Biomass for energy

A framework for assessing the sustainability of domestic feedstocks

MAY 2022

KEY FINDINGS AND RECOMMENDATIONS

Defining a role for biomass in a rapidly changing economic, policy and technology landscape

Domestic biomass presents opportunities for providing sustainable and secure sources of energy - up to 4% of UK primary energy - but also has unique risks that need managing

Over the past decade, the environmental, economic, and social context of energy and climate policy has changed radically. There has been a significant fall in the cost of non-biomass renewable energy and the emergence of new technologies that will compete in biomass's traditional space.

However, defining biomass sustainability has remained challenging due to the inherent complexity and uncertainties of the systems involved, as well as differences in the methodologies used to assess impacts, trade-offs, and thresholds. In particular, concerns over unsustainable levels of land use remain largely unaddressed - as well as the contested 'carbon neutral' status of biogenic carbon dioxide released from biomass combustion. The methods and criteria used by policymakers for assessing biomass sustainability do not adequately take into account these key concerns.

There is good agreement between studies on the levels of domestic biomass 'waste' and 'residue' feedstocks which are likely to be available in the UK in coming decades. However, there is significant divergence in the quantities of biomass that these studies say can or should be produced from dedicated land use (i.e. energy crops and forestry stemwood).

Meanwhile, carbon dioxide removal has become a potential third 'use' of biomass alongside energy and biomaterials. Bioenergy Carbon Capture and Storage (BECCS) could become the primary rationale for promoting biomass-based energy systems as arguments over the technology's energy security and climate mitigation benefits fall away due to the performance and availability of alternatives.

Given the relative cost and risks of biomass – and the increasing attractiveness of other renewable alternatives – it is likely biomass will continue to rely on market demand created by policy.

Land-intensive bioenergy systems face a significant risk of being seen as a 'legacy' fuel by 2050. For this reason it will be critical to ensure the UK avoids excessive physical, institutional, and behavioural 'lock-in' to these technologies in the 2020s.

Key findings

Our analysis found that many types of biomass pose high or very high risks to nature or the climate, while others are moderate or lower risk. Based on our analysis we recommend priority is given to moderate and lower risk types of biomass while those with higher risk levels have upper limits or quotas applied.

Up to 4% of primary energy supply could be provided from low and moderate risk domestic biomass feedstocks in 2050 compared to 7% in the Climate Change Committee's Balanced Net Zero Pathway.

Key recommendations

- The 2022 UK Biomass Strategy* should seek to develop a risk-based biomass sustainability framework similar to the one presented in this report. It should be applied to all feedstock categories consistently and consider a much broader set of sustainability risks (in particular excessive land use and competition with non-energy users of biomaterials).

- For the feedstocks assessed as being 'highest risk' explicit usage quotas should be established to ensure that potential benefits are balanced against environmental and social risks. This could take the form of a UK 'land budget' to complement the UK carbon budget.

- Significant users of biomass should be required to report in detail on the precise nature of biomass being used, with greater chain-of-custody and transparency for feedstocks. Learnings from 'due diligence' requirements on deforestation within the UK Environment Act 2021 should be drawn upon to develop stronger requirements on due diligence of biomass feedstocks, so as to reduce risks identified in this report.

- The complete accounting of the greenhouse implications of biomass should be included within this framework – including full accounting of biogenic emissions. Feedstocks with long carbon payback periods and those that do not deliver energy aligned to sector 1.5°C emissions pathways should be not be incentivised.

- The Biomass Strategy should explicitly explore the potential of different biomass sources to deliver energy security and independence, reducing reliance on imports and our overseas footprint. Biomass systems that are highly dependent on imported raw materials are unlikely to deliver significant energy security dividends at the scales they are used, as well as posing significant challenges to sustainability monitoring.

- The government should seek to incentivise energy demand reduction as a priority, alongside innovation and research into new technologies that compete against biomass. Low carbon, sustainable negative emissions technologies should also be incentivised to avoid bioenergy carbon capture and storage overreliance.

*The Department for Business, Energy & Industrial Strategy is due to publish a new strategy in 2022

Background

Bioenergy is energy produced from renewable, biological sources, such as biomass. It covers a range of traditional and modern technologies including liquid biofuels for transport, anaerobic digestion and combustion of wood (IRENA, 2022).

