent with an overall GHG emissions constraint as defined by the UK carbon budgets.

3. The best use of biomass in 2050

Our estimates of the amount of GHG abatement achieved by using biomass for different end-use applications in the UK in 2050 are shown in Figure 5.2. Given the infancy of many emerging bio-based products our focus here is on energy system and construction applications.

Figure 5.2. Estimated GHG abatement across different biomass applications



Source: CCC analysis.
Notes: This chart shows estimates of GHG abatement provided by an oven dried tonne of biomass used in various sectors, considering the most appropriate counterfactual (i.e. what we would expect it to be displacing, long-term). We have shown abatement broken down by sequestered carbon (the amount of CO_2 stored and/or not released into the atmosphere due to CCS technology) and displaced carbon (the amount of CO_2 that would have been emitted to the atmosphere in the counterfactual case had biomass not been used). The underlying calculations do not include biomass lifecycle emissions, but these will need to be significantly lower than the savings set out above (see Chapter 2). CO_2 capture rates are assumed to be 90% for all BECCS uses. FT refers to the Fischer-Tropsch process. We assume 47% efficiency for aviation biofuels made via FT; 42% where combined with CCS, based on IRENA 2017 and Van Vliet et al (2009). Abatement for timber construction is calculated based on a whole-house unit designed to meet the same SAP ratings, implying lifetime operational emissions equal to masonry counterfactuals. However, in practice operational emissions may vary due to a variety of factors. If timber framed homes are built in such a way that leads to higher operational emissions than counterfactual construction systems then abatement via displacement would be lower than is shown here. 2050 industry emissions for concrete, cement, brick and steel are assumed to reduce by between 50% and 80% compared to today's values.

We draw the following high-level conclusions from this analysis:

- The most abatement is delivered by using wood in construction, providing a route to store carbon and displace high embodied carbon materials. The precise amount of emissions displaced depends on levels of decarbonisation in key industrial sectors such as cement and brick and the lifecycle benefits of different applications (accounting for differences in operational use and end of life disposal) but the overall emissions saving exceeds that from all energy routes.

- BECCS technologies all deliver high and broadly equivalent levels of abatement overall, although the balance between carbon storage and displacement of fossil fuels varies between applications. In the long-run techno-economic differences in the performance of these different BECCS applications (e.g. costs and CO_2 capture rates) will largely determine which is optimal overall, together with the value of the specific energy service provided.
- Where a fuel is produced with BECCS it is only competitive in carbon terms if it is displacing irreducible hydrocarbon use (e.g. aviation fuels) rather than where there are other low-carbon alternatives (e.g. cars).
- If biomass is used in the energy system without CCS (for example in the short-term, or in the longer term if all available BECCS applications are exhausted) then biomass should be used to displace coal, as this also delivers substantial GHG savings. Once all coal has been displaced then any residual biomass used to displace fossil fuels (e.g. aviation biofuels produced without CCS) will only deliver around half of the overall GHG savings of BECCS or coal displacement.

These conclusions are supported by findings from our ESME modelling and feed into our best-use hierarchy (Figure 5.3). They are considered in more detail in the sections below.

Figure 5.3. Best-use of sustainable biomass to 2050

Between now and 2050, the current uses of biomass in the UK need to change:

	Most effective use today	2020s and 2030s	By 2050
Bioeconomy	Wood in construction	Wood in construction, potentially other long-lived bio-based products (within circular economy)	
Buildings	Biomethane, local district heating schemes and some efficient biomass boilers in rural areas		Only very limited additional use for buildings heat: niche uses in e.g. district heat and hybrid heat pumps
Industry	Biomass use for processes with potential future BECCS applications		BECCS in industry alongside other low-carbon solutions
Power	Ongoing use in power sector in line with existing commitments or small scale uses	Demonstration and roll out of BECCS to make H_2 and/or power	Biomass used for H_2 production or power with CCS
Transport	Liquid biofuels increasingly made from waste and lignocellulosic feedstocks	Liquid biofuel transitioning from surface transport to aviation, within limits and with CCS	Up to 10% aviation biofuel production with CCS

Maximising abatement means using biomass to sequester carbon wherever possible (opportunities to do this will increase over time)

Source: CCC analysis.

3.1. Wood in construction

In this section we consider the GHG abatement potential of using wood in construction. We return to the policy implications of these findings in section 5.1.

The use of timber in construction is well established in the UK. In Scotland around 75% of new homes are built using timber frame systems. Across the UK there are an increasing number of non-residential buildings being built using engineered wood products such as cross-laminated timber (CLT) and glue laminated timber (glulam) (Figure 5.4).[84] Traditional masonry systems also incorporate substantial amounts of timber for joists and rafters (in roofs and floors).

Different types and qualities of wood are used in timber construction. Sawn wood (often in the form of solid timber beams cut from the main stem of mature trees) makes up the majority of wood used in timber frame systems and is also required for producing CLT and glulam. In addition, lower quality wood such as forestry and sawmill residues and small round wood from thinnings can be used to make wood-based panels for use in timber frame systems. It is this lower quality material that is also sometimes used for applications such as pulp and paper and bioenergy.

Figure 5.4. Open plan interior of Maggie's Centre, Royal Oldham Hospital

Source: Image credit: Alex de Rijke.
Notes: Maggie's Centre at the Royal Oldham Hospital was built in 2017 using cross-laminated timber and clad in corrugated thermally treated tulipwood. Designed by dRMM, the building won the RIBA North West award for building of the year in 2017.

The GHG abatement potential of using wood in construction

Wood in construction can deliver GHG abatement through two routes. It is one of the few currently available ways to sequester carbon in harvested biomass for long periods of time, and it can also displace materials with high embodied carbon (reducing overall emissions to the

[84] Data on timber frame construction taken from the Structural Timber Association (2017) *Annual survey of UK structural timber markets. Market report 2016*

atmosphere). The Committee appointed Bangor Biocomposites Centre to investigate the potential to scale up timber construction in the UK and deliver GHG savings to 2050. The Bangor study is provided as an annex to this report (and summarised in Box 5.2):

- Provided that forests are managed sustainably with stable or growing carbon stocks over time, felling trees to provide construction timber can increase overall amounts of carbon absorbed from the atmosphere and **sequestered** in living and harvested biomass.
  - The Royal Society has recently estimated that by the end of this century, timber construction globally could contribute between 3% and 6% of total GHG removals required to limit the increase in global temperature to 1.5C.[85]
  - It is estimated that in the UK new solid wood products across the economy sequester around 7 Mt CO_2e/yr net (i.e. after disposals). This is equivalent to around 1.5% of current UK CO_2e emissions).[86]
  - Wood in construction does not currently provide permanent sequestration of carbon. However it provides storage on timescales of decades to centuries and there is significant potential to grow the overall store of carbon in the built environment provided inflows of timber (through new build) exceed outflows (from disposal).
  - End-of-life solutions that prevent or delay the release of CO_2 from waste wood disposal back into the atmosphere are important for maximising the lifecycle GHG benefits of timber construction. Waste wood should be reused and recycled wherever possible, followed by use for energy generation with BECCS as soon as this technology is available.
- Timber frame and engineered wood construction systems also result in the **displacement** of high-embodied carbon materials such as cement and brick. The total amount of displacement over the full lifecycle of a building will vary depending on a wide-range of factors, however the balance of evidence suggests timber construction can reduce fossil fuel emissions to the atmosphere overall.[87]
  - **Embodied emissions** (those caused by the extraction, manufacture and assembly of materials plus maintenance and end-of-life disposal) account for 25% to 50% of the overall carbon footprint of new buildings.[88] Addressing the embodied carbon associated with homes will therefore be a necessary part of any ambition to drive towards 'net zero' emissions. Currently timber frame construction can reduce embodied emissions by up to

---

[85] The Royal Society estimates that wood in construction could contribute to a cumulative total GHG removal of between 20 and 50 Gt CO_2 by 2100. This compares to an average total GHG removal requirement of ~810 Gt CO_2e by 2100 to limit warming to 1.5C in global mitigation models. See: The Royal Society (2018) *Greenhouse gas removal*.
[86] Robson et al (2014) Carbon sequestered in UK forest products and wood based panels in construction: helping to meet UK's greenhouse gas emission reduction targets. *International Wood Products Journal, 5:3, 139-145*. Of this ~16 Mt CO_2e/yr, the authors estimate that only ~10% can be attributed to new housing, with a further ~10% to new non-residential structures and ~40% to work on existing buildings.
[87] A comprehensive review of the literature on lifecycle GHG emissions for different construction methods is provided by Hill & Zimmer in NIBIO (2018) *The environmental impacts of wood compared to other building materials*.
[88] NHBC (2012) *Operational and embodied carbon in new build housing* and UKGBC (2017) *Embodied carbon: developing a client brief*.

around 3 tCO_2e per home[89] although there are uncertainties related to end-of-life processes.[90]

- **Operational emissions** (those associated with energy use during a building's lifetime) can currently account for over 50% of lifecycle emissions although this will change as a function of heat and power sector decarbonisation which are likely to see more rapidly falling emissions than for industrial products.[91]
  - There is some evidence to suggest that the thermal properties of lightweight timber frame systems currently result in higher operational energy usage than concrete and masonry systems, such that overall lifecycle emissions may be broadly equal between these different construction systems (excluding the CO_2 sequestration benefits of timber).[92] However, the impact of thermal mass on building temperature is context-specific and a range of design solutions can be used to minimise the need for additional occupant energy use.[93]
  - In the future, the emissions intensity of operational energy use will fall as the power and heat sectors decarbonise. This means that any current advantage provided by one construction system over another in terms of operational emissions is likely to decrease in the future.
- There is potential to substantially increase the use of timber in construction in the UK. This will provide a low-cost route to GHG abatement through to 2050.

- Building 270,000 homes each year with timber would result in annual net carbon storage of around 3 Mt CO_2e by 2050, accounting for losses due to to demolition and disposals. Similar levels of storage may be possible from timber use in non-residential buildings.
- This level of timber construction could also reduce embodied emissions in the residential sector by 0.5-1 Mt CO_2e per annum in 2050, although this will depend on whether timber systems achieve operational and end-of-life emissions equal to or less than masonry and steel alternatives.

---

[89] Bangor calculates that the structural elements of a new detached 3-bed timber frame house has 'cradle-to-gate' emissions ~3.2 tCO_2e lower than a masonry alternative. A 2012 NHBC study (which takes into account refurbishment and disposal) finds this saving to be ~7 tCO_2e over a 60 year period. See NHBC (2012) *Operational and embodied carbon in new build housing*.

[90] An example is the impact of carbonation on concrete. Concrete can absorb CO_2 throughout its life although this generally occurs at very low levels during the operational phase of a building's life. However during disposal this may increase due to crushing and increased exposure to air. Some estimates conclude that carbonation could reduce the embodied CO_2 of concrete by 7.5% over the full lifecycle - see: MPA (2016) *Whole-life carbon & buildings*. Other sources estimate a smaller reduction of 3-4% - see NIBIO (2018) *The environmental impacts of wood compared to other building materials*. It may be possible to further reduce the embodied emissions by reusing old concrete or processing outputs from waste incinerators as recycled aggregates.

[91] CCC (2015) *Fifth Carbon Budget*.

[92] The 2012 NHBC study *Operational and embodied carbon in new build housing* concluded that "no significant differences emerged between masonry and timber construction in terms of overall CO2 impact over the 60- and 120-year study periods."

[93] Thermal mass can help to regulate indoor temperature peaks and troughs, potentially keeping space warmer for longer in winter and reducing overheating in summer by absorbing heat in the day and releasing it back out at night. However this is not always the case and there can also be additional challenges with keeping high thermal mass buildings cool, particularly for residential buildings in urban locations. A 2016 evidence review by BRE for Zero Carbon Hub (*Solutions to overheating in homes*) concluded that the occupancy patterns of residential buildings means it can be difficult to achieve sufficient ventilation at night to 'recharge' (cool) buildings with high thermal mass, particularly in deep urban areas where noise and air quality make keeping windows open impractical.

- Regardless of the level of timber construction ultimately achieved, it will be essential that deep emissions reductions are achieved across the construction industry as a whole. Whilst use of timber can support climate change mitigation, it will not replace the need for concrete, brick and steel in construction in 2050.[94] Rapid decarbonisation of these sectors will be required for the UK to meet its climate change targets.
- A significant increase in demand for wood for construction would require additional imports of sawn wood over the next decade or two, although some of this increased demand could be met from additional production from UK forests (Box 5.3).

Box 5.2. The GHG abatement potential of timber construction

The Committee commissioned a team led by the Bangor Biocomposites Centre to investigate the GHG abatement potential of increasing the use of timber in construction in the UK - through greater use of timber framed construction systems and engineered wood products such as Cross Laminated timber (CLT) and Glue Laminated Timber (Glulam).

The analysis focused primarily on new-build units in the residential sector. It compared 'cradle-to-gate' embodied emissions and sequestered carbon of timber construction systems with masonry or concrete-framed alternatives. Timber construction deployment scenarios for 2050 were then developed to explore UK-wide GHG abatement potential over time.

The study did not provide a full lifecycle analysis but instead focussed on emissions associated with the manufacture and transportation of the building materials. The basis of comparison was a series of building archetypes that were developed in line with current Building Regulations to deliver equivalent levels of thermal efficiency (e.g. U-values) across timber and masonry or steel-framed alternatives. As far as the modelling approach allowed,[95] this was intended to support a 'like-for-like' comparison of different building systems in which operational energy use and emissions over a 60 year design life could be assumed to be broadly equal.

Some studies suggest that timber buildings can result in higher operational emissions in some circumstances.[96] In practice a range of factors would influence this, including design, location, thermal mass and occupant behaviour patterns. Operational emissions are projected to decrease as a function of heat and power sector decarbonisation (and more rapidly than equivalent industrial product decabonisation). Even in circumstances where lifecycle emissions are broadly equal between timber and masonry/steel alternatives, the carbon sequestered in timber systems provides a substantial overall climate change mitigation benefit.

The main conclusions of the Bangor analysis are:

- The use of timber in construction in the UK is well established and already delivers substantial levels of GHG abatement.
  - Between 15% and 28% of new homes built in the UK in 2016 used timber frame construction systems, and houses built using masonry systems still use substantial amounts of timber for joists and rafters (in roofs and floors).
  - Compared to a masonry alternative, a new timber frame home has the potential to save around 2-3 tCO_2e by displacing materials with high embodied carbon and a further 2-4

[94] Timber frame systems still have significant levels of embodied carbon emissions. This is in part because concrete is still required for building foundations and in most cases brick as the exterior wall cladding.
[95] Building archtypes were modelled using the Standard Assessment Procedure.
[96] NHBC (2012) *Operational and embodied carbon in new build housing.*

Box 5.2. The GHG abatement potential of timber construction

tCO_2e through additional sequestered carbon (assuming operational emissions remain broadly equal).

  - Across the UK, use of timber frame systems currently avoids 'cradle-to-gate' embodied emissions of around 150,000 tCO_2e/year and results in the sequestration of an additional 190,000 tCO_2e/year.
  - Timber frame systems result in broadly equivalent capital costs to masonry systems, implying low costs of abatement.

- If challenges and barriers are overcome, there is the potential for significantly increased levels of timber construction in the UK. This would result in significant additional amounts of carbon stored in the built environment.
  - Although the storage of carbon in buildings is not currently permanent, expected building lifetimes mean that increasing use of timber in construction will build up carbon stores for several decades to come, even after disposals are taken into account.
  - Building 270,000 new homes each year using timber frame and engineered wood systems would result in annual (net) carbon storage of around 3 $MtCO_2e$/yr in 2050. Only some of this would be attributable to the UK's GHG accounts because some wood products are imported.
  - Non-residential buildings such as schools, retail premises and stadiums can be built using engineered wood systems including CLT and Glulam. Whilst the use of timber in the non-residential sector is currently low in the UK, it has the potential to scale up over time with comparable levels of additional carbon storage to the residential sector.
- Timber construction has the potential to contribute to lower levels of embodied carbon even as industrial sectors producing cement and brick decarbonise. Building 250,000 new homes each year using timber frame and engineered wood systems could save an additional 0.5-1 $MtCO_2e$/year by displacing concrete, cement, bricks and steel. This assumes timber systems achieve operational and end-of-life emissions equal to or lower than alternative systems.

Source: Analysis by the Bangor Biocomposites Centre for the CCC.

Box 5.3. Timber supply and imports for construction

Over half of the timber currently used in UK construction comes from imports. Whilst there is potential to increase the supply of UK forest products there is a time lag of decades between tree planting and harvesting of saw logs. This implies that a significant increase in demand for timber in construction in the UK will require increased imports over the next two decades.

- Around 5.5 million oven dried tonnes (Modt) of wood are harvested from UK woodlands each year and delivered to primary wood processors. This provides around one-third of sawn wood and over half of the wood-based panels used in UK.
- The Committee's UK land-use scenarios suggests that planting new woodland and bringing existing woodland back into better management could substantially increase the amount of UK wood available for wood based-panel production by 2050. UK supply could meet demand from the construction sector for wood-based panels even with high levels of timber construction.

Box 5.3. Timber supply and imports for construction

- In a high ambition scenario where up to 50,000 ha of trees are planted each year, UK forestry supply of small roundwood and residues could increase to around 10 Modt in 2050.
- If 80% of new homes are built using timber construction systems in 2050, demand for wood-based panels (for the structural elements of residential buildings) would be around 0.5 Modt.

However even with ambitious rates of tree planting over the next decade, a substantial increase in sawn wood production is only likely after 2050 due to the time it will take for new trees to mature. This means that increases in demand for sawn wood from the construction sector would need to be substantially met from imports.

- Demand for sawn wood for structural uses in the construction sector could reach around 5 Modt by 2050 if levels of timber construction experience high levels of increase in both the residential and non-residential sectors.
- Stakeholders consulted as part of the Bangor consultancy project did however indicate that improvements in UK timber grading systems could lead to some additional increases in UK supply.

3.2. The importance of BECCS

Meeting the challenging emissions reductions required under the Climate Change Act and the Paris Agreement at lowest cost is very likely to require use of finite sustainable biomass supplies in ways that maximise the resultant emissions savings. This finding is supported by our ESME modelling, as well as the modelling at global level that underpins the findings of the Intergovernmental Panel on Climate Change (IPCC).

Using biomass with CCS to store carbon and produce a useful energy service is likely to deliver more abatement than most other potential end-uses. Based on our current expectations of BECCS costs and technical performance, we conclude that **biomass available for use in the energy system (i.e. after wood in construction opportunities have been satisfied) should be used with BECCS applications to the maximum extent possible**.

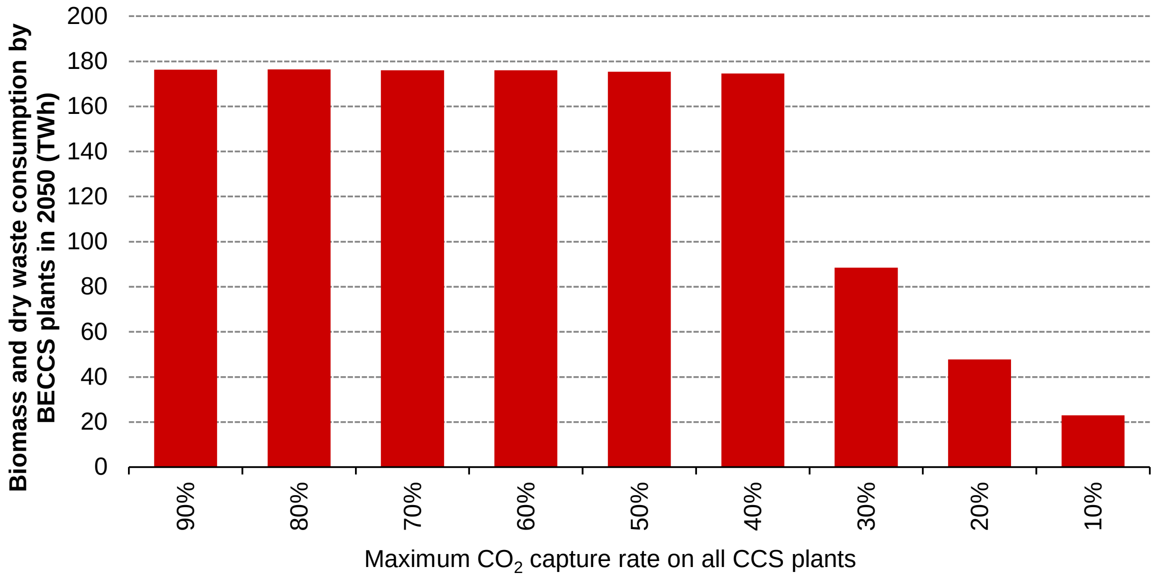
Given the centrality of this conclusion to our analysis we have tested it against key sensitivities, including a range of potential CO_2 capture rates (Figure 5.5). This shows that BECCS applications continue to be a preferred use of biomass in the energy system even if capture rates fall well below our expectations. This gives us confidence in our BECCS best-use conclusion:

- Our central estimate of future BECCS capture rates is 90% (meaning that 90% of the carbon in the biomass feedstock is captured and stored).
- BECCS can still deliver greater emissions savings than non-BECCS energy uses even at much lower rates of CO_2 capture. Consequently BECCS applications may make sense even with CO_2 capture rates as low as 40%,[97] below which the other bioenergy applications (e.g. aviation biofuel production) start to be preferred.
- This finding broadly supports our off-model analysis (Figure 5.2) that shows (under our central assumptions) BECCS providing around twice as much GHG abatement as the next best uses without CCS (e.g. production of aviation biofuel).
- The use of BECCS is currently not incentivised by policy mechanisms intended to drive emissions reductions (e.g. Contracts for Difference and the EU Emissions Trading System).

[97] ESME model results.

Whilst we would not expect BECCS to be deployed at scale immediately, the availability of incentives would encourage those making decisions now to factor it in (e.g. locating a biomass facility near to where CO_2 infrastructure may be developed). The Government should examine how BECCS can be incentivised with changes to existing policy mechanisms and/or new mechanisms.

Figure 5.5. BECCS uptake in 2050 in ESME as a function of CO_2 capture rates



Source: CCC analysis based on the ESME energy system model.

Which BECCS applications are likely to constitute 'best-use' of biomass?

It is not currently possible to say which particular BECCS applications will deliver the greatest GHG abatement and represent the most valuable use of biomass feedstocks. This will ultimately depend on levels of technical performance, CO_2 capture rates, costs and societal decisions on the UK's decarbonisation pathway:

- The Committee has been undertaking a Hydrogen Review in parallel to this report (Box 5.4). Analysis for both reports indicates that to the extent that there is demand for hydrogen in the economy, this could well be a better use of BECCS than use in the power sector:
  - Hydrogen can be used for interseasonal storage, which appears likely to be of particular value given a lack of alternatives. Production of hydrogen is therefore likely to provide greater benefits to the energy system than BECCS for baseload power generation.
  - Use of hydrogen at large scale within the UK energy system is likely to entail a substantial role for use of gas with CCS as a production route. Although gas reforming with CCS is a low-carbon way of producing hydrogen it still has significant residual emissions, which could be avoided by producing hydrogen from BECCS.
- With no/low demand for hydrogen, an appropriate uses of BECCS will be for power generation. This implies displacing other low-carbon baseload generators such as nuclear or

fossil fuels with CCS. The GHG abatement benefits of this form of BECCS result almost exclusively from sequestering carbon rather than displacing fossil fuels. Where possible any excess heat generated by BECCS power plants should be used, for example in district heating networks or industrial applications.

- Producing aviation biofuels with CCS applied to the fuel production stage could deliver equivalent GHG abatement to other BECCS applications if the same CO_2 capture rates are achieved. This use of BECCS combines sequestration (during fuel production) with displacement of fossil fuels (during combustion) to deliver its GHG abatement benefits.
- BECCS is likely to be an option for some industrial processes such as cement, iron and steel and chemicals production as well as in industry combined heat and power. While it has received less attention than BECCS on power generation, some applications indicate promise, such as cement production, which already uses around 2 TWh of bioenergy and where CCS is essential because of the production of large amounts of process emissions from calcination.[98]

Box 5.4. The Committee's 2018 Hydrogen Review

The Committee has been undertaking a review of the opportunities for hydrogen to play roles in achieving UK emissions targets in a *Hydrogen Review*, undertaken in parallel with this report. Condusting the analysis jointly has enabled us to examine both competition and synergies between hydrogen and biomass (e.g. the respective roles for hydrogen and biomass combustion in decarbonising industry, hydrogen production from biomass).

The *Hydrogen Review* considers the range of potential uses for hydrogen across the energy system out to 2050 and how this hydrogen demand could be met in a low-carbon way. It also presents analysis on the potential role of hydrogen as part of a very-low-carbon energy system under different scenarios for its deployment.

The ESME modelling presented in this report has been undertaken jointly for the reports on hydrogen and biomass. This will be set out in more detail in Annex 5.

Source: CCC.

How much BECCS could be deployed by 2050?

The amount of biomass that can be used with BECCS at any given time will depend on BECCS technology readiness and deployment rates. With strong Government action to develop and deploy BECCS technologies, we estimate that most of the biomass resource available to the UK could be used with BECCS by 2050:

- There are currently only a handful of small-scale **BECCS** demonstration projects operational around the world. This mirrors the slow progess over recent years in developing CCS technologies more broadly.
- In our 2018 *Progress Report to Parliament* we made recommendations to Government on CCS. We suggested that by 2030 up to 2GW of CCS could be deployed in the power sector alongside capture and storage infrastructure for around 10 $MtCO_2$ per annum, rising to 20

[98] BECCS in industry will need to achieve comparable capture rates to other sectors - this may be a challenge if emissions are dispersed throughout an industrial process chain. In industrial subsectors/sites where combustion emissions are spread across a series of different parts of the site, biomass use would need to be isolated to parts where CCS is applied, to avoid unabated biomass emissions.

$MtCO_2$ per annum by 2035. A scenario without deployment of CCS in the power sector could have similar volumes of CO_2 captured from other industrial, hydrogen or BECCS projects.

- Our analysis suggests that by 2030 BECCS could be economically competitive with other forms of abatement. Based on our bioenergy supply scenarios, this means that by 2050 between 22 $MtCO_2$ and 67 $MTCO_2$ oer year could be captured and stored. Achieving the upper end of this range would require around 15 GW BECCS by 2050.

What are the air quality implications of BECCS?

In Chapter 2 we cover the air quality impacts of bioenergy combustion. Any scenarios with a role for BECCS will have implications for air quality emissions (particularly particulates and NO_x), although abatement options exist and are currently required for combustion plants under the Industrial Emissions Directive (Box 5.5).

Box 5.5. The air quality implications of BECCS applications

Combustion or gasification of bioenergy results in emissions of pollutants, in the form of nitrogen oxides (NOx), and particulate matter, which, if unmitigated, could pose a risk to greenhouse gas emissions and air quality. Combustion of high sulphur biomass can also produce sulphur dioxide (SO_2). Bioenergy plants are subject to the Industrial Emissions Directive (IED), which limits pollutant emissions. Furthermore, mitigation options exist for all the key pollutants, and the use of CCS technology may avoid the need for some of these technologies.

- Combustion or gasification of bioenergy produces NOx and particulate matter such as $PM_{2.5}$. High sulphur biomass can also produce SO_2. Best-use modelling for this report suggests between 75-530 TWh of bioenergy could be used for BECCS applications, depending on the amount of globally available sustainable supply. Using this amount of biomass could increase national NOx emissions by 4-31%, SO_2 emissions by up to 2-18%, and $PM_{2.5}$ emissions by up to 10-69% compared to UK-wide emissions on these pollutants in 2016, based on current technologies.
- Mitigation technologies exist for all key pollutants and are commonplace in most major power stations today:
  - **NO_x:** Selective Catalytic Reduction (SCR) technologies can be used to reduce NO_x emissions and are commonplace in major power stations.
  - **SO_2:** Flue gas bubbling technologies can remove sulphur compounds in the exhaust fumes of bioenergy plant.
  - **$PM_{2.5}$:** Electrostatic precipitators can reduce PM emissions by up to 98%.
- BECCS plants are subject to requirements under the Industrial Emissions Directive (IED) to limit NO_x and particulate matter, which are expected to remain in place after the UK's planned departure from the EU. All new plants, and existing plants operating beyond 2020, will have to fit mitigating technologies – at additional cost - in order to comply with the IED.
- The cost of fitting pollutant mitigation technologies is expected to be a small overall proportion of plant operating costs. For example, Leigh Fisher & Jacobs (2016) estimated that fitting SCR technology to a coal plant – to reduce NO_x emissions to below IED levels - could incur a cost of between 4-18% of total plant capital expenditure, reducing overall efficiency by less than 1%, with a small increase in variable operating costs.

Any deployment of BECCS technologies would have to be within acceptable pollutant limits. Meeting these limits could require the fitting of pollutant mitigation technologies.

Source: CCC analysis based on Leigh Fisher & Jacobs (2016) *Electricity Generation Costs and Hurdle Rates*, IEA (2005) *Projected Costs of Generating Electricity*, NAEI (2018) *National Atmospheric Emissions Inventory*, Defra (2018) *Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM_{10}, $PM_{2.5}$) emissions*; European Commission (2017) *Best Available Techniques (BAT) Reference Document for Large Combustion Plants*.
Notes: The electrostatic precipitator abatement estimate is based of EC (2017) and assumes a process efficiency of 60% HHV for bio-gasification, and 35% for bioenergy combustion in power.

3.3. Biofuels in aviation

Aviation is one of the most challenging sectors of the economy to decarbonise. Zero-emission planes are unlikely to be available and widely used for long-haul flights before 2050.

Decarbonising aviation will therefore require contributions from a range of solutions (Box 5.6). In 2019 the CCC will publish further analysis on the potential to reduce aviation emissions.

Box 5.6. Reducing GHG emissions from aviation

Aviation emissions have doubled since 1990, whilst emissions in the rest of the economy have reduced by over 40%. This strong growth in aviation emissions has been driven by increasing demand for flying, due to rising incomes. In the absence of measures aviation emissions are likely to continue to increase.

The Committee has previously concluded that UK aviation emissions should be around 2005 levels in 2050, and our advice on carbon budgets has been on this basis.

Achieving 2005 level emissions is feasible by reducing the carbon intensity of flying, and by limiting demand growth to around 60% above 2005 levels:

- **Carbon intensity of flying.** There are a range of options available. These include improving the fuel efficiency of aircraft through engine and airframe developments, efficiency improvements in air traffic management and in airlines' operational practices, and some use of sustainable biofuels. While some electricification of aviation is potentially feasible, this will require significant improvements in battery energy density even for short-haul flights. There is therefore likely to be a role for liquid fuels in aviation into the second half of the century.
- **Demand for air travel.** Demand for flying might be moderated by using alternatives to air travel such as high-speed rail and videoconferencing, and through pricing carbon (e.g. through the EU Emission Trading System which covers intra-EU flights, or the global 'CORSIA' offsetting policy). Given the potential for improvements in the carbon intensity of flying, keeping emissions to 2005 levels in 2050 implies room for around a 60% increase in demand over the same period.

This has implications for the best-use of biomass as it suggests that there are other cost-effective options which should be pursued, rather than relying on fuel-switching as the primary strategy. We will publish further analysis in 2019 on the potential to reduce aviation emissions, and the implications of this for the Government's Aviation Strategy.

Using biomass to produce aviation biofuels will likely need to be in conjunction with CCS in order to remain competitive with other uses of biomass in the long-term:

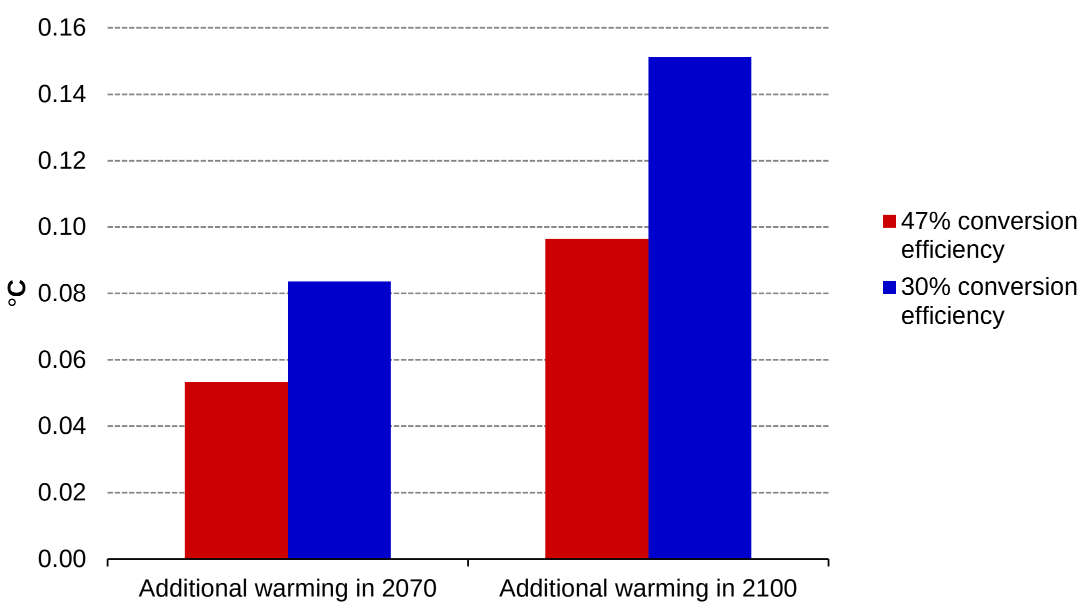
- Once CCS technologies are deployed at scale, aviation biofuels will need to be produced with CCS in order to deliver levels of GHG abatement comparable to other BECCS applications.
- Producing aviation biofuels without CCS is unlikely to be among the most valuable uses because of the limited emission savings compared to CCS applications. Use of aviation biofuels without BECCS would therefore lead to signficantly higher overall global emissions, making it more difficult to limit global temperature rise unless ways were found to offset this effect.
  - If there were no offsetting benefits of using bio-resources in this way (e.g. in terms of expanding the global sustainable biomass supply), the implication of using this biomass resource in a carbon-inefficient way would be driven by the difference in emissions saving between this and use of that biomass resource for BECCS.
  - If 100% of projected global aviation fuel demand in 2050 were to be met with biofuels without CCS,[99] the implications of using this biomass resource in a carbon-inefficient way

[99] ICAO estimate total aviation fuel demand in 2050 to be 7,100 TWh per annum (ICAO 2017 *Trends and scenarios on alternative fuels*).

could be 0.05-0.15°C of additional warming by the end of the century (Figure 5.6) in the absence of offsetting benefits:

- For a higher efficiency for the conversion of biomass to aviation biofuels (47%) the additional warming from inefficient biomass use could be 0.05°C by 2070 and 0.08°C by 2100.
- For a lower efficiency for the conversion of biomass to aviation biofuels (30%) the additional warming from inefficient biomass use could be 0.1°C by 2070 and 0.15°C by 2100.
- This level of effect on the global temperature rise is material, given warming to date of around 1°C and in the context of the Paris Agreement goal to limit global average temperature increase this century to well below 2°C and to pursue efforts to limit it to 1.5°C. While in practice it may not be feasible to utilise this full resource with BECCS, to the extent that it can be achieved the climate benefits are significant.

Figure 5.6. Implications for the climate of carbon-inefficient biomass use



Source: CCC analysis.
Notes: Calculated assuming 100% of global aviation fuel demand in 2050 is met with aviation biofuels (7,100 TWh). Two different conversion efficiencies between primary biomass feedstock and aviation biofuels (47% and 30%) are considered, to reflect cases in which the biofuel production process can or cannot be focused very largely on production of aviation fuel rather than a mix of hydrocarbon fuels. The additional emissions to the atmosphere between the the production of aviation biofuels without CCS compared to use of bioenergy with CCS are consistent with those presented in Figure 5.2. A linear increase in aviation biofuel demand is assumed between 2020 and 2050. A transient climate response to cumulative emissions of 0.45 °C/TtCO_2 is assumed to calculate compatible additional warming. Demand for aviation biofuels in assumed to be constant after 2050, either to 2070 or to 2100.

If aviation biofuel production using CCS turns out to be cheaper than other options, or if options to use biomass with CCS cannot be scaled up, then using biomass for aviation fuel may be the next best option (after wood in construction and displacement of coal).

Given this uncertainty, it does not make strategic sense to plan for high levels of biofuel use in aviation in the long-term:

- Planning for high use of biofuel in aviation that does not materialise would risk diluting incentives for other ways of reducing emissions (i.e. fuel efficiency and limiting demand for flying).
- However, some use of aviation biofuels may be desirable, given the potential for this to be best use depending on how costs and technologies develop, and given the need to develop the market and drive innovation sufficiently so that the option for future large-scale deployment remains open.
- A practical planning assumption is therefore to aim for up to 10% of biofuel use in aviation in 2050.
  - We have previously concluded that aviation emissions should be no higher than 2005 levels in 2050. Based on a 10% biofuel uptake this implies limiting passenger demand growth to around 60% over the same period.
  - To the extent that higher levels of biofuels are used, these should not substitute for other options but should lead to lower emissions than 2005 levels. This is essential, given the conclusion that finite biomass resources should be used in a way that maximises additional emissions savings.

In the period to 2030 Government policy should aim to develop a market for aviation biofuels produced in genuinely CCS-ready facilities and review long-term ambition:

- Biofuel use in aviation is currently very limited and achieving even a 10% use in 2050 will be stretching, requiring Government policy to support development of the market.
- Government should facilitate the transition to aviation uses by achieving more of the 2030 RTFO target through aviation fuels.
- Progress on aviation biofuel production and competing uses - including costs - should be reviewed in 2030. This would allow aviation biofuel production to be scaled up in the period to 2050 should this turn out to be a route for best-use.

In the long-term biomass should only be directed towards aviation at significant scale if three key tests are met. Should the long-term 2050 target be tightened then these tests would need to be reviewed:

1. Overall levels of abatement from producing and using aviation biofuels must be equal to or better than other biomass best-use applications. This is likely to require:
   -Efficiencies, capture rates and costs that are at least as good as other BECCS applications.
   -Co-products from aviation biofuel production being used to displace residual fossil fuels elsewhere in the economy (i.e. that cannot be abated via any other feasible route).
2. All aviation biofuel production plants should be genuinely 'CCS ready' and be retrofitted / built with CCS as soon as this technology is available. Being genuinely ready for CCS means being technically suitable for its retrofit and located where it is likely to be able to connect to CO_2 transportation and storage infrastructure in future.
3. Biomass use in aviation beyond 10% uptake should be used to reduce emissions below 2005 levels, not as a substitute for other options.

In order to meet these tests the aviation industry will need to take a lead role in developing sustainable supply chains, global sustainability governance, and application of CCS technology.

3.4. Bioenergy in industry

Biomass can be used for a range of applications in industry and is already used to produce heat and electricity in some industrial sub-sectors such as paper and cement. It is one of the main abatement options available to industry alongside energy efficiency, resource efficiency, carbon capture and storage, electrification and product substitution. New evidence by Element Energy and Jacobs (Box 5.7) also suggests that in all industrial applications where biomass could be used as a fuel, hydrogen could also be used.[100]

While biomass can contribute towards near-term decarbonisation of industry it should only have a long-term role if used with CCS and on the basis that overall CO2 capture rates are similar to other BECCS applications. Industrial decarbonisation policy should work towards a mix of future low-carbon technologies based on hydrogen, CCS with fossil fuels , BECCS and electrification. It is not yet clear what the most appropriate combination of technologies will be:

- Our ESME modelling indicates that in 2050 biomass should only be used in industry when combined with BECCS. This assessment is supported by off-model analysis based on the Element Energy and Jacobs work. Whilst bioenergy without CCS is likely to be a cheaper direct replacement for fossil fuels than hydrogen based on today's biomass prices, this does not take into account the future value of biomass and the opportunity cost of not using biomass with BECCS as a route to carbon sequestration.[101]
- The only circumstance in which using biomass in industry without BECCS would constitute best-use is to displace coal use in applications where neither hydrogen nor CCS are available. However we do not anticipate that any such opportunities will exist in the UK by 2050.
- Even if widespread hydrogen use in industry fails to materialise, using bioenergy without CCS to displace natural gas would not be desirable. This is because the abatement delivered by using biomass with BECCS to sequester emission elsewhere would exceed emissions saved by displacing gas in industry.
- BECCS will not be feasible for all industrial applications. The clearest examples of this are (a) where the emissions source is too small to make CCS cost-competitive, and (b) in a number of direct firing applications where the use of biomass may impact on the product quality.

We estimate that a combination of hydrogen, CCS with fossil fuels and BECCS could abate around 30 $MtCO_2$ of industry emissions cost-effectively in 2050.[102] Our current modelling suggests that of this total BECCS could contribute around 10 $MtCO_2$, but this result is highly sensitive to assumptions.[103] We are planning further work to produce more robust estimates of the optimal levels of BECCS use in industry.

[100] CCC (2018) *Hydrogen Review*.
[101] The Element Energy and Jacobs study found bioenergy use in industry to be lower cost than hydrogen use under their fuel price assumptions. However these assumptions did not account for bioenergy prices rising to reflect the high value for using biomass with CCS as a GHG removal technology. When this is taken into consideration, the model replicates the result that using biomass without BECCS is more expensive than hydrogen use.
[102] The potential may be higher as this analysis excluded consideration of hydrogen or CCS use (a) in most of the 'unclassified' industrial sector (b) on emissions arising from internal fuel use, such as blast furnace gas and (c) in fossil fuel production or on fugitive emissions.
[103] Requires further investigation. The 10 $MtCO_2$ includes both avoided CO_2 and stored CO_2.

Box 5.7. Industrial Fuel Switching

Element Energy and Jacobs were commissioned by BEIS in 2018 to explore the potential for industries to switch to biomass, hydrogen and electric technologies and identify constraints and opportunities to realise this potential.

The scope of the analysis focussed on the potential to fuel switch 120 TWh of fossil fuel use in the manufacturing and refining sectors. This excluded consideration of switching fossil fuels used for: industrial combined heat and power plants, producing steam at external sites and unclassified industrial energy uses as well as the option to switch the fuels that produce 'internal fuels' such as blast furnace gas and coke oven gas. From the 120 TWh considered, they found that around 90 TWh could be switched to hydrogen, around 50 TWh to biomass and 50 TWh to electricity.

Biomass was typically found to be suitable for indirect heating processes (where the combustion gases do not come into contact with the product) rather than direct heating processes (because of the impact of combustion gases on product quality). The study did however identify potential to use biomass in direct heating in the cement sector (which is already practiced) and the potential to use it as a reductant in the production of pig iron.

The study found that some fuel switching technologies may not be available until 2035, particularly hydrogen heaters and kilns outside of the chemicals and refining subsectors. It also found bioenergy use to be lower cost than hydrogen in many applications under their fuel price assumptions. However these fuel price assumptions did not account for bioenergy prices rising to reflect high demand and the value of sequestered carbon in the future. Whilst the analysis did not consider BECCS it did suggest that further work should consider BECCS potential at large industrial sites with high process emissions.

Source: Element Energy and Jacobs, *Industrial Fuel Switching Market Engagement Study*, draft.
Notes: The study does not consider the fossil fuel production sectors, which the CCC includes in its industry sector.

3.5. Other niche uses of bioenergy

There are some specific smaller-scale niche uses of bioenergy, some without CCS, that are likely to remain part of the overall best-use picture in 2050:

- Whilst bioenergy does not have a significant long-term role in decarbonising heat in buildings, there is a case for some ongoing use of biomass within hybrid heat-pump systems in hard-to-decarbonise off gas-grid homes. There may also be a case for some small-scale biomass use in local CHP and district heat schemes.
- Some 'wet' biogenic wastes such as food waste and sewage are likely to continue to be best-used with anaerobic digestion (AD). In the long-term we would expect the resulting syngas to be upgraded to biomethane and injected into the gas grid wherever possible. Where possible the CO_2 emissions from AD plants should be captured and used or stored.
- In some cases it may not be economically viable to transport waste feedstocks or agricultural residues the distances required for use in centralised BECCS plants. Alternatively the location of farm based AD plants may be too far from the gas grid to allow methane injection. In these circumstances biomass feedstocks may be better used for local production of heat and power.
- Some other wastes such as used cooking oil (UCO) and tallow are well suited to the production of liquid biofuels.

3.6. Developing key cross-cutting technologies

A number of key technologies are required to unlock the use of biomass. The development of these technologies should be actively supported by Government as part of wider innovation and energy sector incentive programmes:

- Effective, low-cost **CCS** that can be applied at large scale and with high capture rates is vital to getting the largest possible carbon reduction from scarce biomass supplies (Figure 5.2). The UK needs to set policy to allow effective business models to develop, to build out a transport and storage infrastructure and to underwrite long-term storage risks. The CCUS Deployment Pathway, to be published by the Government by the end of the year, should implement the recommendations set out in the Committee's 2018 Progress Report to Parliament and include within this a clear pathway for the deployment of BECCS technologies across different end-use sectors from 2030.
- **Gasification** technologies capable of producing ultra clean syngas from a wide range of biomass feedstocks are needed to provide a route to high value energy products such as hydrogen or biomethane as well as some forms of BECCS. However development of these technologies has been slow and technical barriers remain (Box 5.8). We recommend Government support for these technologies shifts from the power sector to transport and heat sectors where there is a market for ultra-clean syngas. Over time it should evolve to support deployment with CCS and using a wide-range of feedstocks.
- **Anaerobic Digestion (AD)** is an established and widely deployed technology for converting non-woody and non-animal matter biomass feedstocks into syngas. This syngas can be burnt for heat and power or upgraded to produce biomethane. The Government should continue to support AD deployment using sustainable low-carbon feedstocks and over time explore the feasibility of deploying AD with carbon capture, utilisation and storage (CCUS) - to capture and use or store the residual CO_2. There is also a risk of fugitive methane emissions from AD plants and it will be important to minimise this risk to ensure the benefits of AD.
- Recent work by the Energy Technologies Institute suggests current **biomass feedstocks** often do not consistently meet quality standards for wood pellets and that this represents a long-term risk to the uptake of second generation ligno-cellulosic feedstocks. To mitigate this risk there is a case for investing in the development of **pre-processing technologies** such as water washing as well as supporting R&D in plant breeding.

Box 5.8. What is gasification and what are the barriers to its deployment?

Gasification technologies convert solid biomass into a range of other energy products. They involve the thermal treatment of biomass in the presence of limited oxygen to produce an intermediary gas known as syngas which consists mainly of CO_2, CO and H_2, alongside some contaminants such as tar. This syngas can then be upgraded with contaminants removed to create 'ultra-clean' syngas. This in turn can be used to produce hydrogen, or through a methanation process to produce biomethane, or through a Fischer Tropsch process to produce liquid biofuels. During these processes carbon is separated out and can be captured and stored – a form of BECCS. However, if this syngas is not upgraded it can only be burned to produce electricity in a gas plant.

Currently there are no commercial-scale biomass gasification plants in the UK that can produce ultra-clean syngas. Most existing biomass gasification plants in the UK produce electricity, incentivised under current Government support mechanisms. As a result, there is currrently some uncertainty

Box 5.8. What is gasification and what are the barriers to its deployment?

around whether and when these gasification technologies to produce ultra-clean syngas will be deployable at scale and when the full flexibility of biomass in the energy system will be unlocked.

The main barriers that need to be overcome in producing ultra-clean syngas are:

- Demonstrating that a sufficient amount of the contaminants in the syngas can be removed to allow upgrading to a high-quality end product. The main technical challenge is tar removal.
- Demonstrating and deploying biomass gasification plants at commercial scale. Two pilot plants aiming to produce ultra-clean syngas are due to come online in 2018 in the UK. Whilst this is a positive step these technologies need to be proven and deployed at larger scales over the coming years to remove uncertainty around their commercial viability.

3.7. Sub-optimal uses of biomass

The flexibility of biomass as a low-carbon energy resource means there are a large number of potential end-uses. However our analysis suggests many of these uses are sub-optimal in the long-term and likely to reduce overall levels of ambition on emissions reduction and/or increase overall costs. These end-uses should not be supported by Government in the long-term.

- Converting large quantities of biomass to synthetic natural gas (bio-SNG) via gasification as a route to decarbonising the gas grid implies bioenergy being used instead of other viable low-carbon options (e.g. heat pumps). This undermines the abatement potential of biomass.
- Producing aviation biofuels without CCS will deliver substantially less GHG abatement than using biomass with CCS to make hydrogen or electricity.
- Using biomass to generate electricity without CCS after 2030 is unlikely to displace significant amounts of fossil fuel emissions because the power grid will be largely decarbonised by this time. Biomass would be more effectively used elsewhere or with CCS.
- Using biomass to make biofuels for surface transport beyond 2030 would mean displacing other low-carbon options such as electric vehicles. Using biomethane or bio-SNG to fuel heavy goods vehicles is unlikely to reduce emissions overall as this limited resource would otherwise be used elsewhere in other hard-to-decarbonise sectors.

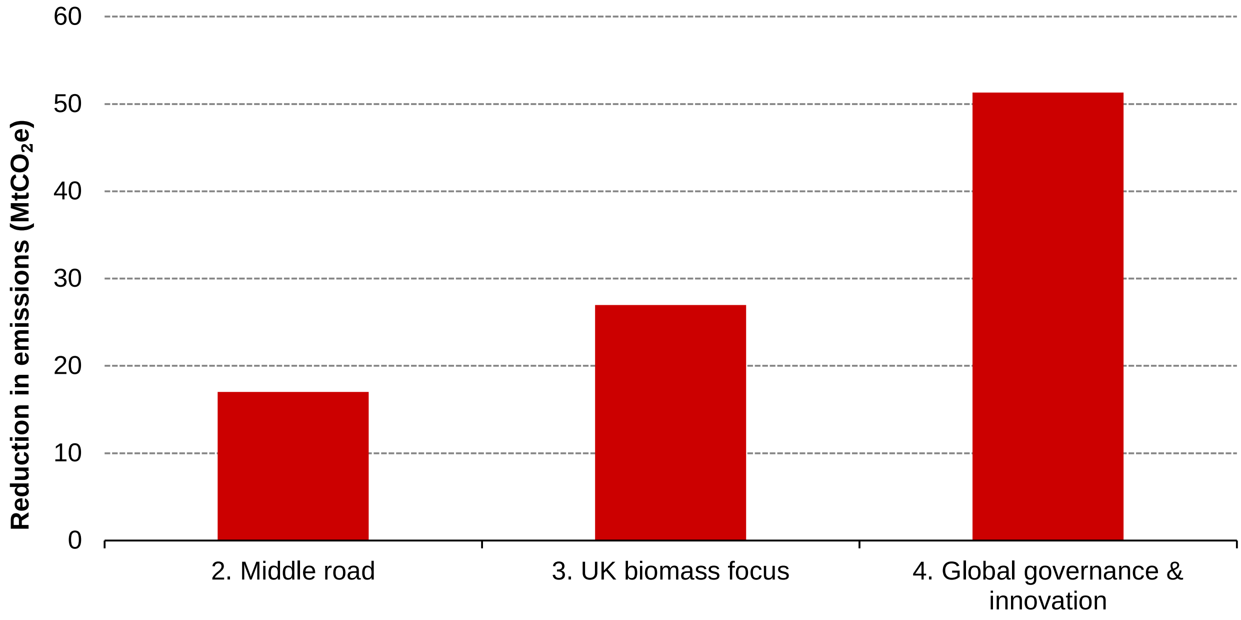
3.8. The overall impact of biomass on decarbonising the UK's energy system

Our ESME modelling shows that higher levels of sustainable biomass use enable greater emissions reduction (Figure 5.7). However, to the extent that the UK uses more biomass by taking a greater share of internationally traded feedstocks (e.g. supply scenario 4a), this may reduce the potential to reduce emissions outside the UK. We therefore do not consider the abatement benefit beyond the UK's equal share of the global resource (see Chapter 4 for more on our resource scenarios).

The Committee is in the process of reviewing the UK's long-term emissions targets in the light of the Paris Agreement, and will provide advice in 2019. The work undertaken in this review on the implications of biomass use will help to inform estimates of the levels of emissions reductions that might be achievable in the UK.

Analysis by the Energy Technologies Institute (ETI) using the ESME model indicates that it could be around 50% more expensive to achieve the UK's existing 2050 target for an 80% reduction in greenhouse gas emissions by 2050 with only very low levels of bioenergy supply.[104]

Figure 5.7. The impact of biomass supply on energy system CO_2 emissions in 2050 (increase in achievable emissions reductions ($MtCO_2e$) in 2050 vs. scenario "1.Poor global governance")



Source: CCC analysis using the ESME energy system model.

4. Energy sector transitions to long-term best-use

In this section we provide further detail on biomass use in the short-medium term. We describe how current biomass use should change over time to support and align with long-term best use.

4.1. Scaling up the use of wood in construction

There is significant potential for this to scale-up in the future both by increasing timber frame construction and by expanding the use of engineered wood, particularly in the non-residential sector.

Such a scaling up aligns with Government priorities:

- The *Clean Growth Strategy* (2017) includes a commitment to increase the amount of UK timber used in construction.
- As part of its Industrial Strategy, the Government has agreed a new 'Sector Deal' with the Construction Industry which will include up to £170m funding for a 'Transforming Construction' programme. This aim of this new programme is to develop the UK's capabilities in integrating construction with digital and energy efficiency technologies, to develop buildings that use much less energy to build and run.

[104] ETI 2018 *The role for bioenergy in decarbonising the UK's energy system.*

- The Government has also committed to using public sector spending to drive an update of modern methods of construction, many of which involve the use of timber systems.

Barriers and challenges

There are a number of challenges and barriers that will need to be overcome in order for a significant increase in timber construction in the UK to be achieved (Box 5.9).

Some of these challenges relate to the construction industry as a whole as it adapts to meet the changing needs of society. These include the need to build homes that are well adapted to the UK's changing climate; that have healthy and energy-efficient environments; and that are built in ways that minimise GHG emissions to the atmosphere.

There are also a range of barriers specifically related to timber construction. These barriers include inertia and a lack of expertise and skills in the construction sector (particularly with respect to the use of engineered wood in non-residential buildings) and the use of business models and procurement processes that inhibit consideration of timber designs.

Box 5.9. Construction industry-wide challenges resulting from the need to mitigate and adapt to climate change in the built environment

The construction industry as a whole faces a range of challenges in adapting to meet the changing requirements of society over the coming decades. Addressing these challenges will require improvements to the way all types of building are designed and constructed, including those based on timber construction systems.

- The **overheating** of UK buildings is already a material problem. Anticipated climate change over the coming decades means this has the potential to worsen if measures are not taken to manage risks. Around 20% of homes standing in 2050 are yet to be built. The Committee has previously recommended to Government that a new mandatory standard is needed to prevent overheating in new homes. Factors which determine the risk of overheating in buildings include location, orientation and exposure, ventilation, occupant behaviour, type of property (e.g. top floor flats are particularly vulnerable) and fabric characteristics such as insulation, levels of glazing and the thermal mass of building materials. These risk factors should be considered holistically at design stage. Solutions to prevent overheating in buildings include limiting heat gains; enhancing ventilation, cooling and heat rejection (through passive and active mechanisms); and changing occupant behaviour. The Committee will further explore overheating risks in new buildings as part of its upcoming report report on housing (due to be published in 2019).
- The **indoor air quality** in buildings can be heavily influenced by decisions made at design and construction phases. Increasing air tightness in homes has potential to negatively impact on air quality where the building is not properly ventilated. There are a range of solutions to improving ventilation and indoor air quality, including preventing single-aspect build, and introducing ventilation systems such as mechanical **v**entilation and heat recovery (MVHR). Further work will be needed to ensure MVHR systems deliver their intended benefits, including improving installation and commissioning and addressing problems related to the fact that the filters need replacing every few years. Broader design decisions can also have an impact. Consideration should also be given to wider air quality considerations such as volatile organic compounds in building materials. Further action is required across the construction industry to address indoor air quality issues.
- UK Government is currently reviewing elements of the UK's building regulations that relate to **fire safety** following the Grenfell Tower tragedy in 2017. All construction systems will need to fully comply with future fire safety standards.

Sources: Zero Carbon Hub (2015) *Overheating in homes. The big picture;* Zero Carbon Hub (2016) *Solutions to overheating in homes.*
Notes: Some estimates suggest up to one-fifth of UK homes may already exceed overheating thresholds in summer and that up to 90% of hospital wards may be prone to overheating. For more analysis of overheating in the built environment see the CCC's Adaptation Sub-Committee 2014 Progress Report to Parliament, *Managing climate risks to well-being and the economy*.

A framework for driving down the lifecycle emissions of buildings

Currently the policy and regulatory framework for new buildings in the UK focuses on operational emissions and does not adequately consider the contribution of embodied emissions or sequestered carbon.

There are a wide range of policy levers that could (and in some cases already do) play a role in reducing whole-life carbon impacts, ranging from measures such as carbon pricing to the evolution of Building Regulations. Assessments of whole-life carbon should account for sequestered carbon, even if this is treated differently to embodied and operational emissions:

- Building Regulations have been key to reducing the operational emissions of buildings to date, but have not historically sought to influence lifetime emissions more broadly. Whilst there will be a need to consider the range of policy measures available, the upcoming review of Building Regulations offers an important opportunity for Government and industry to consider and address this part of the regulatory gap.
- Over the next 3-5 years, Government and industry should lay the groundwork to support assessment and benchmarking of whole-life carbon. This should include developing a standardised approach to carbon quantification (making use of consistent methodologies over comparable scopes), development of databases for lifecycle assessments and environmental product declarations (including on a national basis where needed), and steps to drive skills development. Initial roll-out could be driven by public procurement, planning requirements and through evolution and consolidation of a voluntary framework which supports developers to develop their design and materials sourcing strategies in anticipation of mandatory implementation at a clearly specified future date.
- This groundwork should inform a decision on a mandatory regulatory framework in the 2020s that drives whole-life carbon savings. An effective framework would need to cover all construction systems through technology and material neutral standards that rachet up over time to drive innovation, best practice and ongoing decarbonisation of industrial sectors.

Potential policies to scale up timber construction supply chains

In their work for the Committee, Bangor Biocomposites Centre engaged with industry stakeholders to scope out barriers to timber construction and identify potential steps that could be taken to overcome them. These are outlined below and should be considered by Government as part of its broader policies towards the construction sector and decarbonisation:

- Set appropriately ambitious targets to provide market confidence, allow supply chains to develop and build capacity.
- Harness the momentum generated by recent reviews of Construction sector activities, including the Farmer Review,[105] to drive a change in procurement processes to recognise whole project costs, sustainability and performance rather than direct cost only.
- Continue to invest in site skills for construction, including groundworks, bricklaying, carpentry, ventilation and sustainable technologies. Ensure wider industry skills programmes include the assembly, manufacture, design and installation of timber systems, and that graduate programmes adequately address engineering in timber alongside traditional materials.
- Support an ongoing programme of good practice guides, case studies and exemplar buildings to address perception barriers and build demand.
- Provide support to establish and expand UK manufacturing capacity of timber products, including engineered wood products such as CLT. Use this opportunity to support growth in the supply chain of home grown timber.
- Measures to scale up wood in construction alongside policies to increase tree planting and forestry management in the UK, increasing future UK timber supply.
- Innovation in off-site manufacture may also have a beneficial impact.

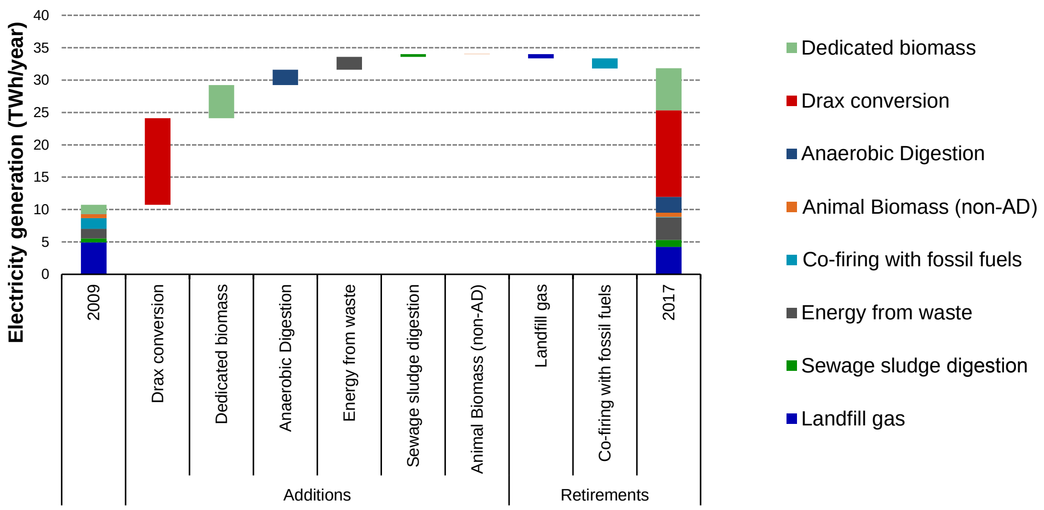
[105] Farmer M. (2017) *Farmer Review of the UK Construction Labour Model.*

4.2. Power sector

Biomass produced around 10% of the UK's electricity in 2017, a significant increase from around 3% in 2008 (Figure 5.8). This increase was driven by the Renewables Obligation (RO) and Contracts-for-Difference (CfD) incentive schemes:

- Bioelectricity comes from a variety of sources: landfill and sewage gas, dedicated biomass combustions plants (using wood pellets or straw), co-firing biomass with coal, Anaerobic Digestion (AD), waste incineration, and Advanced Conversion Technologies (ACTs).[106]
- Around half of the increase since 2009 is from coal to biomass conversions, principally Drax power plant. Between 2013 and 2018 Drax power station – the UK's largest – converted four of its six units to burn biomass pellets instead of coal. The company now imports 34 TWh of primary bioenergy to the UK, mostly from feedstocks in North America.[107] Drax currently generates around 13 TWh electricity per annum, around 40% of all UK bioelectricity.

Figure 5.8. Bioenergy in the power sector: 2009 to 2017



Source: CCC analysis based on BEIS (2018) *Energy Trends*.
Notes: 'Dedicated biomass' includes the use of straw and energy crops, as well as enhanced co-firing (>85% biomass).

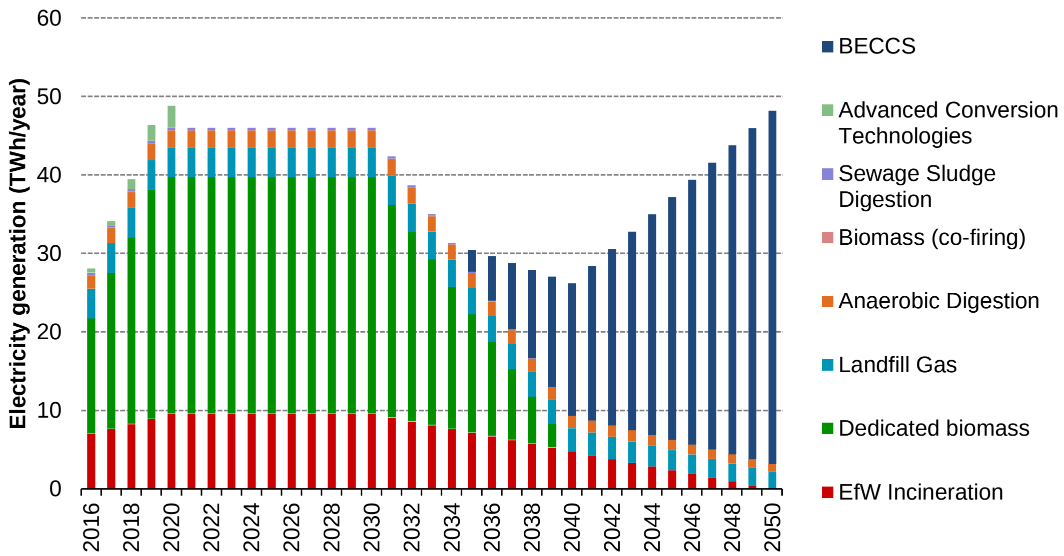
The availability of other cost-effective low-carbon technologies in the power sector means that this biomass has no long-term role in electricity generation unless it is coupled with CCS (Figure 5.9). The exception to this may be small-scale local or niche uses of biomass for CHP where it is infeasible to transport and use feedstocks elsewhere. This conclusion has a number of implications:

[106] Advanced Conversion Technologies (ACTs) use biomass to produce electricity via gasification and pyrolysis (including advanced bioliquids).
[107] Drax group plc (2018) Annual report and accounts 2017. Assuming 5 MWh per tonne of biomass.

- No further policy support (beyond current commitments) should be given to large-scale biomass plants that are not deployed with CCS technology.[108]
- Currently Drax receives Government subsidies under the RO and CfD schemes of over £600m per year.[109] These will end in 2027. Committee analysis for our 2018 Progress Report to Parliament suggested that Drax may continue to operate beyond the 2027 subsidy deadline, if it is able to cover its fixed costs through the UK's Capacity Market mechanism.
- Over time biomass in power should transition to use with CCS, either in existing large-scale biomass units if their remaining lifetimes justify this investment or in new plants with CCS, building on existing supply chains where these are sustainable.
- The use of BECCS for power generation could be cost-effective at a carbon price of between £80-140/tCO_2. By 2030 this would be within the Government's Green Book carbon value trajectory.

Gas produced from biogenic sources via AD will be best used outside of the power sector (e.g. injected into the gas grid). Once current policy commitments have expired, biogas burnt for power should be limited to cases where the transportation of biogas or biomass feedstocks to other facilities is not feasible.

Figure 5.9. Illustration of a transition to the 'best-use' of bioenergy in the power sector



Source: CCC Analysis based on BEIS (2018) *Renewable Energy Planning Database*, LCCC (2018) *CfD Register*, CCC projections.
Notes: The chart provides an illustration of what a transition from projected bioenergy in power generation in the 2020s to a 'best-use' bioenergy scenario for 2050 could look like. In a 'best-use' scenario, biomass in power is focused on BECCS; other uses of biomass in power are restricted to small-scale local or niche uses of biomass for CHP where it is infeasible to transport and use feedstocks elsewhere. EfW = Energy from Waste.

[108] This appears to be line with the current direction of Government policy which has largely restricted Government support for further new biomass power plants to ACTs which are currently included in CfD auctions. Whilst dedicated biomass plants and coal to biomass conversions are still eligible for support through the CfD auctions, they have now been moved into 'pot 1' (technology neutral) and it is highly unlikely that a biomass plant would win a contact due to competition from cheaper low-carbon technologies such as onshore wind or solar PV.
[109] Drax Group plc (2018) *Annual report and accounts 2017.*

Whilst the development of gasification technologies capable of converting biomass feedstocks into ultra-clean syngas should be a priority for policy support, this would be more effectively done in sectors other than the power sector:

- ACT plants currently being supported under the CfD scheme do not use technologies capable of producing ultra-clean syngas by removing tar and other contaminants.
- Further support for ACTs in the power sector does not appear to represent a clear pathway to developing technologies capable of creating higher-value energy carriers such as biofuels, biomethane or hydrogen.

A more effective route to develop gasification technologies would be to provide support via sectors and end-uses that require ultra-clean syngas, for example in the transport or heat sectors.

4.3. Transport

Current biofuel use in the UK is mostly made up of bioethanol from fermentation of crops and biodiesel made from waste fats. There is little commercial deployment of biofuels outside of road transport, and most advanced production routes are still at demonstration stage (Box 5.10).

The use of biomethane as a heavy goods vehicle fuel is growing in the UK, but there remain significant risks that this could delay the deployment of ero emission options and not necessarily lead to emissions reductions (Box 5.11).

Box 5.10. Current biofuel usage in UK transport

Biofuels are used in the UK today in road vehicles and are mostly comprised of bioethanol from fermentation of crops such as wheat, corn and sugar beet, and biodiesel made from waste fats, such as used cooking oil and tallow. Sustainability concerns have increasingly highlighted the need to move towards advanced biofuels conversion processors. These processes are the subject of current research, with some demonstration plants in operation, but they are not yet widely deployed.

The Renewable Transport Fuels Obligation (RTFO) is one of the Government's main polices for reducing greenhouse gas emissions from use of fossil fuel in the transport sector, by incentivising the adoption of biofuels. There has been a gradual improvement in the sustainability of biofuels used in transport in recent years, and in 2016/17 average GHG savings were 79% relative to fossil fuels, excluding emissions from indirect land-use change. Changes made to the RTFO have helped drive improvements in sustainability:

- Renewable fuels derived from certain waste or residue feedstocks are awarded double certificates to incentivise take-up of the most sustainable sources.
- The cap on the level of crop-based biofuels supplied is set at 4% of fuel in 2018. This cap will gradually tighten from 2021, reaching 2% by 2032.
- A development fuels sub-target, to encourage the production of advanced fuels. This requires a rising proportion to be supplied from a combination of renewable aviation fuel, bio synthetic natural gas (bio-SNG - a form of biomethane produced from gasification or pyrolysis), renewable hydrogen or fuels that can be blended in to petrol or diesel at rates of above 25%, as well as meeting certain standards. The sub-target has been set at 0.1% of fuel in 2019, rising to 2.8% of fuel in 2032.

Box 5.10. Current biofuel usage in UK transport

Aviation biofuels

There are limited volumes of aviation biofuels produced and used in the UK today:

- Gasification through the Fischer-Tropsch method has been certified as a technology pathway to produce bio-jet fuels by the American Society for Testing and Materials (necessary before commercial airlines can use a fuel for an international flight), and can also produce diesel.
- Use of Hydro-processed Esters and Fatty Acids (HEFA) has also been certified for aviation, and is similar to the process used to produce Hydrogenated Vegetable Oil (HVO) diesel, albeit with additional processing steps. The vast majority of currently available bio-jet fuels are produced using this method.
- Hydrocarbon fuels including jet fuel and diesel can be produced from sugars. The 'direct sugar-to-hydrocarbon' route has been certified for use in aviation.
- Short-chain alcohols can be catalytically converted to jet fuel and diesel, with a technology pathway involving producing jet fuel from isobutanol certified for use in aviation fuel in 2016.

Source: Department for Transport (2017) *The renewable transport fuel obligations order: Government response to consultations on amendments*; IRENA (2017) *Biofuels for aviation: Technology Brief*; E4Tech and Ricardo Energy & Environment for Department for Transport (2017) *Future Fuels for Flight and Freight Competition - Feasibility Study*.

Box 5.11. Natural gas in transport

The Committee's analysis for the advice on the fifth carbon budget suggested that the use of natural gas in industry, buildings and power could fall from around 700 TWh in 2030 to around 370 TWh in 2050. This compares to our estimate of available biomethane resource from AD of around 20 TWh, which is insufficient to satisfy these demands.

As existing uses of natural gas require no additional investment in vehicles or infrastructure, they represent a cost-effective way to use a finite biomethane resource. Diverting biomethane away from meeting existing gas demands towards the transport sector would necessarily lead to a corresponding increase in natural gas consumption in the other sectors. Therefore, to ensure that the use of natural gas in heavy duty trucks represents cost-effective abatement at a system-wide level, fossil natural gas must be used as the comparator to diesel (Figure B5.11).

In order to achieve stretching long-term emissions targets, heavy duty vehicles will need to move to carbon-free energy carriers (e.g. hydrogen and/or electricity) where these are available. Therefore, any use of methane vehicles would only be for an interim period, before switching again to an ultra-low-emission solutions.

Large trucks have a lifetime of eight to twelve years, so in order to completely decarbonise the road transport sector by 2050, all new trucks sold must be zero emission by the late 2030s. As the economic case for a natural gas refuelling station would likely be evaluated over a ten year basis, this means there is limited time to develop a refuelling network for natural gas vehicles as a commercial proposition, especially in light of the low penetration of natural gas vehicles today. When considered alongside the limited research and development budgets of vehicle manufacturers, there is a risk that transitioning to natural gas heavy duty trucks in the medium term could delay a further transition to zero emission truck options in the longer term.

Box 5.11. Natural gas in transport

Although the economic case must be satisfied over a shorter time period of ten years, natural gas refuelling stations have a lifetime of 15-25 years. There are indications that zero-emissions solution may become cost-effective by around 2030:

- The Energy Transitions Commission has estimated that by 2030, electric trucks will have a lower total cost of ownership than diesel for long distance truck applications.
- The ICCT estimate that overhead catenary electric or hydrogen fuel cell trucks will be substantially cheaper than diesel vehicles over the same time period.

If cost-effective zero emission options materialise, truck operators should be encouraged to switch to these technologies, running the risk that the refuelling infrastructure is not used for its full lifetime. Whilst natural gas refuelling stations could be converted to hydrogen refuelling stations, there are limited opportunities to reuse equipment from natural gas stations, as hydrogen is more corrosive to pipeline and storage materials than natural gas and hydrogen compression, and storage systems generally operate at higher pressures.

If the Government chooses to support the deployment of natural gas in trucks in spite of these issues, they should focus on types of vehicles where there are no existing zero emission options and where there are the greatest potential emission reductions:

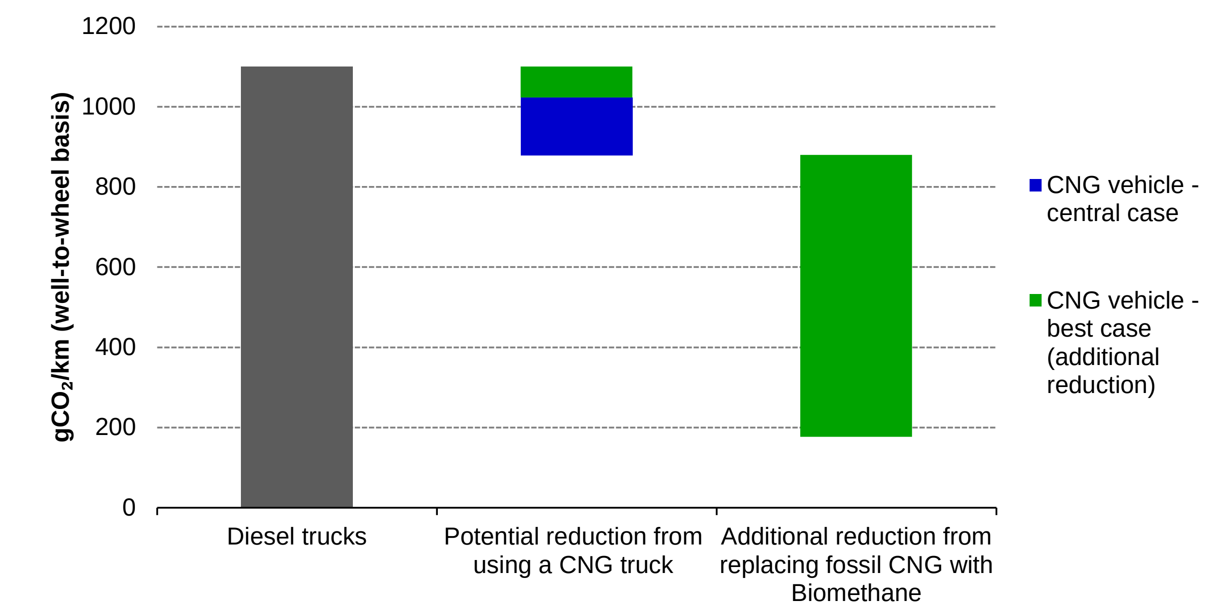
- Natural gas trucks are best suited for duty cycles with continuous speeds, so long-haul motorway journeys are likely to represent the largest opportunity for reduced emissions. Natural gas refuelling infrastructure should connect to the grid where there are minimal energy losses from compressing the gas to refuel vehicles using the high and intermediate pressure distribution network systems.
- However, urban delivery trucks and refuse vehicles with stop-start operations are best suited to transition to electric vehicles in the near term.

Independent testing is essential to ensure that natural gas vehicles offer real-world improvements over diesel vehicles in CO_2 equivalent per km (including measurement of methane slip and N_2O) and improved air quality with respect to the latest Euro VI diesel vehicles. It is important to be clear that methane vehicles represent transitional solutions at best.

Fleet operators should be actively considering deploying electric trucks for their short haul operations in the near term and preparing for the arrival to market of zero-emission long-haul heavy duty trucks.

Box 5.11. Natural gas in transport

Figure B5.11. Lifecycle emissions from compressed natural gas (CNG) trucks



Source: Energy Technologies Institute (2017) *Natural Gas Pathway Analysis for Heavy Duty Vehicles; Element Energy for Cadent (2017) Independent assessment of the benefits of supplying gas for road transport from the Local Transmission System.*

Notes: The chart shows the best case and central case from ETI report. The worst case scenario in this report has only a 2% potential reduction in emissions from CNG trucks in comparison to a diesel truck. The best case scenario assumes 20% and the central case assumes 13%. For replacement with biomethane, the calculated reduction is from the Element Energy report and assumes a 12-15% well-to-wheel CO_2 saving compared to an equivalent diesel vehicle. The emissions saving from replacing fossil natural gas with biomethane is equivalent to that from injecting biomethane into the gas network.

Source: L.Yang et. al (2013) *Evaluation of the economics of conversion to compressed natural gas for a municipal bus fleet*; A.M.Jaffe et. al (2017) *The potential to build current natural gas infrastructure to accommodate the future conversion to Near-Zero transportation technology*; Energy Transitions Commission (2018) *Reaching zero carbon emissions from Heavy Road Transport; ICCT (2017) Transitioning to zero-emission Heavy Duty Freight vehicles.*

There is no long-term role for biofuels in surface transport (with the possible exception of HG s) because there are other viable low-carbon options. In shipping there are also likely to be other low-carbon options by 2050, although there may be a transitional role for some biofuel use. In aviation there may be a long-term role for some use of liquid biofuels provided production of these biofuels is coupled with CCS. These conclusions imply that over the next decade policy should not incentivise significant additonal uptake of biofuels in surface transport and instead use mechanisms such as the RFTO to support the development of key technologies and aviation biofuels:

- **Road Transport.** In the Committee's analysis for the fifth carbon budget, biofuel use was assumed to increase to 8% by 2020 to meet EU renewable energy targets as a result of the RFTO. As cars and vans increasingly electrify, the volume of petrol and diesel consumed falls in our scenarios from 47 billion litres in 2017 to 30bn litres in 2030, and will continue to fall in the 2030s. By 2030, biofuels displace around 3 billion litres of petrol and diesel in our modelling, equating to around 11% of liquid fuel by energy. The likely timing of the transition of HGVs to zero emission options - including hydrogen and electrification - is uncertain, suggesting the role of biofuels usage in HGVs should be reviewed in the 2020s.

- **Shipping.** Shipping has a range of promising decarbonisation options. However, the high payloads and long distances pose some technical challenges implying there may be a role for transitional uses of biofuels depending on how alternative technologies develop.
- **Aviation.** Government should not plan for significant uptake of biofuels in aviation. An appropriate planning assumption is for around 10% use in 2050. Aiming for this level would develop the market and keep open the option for further deployment should higher priority best uses fail to develop, or if sustainable supply turns out higher than anticipated.

4.4. Industry

Bioenergy met around 15 TWh of industrial energy demand in 2016, mainly in the cement and paper sectors. Over time industry should transition towards to a mix of low-carbon technologies including hydrogen, CCS with fossil fuels, BECCS and electrification. Because the best long-term mix is unclear, transitional measures are needed to develop and maintain these options.

This means that industrial BECCS should be further investigated and developed where appropriate. In the near term use of bioenergy without CCS should be supported (or preserved) at sites where longer term cost-effective BECCS use is considered possible:

- Government should support the research and development of BECCS technologies in industry. This should aim to understand which sectors and industrial processes are most suitable for BECCS and how overall capture rates can be maximised. To identify cost-effective opportunities, it should consider sources of emissions that are likely to have sufficient size (or be close to a wider cluster). To determine the cost-competitiveness, it will be necessary to compare BECCS to industrial hydrogen use and (post-industrial-process) CCS.
- In industrial sectors and processes where BECCS is identified as potentially cost-effective, a phased programme of bioenergy to BECCS should be supported. This could sit alongside development of hydrogen or fossil-fuelled CCS in industrial clusters. It could involve an initial and time-limited phase of support for biomass without CCS to help scale-up supply chains and enable learning.

New biomass use in industry should not generally be supported outside of sectors with long-term BECCS potential. However there may be a limited transitional role for some forms of bioenergy in applications without future BECCS potential provided this avoids lock-in of infrastructure and behaviour and does not detract from wider decarbonisation efforts. An example of this could be the use of biomethane delivered via the gas grid.

Policy should also avoid simply displacing biomass use in industrial sectors by incentivising its use in other parts of the economy, unless there is a clear carbon benefit for doing so (or unless such a transfer supports the development of long-term options in line with best-use). The cement sector has reported that support for biomass use in buildings through the Rewnewable Heat Incentive has led to the displacement of bioenergy in the cement sector. This is potentially moving biomass from a sector where it may have a long-term role (BECCS in cement production) to sector where it does not (see below).

4.5. Buildings and heat

In total, wood for heating homes makes up half of heat produced from bioenergy in the UK. Currently around half of this is burnt on open fires,[110] with most of the remainder consumed in wood-burning stoves. This is both inefficient and a cause of air pollution (Figure 2.8), but has other benefits (e.g. comfort, aesthetics). Since 2011, the non-domestic Renewable Heat Incentive has led to an big increase in bioenergy in non-residential buildings (commercial, public and agricultural), contributing to a further 20% of bioenergy heat. The remainder is used by industry.

Long-term use in buildings should be limited to niche roles to smooth demand peaks in the context of heat networks and hybrid heat pumps, along with a continued role for biomethane produced through anaerobic digestion (up to around 20 TWh, or 5% of current heating demand):

- BEIS should end support for biomass boilers for heat where there are other low-carbon options and target support at hybrid options rather than drop-in fuels (e.g. retaining an oil boiler but replacing oil with bio-LPG).
- Widespread bio-synthetic natural gas (bio-SNG) injection is undesirable due to the residual carbon emissions and availability of other heat decarbonisation options to reduce methane demand. To the extent that bio-SNG plays a role, this should include use of CCS on the bio-SNG production facility, to ensure that the emissions saving is comparable to other BECCS routes.
- CO_2 emissions from anaerobic digestion (AD) to produce biomethane should be minimised, along with air quality impacts. Towards 2050, it should be used as a production route for hydrogen where possible.
- Near-term, policy should maximise biomethane production from waste via AD for gas grid injection and consider support small-scale demonstration projects for bio-SNG for grid injection or off-gas liquid fuels as a route to developing gasification technologies.

5. The bioeconomy

The emerging concept of the bioeconomy is defined at its broadest level as including all economic sectors that utilise biomass to make products. This includes traditional sectors such as agriculture, food and drink and wood-based products, but also new sectors such as bio-based chemicals, pharmaceuticals and plastics (Box 5.12).

Whilst there is significant focus at both UK and EU levels on the potential of these new bioeconomy sectors to drive economic growth,[111] there is currently high uncertainty as to the future size of these markets, their potential demand for biomass resources and the level of GHG emissions reductions they might offer. For this reason we do not currently include these uses of biomass in our best-use hierarchy, but instead we aim to identify the circumstances in which bio-based products (in particular bio-based plastics) might emerge as best-uses over time.

---

[110] BEIS (2016) *Summary results of domestic wood use survey*

[111] The UK Government held a Call for Evidence in 2016 as part of a planned Bioeconomy Strategy (yet to be published), and the European Commission published an update to its Bioeconomy Strategy in 2018.

Box 5.12. What is the bioeconomy?

The bioeconomy is described by the UK Government as *'The economic opportunity of using biology to help solve challenges we face in agriculture, energy, health and more… The bioeconomy includes all economic activity derived from bio-based products and processes. These have the potential to contribute to sustainable and resource efficient solutions to the challenges we face in food, chemicals, materials, energy production, health and environmental protection' (BEIS, 2016).*

Across Europe the Bioeconomy is estimated to support over 18 million jobs with an annual turnover over 2 trillion euros. The largest sectors are agriculture, food and drink, wood products and paper, with newer sectors such as bio-based chemicals, pharmaceuticals and plastics currently contributing a much smaller share (Figure B5.12) (JRC, Bioeconomy Report 2016).

In the UK, recent work commissioned by the Biotechnology and Biological Sciences Research Council (BBSRC) provided an assessment of the bioeconomy covering sectors such as construction, agriculture, forestry, industrial biotechnology, bioenergy and food and beverage products. The BBSRC study concluded that in 2014 the bioeconomy generated £220bn in GVA for the UK, 13% of total national GVA, with the UK one of the world's leading countries in bioeconomy innovations (Capital Economics, TBR and E4Tech, 2016).

Whilst some of these sectors are focussed on high-value, low-volume uses of biomass feedstocks others have the potential to scale-up over the coming decades, which could result in significant levels of demand for biomass feedstocks. Bio-based plastics (made from monomers and polymers derived from biomass rather than fossil fuel feedstocks) are the key example of this that we focus on in this report.

Box 5.12. What is the bioeconomy?

Figure B5.12. The size of the EU bioeconomy in 2015

EMPLOYMENT (MILLION JOBS)	TURNOVER (TRILLION EUR)	VALUE ADDED (BILLION EUR)
18	2.3	621

	EMPLOYMENT (MILLION JOBS)	TURNOVER (BILLION EUR)	VALUE ADDED (BILLION EUR)
AGRICULTURE	9.2	380	174
FORESTRY	0.5	50	24
FISHING AND AQUACULTURE	0.2	12	7
FOOD, BEVERAGES AND OTHER AGRO-MANUFACTURING	4.5	1 153	233
BIO-BASED TEXTILES	1.0	103	28
WOOD PRODUCTS AND FURNITURE	1.4	174	47
PAPER	0.6	187	46
BIO-BASED CHEMICALS AND PHARMA - CEUTICALS, PLASTICS AND RUBBER	0.4	177	56
LIQUID BIOFUELS	0.03	12	3
BIOELECTRICITY	0.01	11	3

DATA 2015

Research and Innovation

Source: based on Ronzon & M'Barek, 2018
https://doi.org/10.3390/su10061745
European Commission's Knowledge Centre for Bioeconomy

Sources: European Commission (2018) *Bioeconomy Strategy Booklet*. https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy; BEIS (2016) *UK bioeconomy: Call for Evidence*; Ronzon, T. et al (2017). *Bioeconomy Report 2016. JRC Scientific and Policy Report*; Capital Economics, TBR and E4Tech (2016) *Evidencing the bioeconomy*.

5.1. Bio-based plastics[112]

Plastics have become a ubiquitous material in the global economy, used to make a wide range of products including packaging, coatings, clothing and electrical applications:

- Global plastic production has increased from a few million tonnes a year in 1960 to around 350 Mt today. A significant proportion of this is for single-use plastics applications.
- Plastic production is the UK's third largest manufacturing sector with around 2,600 UK companies supporting over 160,000 jobs. The UK is also home to major plastics end-user markets such as aerospace and automotives.
- Despite the many benefits plastics have brought they are also associated with a number of negative environmental impacts.
  - Currently less than 15% of plastic packaging is recycled, resulting in high levels of plastic in our waste streams and plastic pollution in ocean and terrestrial ecosystems (Figure 5.10).
  - Almost all plastics are currently made with fossil fuel feedstocks. It is estimated that an average of around 2.5 tCO_2e is emitted for every tonne of plastics made, with around another 2.7 tCO_2e embedded as fossil carbon in the plastic itself.

There is significant potential to implement ambitious measures to reduce, reuse and recycle plastics at the global level. However annual virgin feedstock requirements for new plastics production is still likely to increase substantially over today:

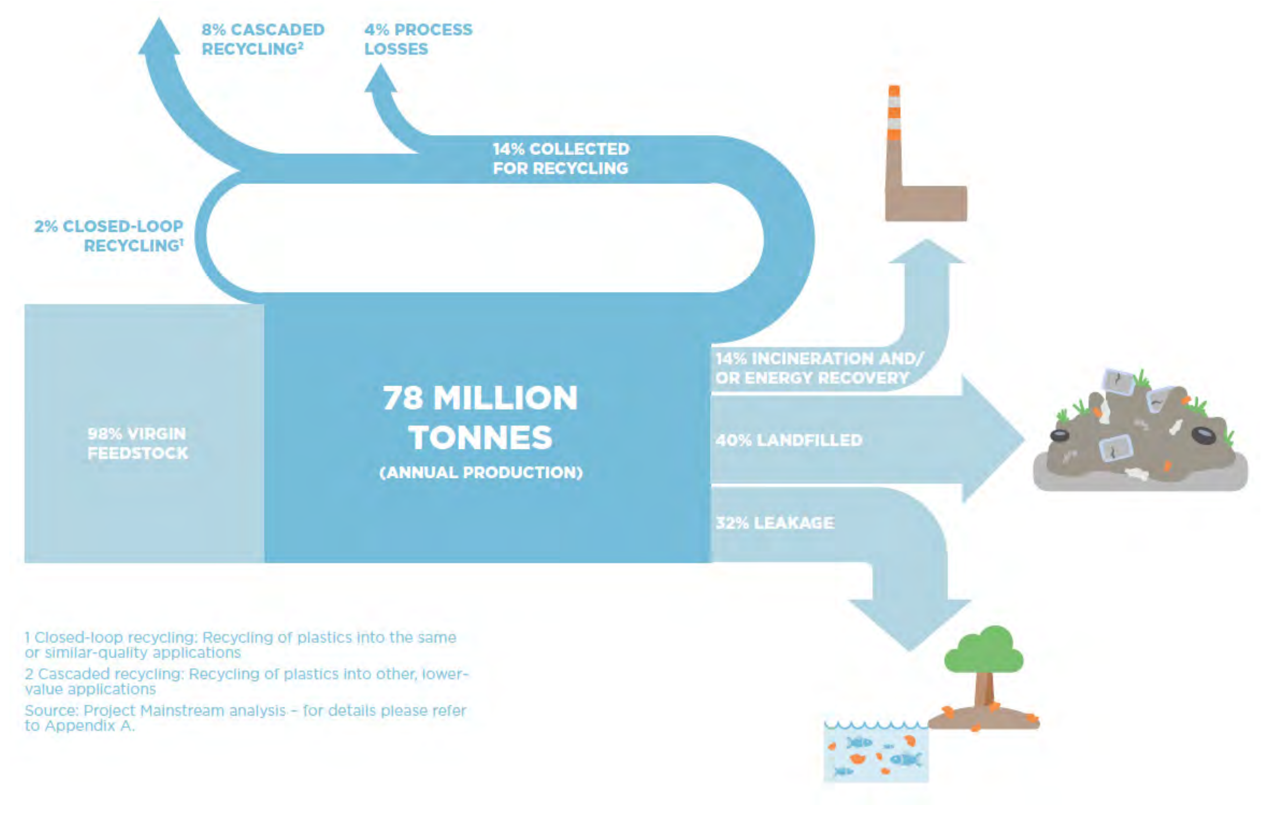
- If current trends continue, it is estimated that plastics production could require up to around 20% of global oil consumption in 2050, equivalent to around 15% of the total global carbon budget in a scenario that limits the rise in global temperature to 2C.
- Even if ambitious progress in the efficient use, reuse and recycling of plastics is achieved, more virgin feedstock may be needed in 2050 than today. This is because even low end projections of future plastic demand imply an increase in feedstock requirement that exceeds recycling potential.[113]
- There are two main options for decoupling plastics production from fossil feedstocks. One option is to use methane or CO_2 captured from landfill sites or anaerobic digestion (and potentially other sources in the future) and use this to directly produce plastics, for example via electro-chemical production routes. However methods to do this are not yet proven at commercial scale. The other option is to use biomass. It is estimated that bio-based plastics currently make up less than 1% of total plastics production worldwide.

---

[112] This section is mainly based on a supporting paper produced by Professor Callum Hill as part of the Bangor Biocomposites Centre team appointed by the Committee. This paper is published alongside this report, as well as the following recent studies: World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company (2016) *The New Plastics Economy - Rethinking the future of plastics*, http://www.ellenmacarthurfoundation.org/publications; Material Economics (2018) *The circular economy, a powerful force for climate mitigation;* Nova Institute (2017) *Bio-based building blocks and polymers: Global capacities and trends 2016-2021.* Other academic studies are also used and referenced in footnotes where relevant.

[113] The Ellen MacArthur Foundation (2016) estimate that ~600 Mt plastics may still be required from virgin feedstocks in 2050, double that of today. This is based on a scenario with high levels of reuse and recycling.

Figure 5.10. Global flows of plastic packaging materials in 2013



Source: World Economic Forum, Ellen MacArthur Foundation and McKinsey & Company (2016) *The New Plastics Economy - Rethinking the future of plastics*, http://www.ellenmacarthurfoundation.org/publications

Estimates vary as to the potential of bio-based plastics to scale up by 2050 and the amount of biomass feedstocks that would be required to support this. At the high-end however, these requirements would exceed the CCC's global biomass supply scenarios:

- Academic studies suggest a technical potential for between 35% and 90% of plastics to be bio-based in 2050, implying up to around 210 to 540 Mt bio-based plastics produced each year.[114]
- There is no set amount of biomass required to produce a tonne of plastic. This will depend (amongst other factors) on the feedstock, production route and conversion efficiency. However applying a wide range of feedstock to plastic ratios indicates that meeting the total technical potential of bio-based plastics in 2050 would require a total biomass resource of 15-125 EJ per year, compared to around 85 EJ per year resource in the Committee's high supply scenario (Figure 5.1).[115]

[114] Technical potentials taken from: Shen et al (2010) Present and future development in plastics from biomass; Saygin et al (2012) Assessing industrial energy use and CO2 emissions. Opportunities for energy efficiency, biomass and CCS. These technical potentials were then applied to the *Ellen MacArthur Foundation* estimate of 600 Mt plastics from virgin feedstocks p/a by 2050.

[115] A ration of 12 Modt to produce 1 Mt plastics was derived from: Saygin et al (2012) *Assessing industrial energy use and CO2 emissions. Opportunities for energy efficiency, biomass and CCS;* Energy Transitions Commission (2018) *Reaching zero emissions from plastics. Consultation paper.* A lower ration of 4:1 was calculated through discussions with members of the CCC's expert advisory group and the Bangor Biocomposites Centre team.

5.2. GHG emissions and sustainability impacts of bio-based plastics

Currently, there is substantial variation in the GHG and sustainability impacts of bio-based plastics. The extent of future benefits compared to fossil plastics are uncertain:

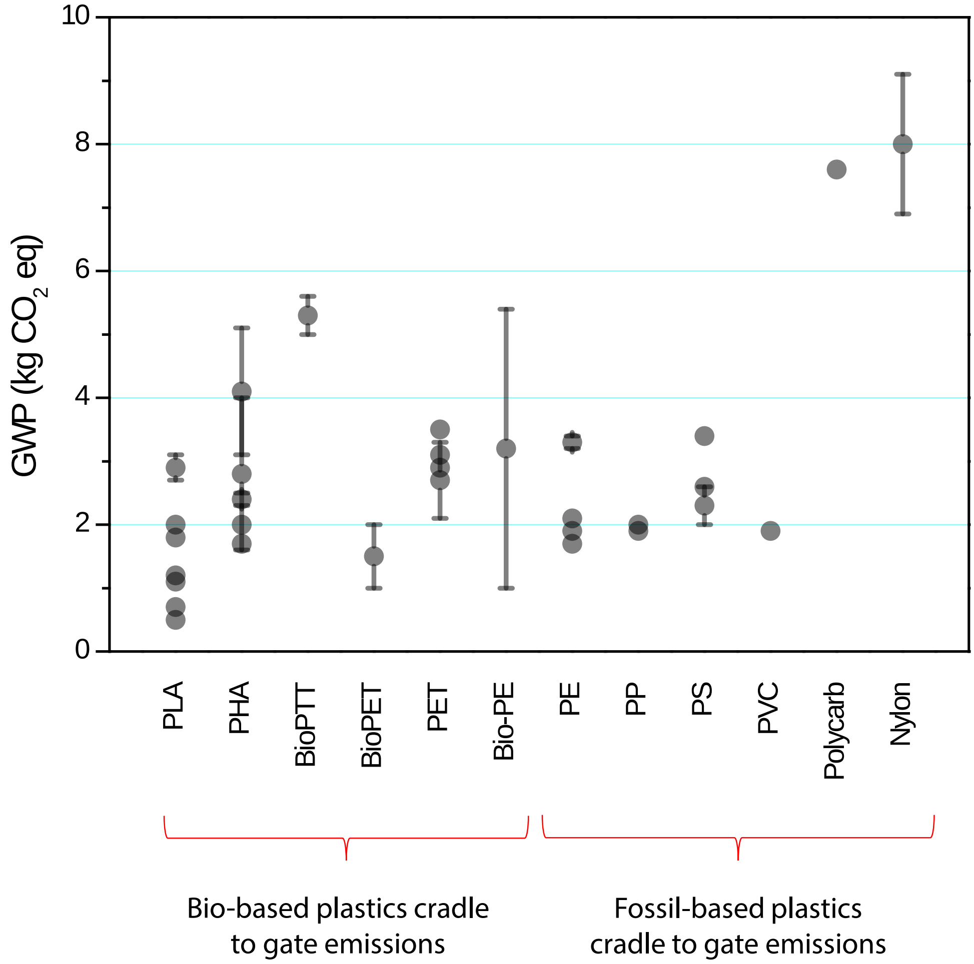
- A review of studies on 'cradle-to-gate' GHG emissions associated with different plastics was undertaken for the Committee by the Bangor Biocomposites Centre (Figure 5.11).[116] This found only limited evidence that bio-based plastics currently deliver emissions reductions compared to fossil-based plastics, although it is possible that if supply chains for bio-based plastics scale up and mature in the future then greater carbon savings could be achieved.
- At the end of a plastics' useful life it may be incinerated or degrade via aerobic processes, releasing CO_2 back into the atmosphere. However the carbon in bio-based plastics is biogenic not fossil in origin. Providing biomass feedstocks are produced as part of sustainable, low-carbon land-use strategies then this release of biogenic carbon can be considered part of the carbon cycle with new plant growth ensuring minimal net additions of GHG to the atmosphere. In contrast the release of fossil carbon into the atmosphere will result in atmospheric GHG concentrations increasing over time.
- In some cases however the end-of-life phases of bio-based plastics could differ from fossil-based plastics. If, for example, a non-degradable fossil-based plastic is replaced by a bio-based plastic that degrades quickly in anaerobic conditions (releasing methane into the atmosphere), this could result in worse overall outcomes for the climate. It will be important that plastics disposal systems mitigate this risk.
- As the amount of bio-based plastics in the economy increases, there will be an increase in the overall amount of carbon sequestered in the product pool. However many plastics are short-lived so any increase in overall levels of sequestered carbon is likely to be limited. This may change in the future if approaches are developed to dispose of plastics in ways that do not release carbon back into the atmosphere, e.g. waste incineration with CCS.
- There is also evidence that in some circumstances bio-based plastics can result in greater life cycle impacts than fossil equivalents in some environmental impact categories such as acidification and eutrophication.[117]

Overall this uncertainty points to the need for further development of supply chains and careful consideration of full lifecycle impacts before substantial amount of limited biomass resources are directed towards bio-based plastics:

- The end-of-life phase is likely to be critical in determining whether substantial GHG emissions reductions can be delivered compared with equivalent fossil-based plastics.
- In line with the evolution of waste management more generally, plastics should increasingly be reused and recycled wherever possible and the use and disposal of biodegradable plastics carefully considered to maximise environmental benefits and minimise emissions.
- The development of a circular economy and the cycling of bio-based plastics through numerous product life-cycles could represent a route to long-lived storage of carbon absorbed from the atmosphere. If CCS technologies are fitted to waste incineration plants, this could allow for the permanent capture and storage of biogenic carbon.

[116] Covering GHG emissions from feedstock production, processing and transportation.
[117] Yates & Barlow (2013) *Life cycle assessments of biodegradable, commercial biopolymers - A critical review.*

Figure 5.11. Cradle-to-gate GHG emissions from the production of bio-based and fossil plastics



Source: Professor Callum Hill, part of Bangor Biocomposites Centre team commissioned by the CCC.
Notes: A wide-range of studies were reviewed as part of this analysis: Heyde (1998), Gerngross (1999), Kurdikar et al. (2000), Akiyama et al. (2003), Vink et al. (2003), Kim and Dale (2005), Patel et al. (2006), Liptow and Tillman (2009), Madival et al. (2009), Vink et al. (2010), Khoo et al. (2010), Gironi and Piemonte (2011), Kendall (2012), Hottle et al. (2013), Yates and Barlow (2013), Tsiropoulos et al. (2015), Broeren et al. (2016). Full references are provided in the bio-based plastics paper published with this report.

Chapter 6: Conclusions

Limiting the increase in global temperature to well below 2 degrees in line with international commitments under the 2015 Paris Agreement requires large increases in the amount of carbon stored in plants and soils. In addition, most pathways for successfully mitigating climate change require some harvesting of this biomass as a route to increasing overall levels of carbon storage and to provide useful low-carbon services (e.g. energy, long-lived products which displace high-carbon materials) in the economy.

Biomass differs from other responses to climate change in two key ways. First, it provides a mechanism to absorb carbon *from* the atmosphere, in contrast to other approaches which focus on the reduction of emissions *to* the atmosphere. Second, it is characterised by the complexity of interactions between land-use, natural ecosystems, the carbon cycle and the energy system. As a result, the risks associated with biomass production and use are substantial. Unless sustainable land management practices are applied and lifecycle emissions carefully minimised, there is the potential for worse outcomes for the climate than ongoing use of fossil fuels, as well as negative impacts across a range of other sustainability issues.

It is in this context that the Committee has undertaken the analysis and drawn the conclusions set out in this report. We have reviewed a wide range of scientific evidence and engaged with stakeholders from academia, Government, industry and the third sector. We were also supported by a specially convened external expert advisory group with expertise across a range of relevant disciplines, which provided challenge an advice throughout the process. Our advice to Government has been developed based on our synthesis of these inputs.

We conclude that biomass, in its broadest sense, will play an important role in decarbonising the UK's economy through to 2050. There is evidence that a range of different biomass feedstocks - including biogenic wastes, energy crops and forestry and agricultural residues - *can* be produced sustainably and in a low-carbon way, but *only if* certain critical criteria are met. Achieving this *in practice* is the fundamental challenge which requires changes to be made to how we manage risks. To 2050, the focus must be on building up carbon stocks in soils and living biomass, alongside further sequestration in buildings and geological stores. Any harvested biomass needs to be used in the most effective way, prioritising those uses which enable long-term carbon storage. That means that current uses will need to change. Our recommendations set out how.

Whilst the evidence base for biomass production and use has improved over the last decade there are still significant uncertainties in some areas. New evidence in the future may challenge the findings we have set out here and require changes to the way that biomass is used to mitigate and respond to climate change. This points to an adaptive approach being required by Government and industry; balancing the risks of failing to develop sustainable biomass supply chains with the risks of significant negative consequences if biomass is produced and used unsustainably.

Recommendations

We have three overarching recommendations, supported by specific, targeted actions, directed at Government, industry and the research community. These recommendations are set out in Box 6.1 and summarised in the following infographic (Figure 6).

Biomass is an integral part of the global carbon cycle

Plant 27,000 hectares of new forests every year in the UK by 2030

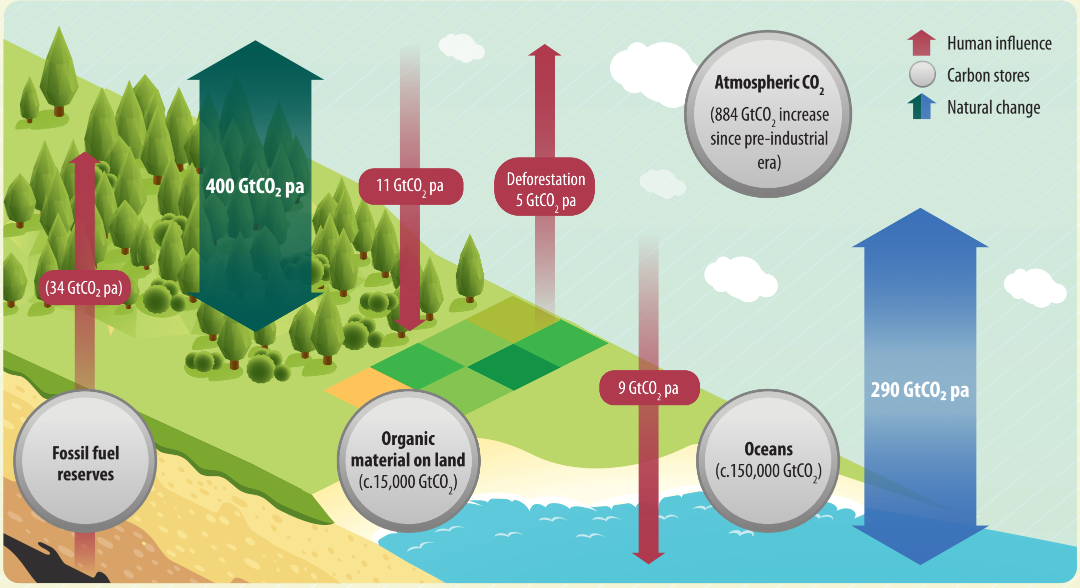
Increase planting of energy crops on lower quality land

Organic wastes: reduce, reuse and recycle, then use what's left for energy

No biodegradable waste to landfill by 2025

The careful management of biomass stocks will play a critical role in limiting the rise in global temperature in the 21st century…

…most pathways for mitigating climate change also require some harvesting of biomass to increase total carbon storage and provide useful low-carbon services (e.g. timber, energy).



Producing biomass in a sustainable, low-carbon way

Harvesting and using biomass *can be* sustainable and low-carbon, but *only if* the following critical criteria are met:

- ✓ Protects or enhances biodiversity, soils and water quality
- ✓ Minimises supply-chain GHG emissions
- ✓ Does not compete with food production and respects land rights
- ✓ Only from forests managed sustainably for a range of products
- ✗ Not from virgin slow-growth, highly-diverse or high-carbon forests
- ✗ No 'mining' of carbon stocks in the landscape
- ✗ Not using residues needed for soil carbon and quality or other existing uses
- ✗ Not producing harmful levels of air pollution when burnt

Stronger sustainability governance for managing risks

Achieving this *in practice* is the fundamental challenge. The UK Government must:

- **Tighten sustainability criteria** based on the latest evidence and drive a race-to-the-top
- **Lead a shift towards high-quality independent monitoring and reporting** (e.g. using satellite data, track-and-trace, better soil carbon monitoring)
- Encourage new supply-chains to **drive up standards globally** (e.g. in developing countries)
- Extend scope of **governance beyond subsidy-schemes** (e.g. trade and development policy, standards, procurement and finance rules)

The long-term role of biomass imports to the UK should depend on the success of these efforts.

How can biomass be used effectively?

In the future, demand is likely to outstrip sustainable supply. Harvested biomass will be used most effectively where it *maximises* the removal and *minimises* the release of carbon into the atmosphere.

- More timber used in buildings **up to ~3 $MtCO_2e$/yr of carbon storage by 2050**
- No new subsidies for large-scale biomass to power plants unless with CCS*
- Use biomass to produce hydrogen, electricity or industrial products whilst sequestering carbon with CCS **up to 65 $MtCO_2e$/yr of UK emissions saved**
- Phase out biofuels in cars and vans in the 2030s
- Plan for up to 10% of aviation fuels as biofuel produced with CCS by 2050

Between now and 2050, the current uses of biomass in the UK need to change:

	Most effective use today	2020s and 2030s	By 2050
Bioeconomy	Wood in construction	Wood in construction, potentially other long-lived bio-based products (within circular economy)	
Buildings	Biomethane, local district heating schemes and some efficient biomass boilers in rural areas		Only very limited additional use for buildings heat: niche uses in district heat and hybrid heat pumps
Industry	Biomass use for processes with potential future BECCS** applications		BECCS in industry alongside other low-carbon solutions
Power	Ongoing use in power sector in line with existing commitments or small scale uses	Demonstration and roll out of BECCS to make H_2 and/or power	Biomass used for H_2 production or power with CCS
Transport	Liquid biofuels increasingly made from waste and lignocellulosic feedstocks	Liquid biofuel transitioning from surface transport to aviation, within limits and with CCS	Up to 10% aviation biofuel production with CCS

Maximising abatement means using biomass to sequester carbon wherever possible (opportunities to do this will increase over time)

* Carbon Capture and Storage **Bioenergy with Carbon Capture and Storage

Box 6.1. Recommendations

1. Build up the UK's forest and land carbon stores and, at the same time, increase the supply of sustainable harvested biomass from UK sources.

- Deliver the current ambition to increase the annual rate of forest planting from 9,000 hectares per annum on average in the last five years, to 20,000 hectares p.a. by 2020 and 27,000 hectares p.a. by 2030. Explore the potential for this to be increased further by 2050. This will require new strategies in England, Scotland, Wales and Northern Ireland to address barriers and incentivise planting.
- Undertake more work to deliver the commitment to bring 66% of England's forests back under active management (from 59% currently), and seek to extend the ambition where the evidence supports this (*note 1*).
- Introduce policies to increase planting of perennial energy crops on lower-grade agricultural lands where this can contribute to increasing soil carbon and deliver other ecosystem benefits. This will require clear signals of Government commitment, planting rate targets and a number of economic, policy and regulatory barriers to be addressed.
- Build rewards for carbon sequestration in forests and soils and other ecosystem services such as alleviation of flood risk into the UK successor to the Common Agricultural Policy. Energy crop production should be included in this rewards scheme where it delivers these wider benefits and provided is not already incentivised through other subsidies.
- Ensure food and other biodegradable wastes are collected separately in all areas across the UK and then used in line with the waste hierarchy (i.e. prioritising reuse and recycling). By 2025 no biodegradable wastes such as food, paper, card, wood, textiles and garden waste should be sent to landfill. Agricultural residues could also play a long-term role provided soil fertility requirements are met and other uses satisfied.

2. Improve UK and international governance over biomass feedstocks. The long-term role of biomass imports to the UK must depend on the success of these efforts.

- As a general rule, unsustainable or high-risk feedstocks (e.g. feedstocks from primary, high-carbon, highly biodiverse or slow-growing forests) should be regulated out and best practice encouraged (e.g. use of organic wastes and genuine agricultural or forestry residues (*note 2*), certain perennial crops grown on marginal land). BEIS and DfT should update sustainability criteria to reflect the growing evidence base in this area (building on criteria recently developed by Forest Research). They should also assess better ways to incentivise a 'race to the top' in lifecycle greenhouse gas emissions.
- BEIS and DfT should address the current weakness in the criteria on preserving carbon stocks in existing forests, by requiring that any long-term changes in forest carbon stock at landscape scale are included in the calculation of the climate impacts of bioenergy systems. The general principle is to rule out feedstocks sourced from areas with falling carbon stocks. In applying the principle, account should be taken of appropriate spatial scales, the CO_2 fertilisation effect and relevant exclusions, for example in relation to diseased trees (*note 3*). BEIS and DfT should also explicitly rule out the harvest of whole forest tracts exclusively for energy uses, in line with best practice as applied by the Green Investment Group (*notes 4 and 5*).
- Government (BEIS, DfT, DfID, DIT, FCO) should assess ways to encourage new supply-chains (e.g. in developing countries) in addition to sourcing from low-risk regions (*note 6*): through wider trade and development activities, and through continued efforts to improve multilateral governance. It should extend the scope of governance beyond the current subsidy-linked criteria into a broader

Box 6.1. Recommendations

range of policy levers (e.g. to standards, procurement rules, trade and development policy – following the forestry governance example) (*note 7*).

- The UK should lead a shift towards using improved monitoring techniques (e.g. satellite imaging, track and trace, improved soil carbon monitoring) and geographically-specific datasets. There should be high-quality independent monitoring and reporting of domestic UK stocks and supply chains at an aggregate level (and mapping these to other data such as international forest inventories).
- Standards should be designed so as to ratchet up over time, with regular review points.

3. Ensure biomass is used in the most effective way. This means current uses of biomass will need to change.

- BEIS, Defra, DfT and HMT must design biomass policies and support mechanisms to support long-term best use and to ensure the amount of biomass used does not exceed sustainable levels of supply.
- MHCLG should develop new policies to support a substantial increase in the use of wood in construction. This will need to focus on overcoming a range of cultural, skills and financial barriers in the construction sector. A new mechanism is needed to incentivise and drive whole-life carbon savings for new buildings. This should cover embodied emissions and carbon sequestration.
- BEIS and HMT should develop support schemes (including carbon pricing) to ensure that removing CO_2 from the atmosphere and storing it for long-time periods is valued alongside emissions reductions.
- BEIS should support the development of the key enabling technologies for carbon capture and storage (CCS) and gasification.
- Over the next decade Government policies should only support biomass use where this a) provides cost-effective abatement whilst avoiding 'lock-in' to sub-optimal uses, and/or b) develops key technologies and sustainable supply chains. This means:
- Do not provide further policy support (beyond current commitments) to large-scale biomass power plants that are not deployed with CCS technology.
- Phase out biofuel use in cars and vans in the 2030s (*note 8*). The RTFO mechanism should focus on developing key technologies that enable the use of organic wastes and other sustainable feedstocks.
- Support deployment of aviation biofuels up to 10% of total aviation fuel demand by 2050, ensuring all aviation biofuels are produced with CCS as soon as this technology is available. Facilitate the transition to aviation uses by achieving more of the 2030 RTFO target through aviation fuels.
- In industry, work towards a technology mix based on low-carbon hydrogen, fossil-fuelled CCS, BECCS and electrification. This means no long-term use of biomass as a fuel, unless in combination with CCS.
- Limit support for bioenergy use in buildings to biomethane produced from anaerobic digestion and other niche uses (as part of hybrid heat pumps systems in hard to treat off-gas homes, local combined heat and power systems and small-scale district heat networks) - whilst minimising air quality impacts.
- Support for the bioeconomy should reflect the current uncertainty and variability in lifecycle greenhouse gas emissions of emerging uses of biomass such as bio-based plastics. Policy should

Box 6.1. Recommendations

balance support for the development of these new products with recognition that they may not ultimately be in line with long-term best-use. A concerted effort will be needed to build sustainable supply-chains with efficient conversion processes and end-of-life material recovery and reuse.

Notes: 1.The 67% target for bringing woodlands in England back under active management was set to be achieved by 2018, under the Defra (2013) *Government Forestry and Woodlands Policy Statement*. The 59% estimate is given at 31st March 2018 in Forestry Commission England (2018) *Corporate Plan Performance Indicators 2018*.
2. i.e. genuine residues that are not needed for soil health and fertility or maintaining existing soil carbon stocks, and which would have otherwise been discarded.
3. Scale is important – we typically assume that this would be at the landscape or 'wood-basket' level (i.e. the area which a mill sources its product from) rather than country-level. This could be supported by other measures such as requiring owners take steps to restock and encourage natural regeneration following a thinning.
4. This is based on a requirement set by Green Investment Group (formerly UK Green Investment Bank, now part of Macquarie Group), which requires funded projects not to include biomass from forest tracts harvested exclusively for energy uses (with certain exclusions, e.g. for diseased trees). The requirement aims to ensure that forest management (such as felling decisions and determination of rotation length) continues to be driven by demand for higher value timber products rather than demand for bioenergy. Green Investment Group also have a requirement to source only from areas with stable or growing carbon stocks.
5. The second part to our recommendation recognises the evidence that where used solely for energy, over 'climate policy relevant timescales (30 years, and in most cases significantly less)', using all of the stemwood from forest directly for energy leads to net increases in GHG emissions (see Forest Research (2018) *Biomass Carbon Impacts*, and Matthews, R., et al (2014) *Carbon Impacts of Using Biomass in Bioenergy and Other Sectors: Forests*). It does not rule out using all thinnings (including for example diseased trees, when removed as part of sustainable forest management).
6. Country-level risk assessments are used in both forestry and bioenergy governance as part of a risk-based approach.
7. See EU timber governance (EU FLEGT).

Committee on Climate Change
7 Holbein Place
London
SW1W 8NR

www.theccc.org.uk

@theCCCuk