Globally, approximately three-quarters of renewable energy use involves bioenergy, including a significant amount of traditional biomass use. Bioenergy and waste currently make up more than 10% of the total UK primary energy supply and are the largest source of renewable power after wind generation. Approximately a third of total bioenergy feedstock and fuel supply is imported (BEIS 2022).

This report, which is aimed at policymakers, summarises the key findings and recommendations of research commissioned by the RSPB to assess the availability of sustainable domestic biomass - and proposes improvements to how biomass should be incentivised and controlled by policymakers. This research focusses on bioenergy produced from domestic UK sourced solid and gaseous biomass.

The work was commissioned ahead of a new Biomass Strategy, that will set out in detail how the UK Government believes biomass can best contribute towards net zero across the economy.

A longer technical report is available separately.

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INTRODUCTION

Key challenges in defining biomass sustainability

Four aspects of biomass systems that need consideration by policymakers

Biomass systems have well documented potential for both positive and negative social, economic, and environmental impacts. These include impacts on climate, water, biodiversity – and wider resource competition with other sectors.

Defining 'sustainability' of feedstocks is extremely challenging due to the inherent complexity of these systems - and differences in methods, criteria and assumptions used when comparing or assessing their impacts using tools such as life cycle assessment.

As a result, published estimates of 'sustainable' biomass supply can differ widely. The reality is that these uncertainties place limitations on how precise we can be about the availability of biomass and land resources - or pinpoint when detrimental impacts outweigh benefits. However these aspects do need to be taken into account when designing policy.

We identify four aspects of biomass systems and sustainability assessment approaches that contribute to significant uncertainty and need integrating into any assessment or incentivising of biomass feedstocks.

Land use thresholds and constraints: how much is too much?

Many forms of bioenergy are highly land intensive. Compared to solar PV, the amount of electricity that can be produced from a hectare of land from biomass is up to 100 times less. As land is limited, land-intensive bioenergy technologies could transform lands at a scale that is, in the absence of protections, fundamentally unacceptable.

The IPCC stresses the risks of side effects that could arise from inadequate control of bioenergy implementation.

Measurement of the land use efficiency of different bioenergy feedstocks, per unit of energy delivered, does not address the core question in bioenergy sustainability of how much land in aggregate should be used for different purposes – for example food, energy, materials, carbon removals or nature. While the use of concepts such as 'indirect land use change' have attempted to integrate the impact of crop expansion into bioenergy climate change indicators, these measures are uncertain and do not adequately address the question of 'how much is too much?'.

For these reasons the establishment of clear 'quotas' or a 'budget' for the most land-intensive bioenergy sources is needed. This is the only way to ensure that bioenergy – or indeed bioenergy carbon capture and storage – does not transgress ecological limits.

Complex systems: avoiding unintended consequences

The relative environmental merit of alternative bioenergy production pathways has been the subject of many studies and much debate. Most studies have used the Life Cycle Assessment (LCA) method to quantify the environmental burdens. The methodology has several well-known limitations.

Bioenergy systems appear highly susceptible to these shortcomings of the LCA approach and to differences in interpretation. This susceptibility arises because of the multi-scale and complex nature of biomass production and supply chains.

Bioenergy technologies can exhibit substantial side-effects including land use change, food and water competition and ecosystem disturbances. A full understanding of bioenergy side-effects is often missing from life cycle assessment studies.

For this reason, biomass sustainability cannot be defined purely in terms of individual LCA-based indicators applied at feedstock level. Greater nuance is needed and the use of more defined rules. LCA is only one of the tools to assess technologies on their (environmental) performance. Alternative assessment approaches should be used in a complementary way, such as a broader risk assessment approach explored in this report that assess wider economic and environmental risks of biomass use (e.g., resource and land competition).

Biogenic carbon accounting: is biomass carbon neutral?

One of the key areas of debate in bioenergy policy remains the accounting of biogenic carbon dioxide emissions from combustion of biomass.

One of the most well known examples of this in the UK is the conversion of Drax power station from the use of coal to be a significant user of wood pellets (in 2021 Drax used almost 8.5Mt of woody biomass in its operations to produce approximately 12% of the UK's renewable electricity).

Drax describes its energy as carbon neutral but ignores the biogenic CO_2 emissions (the "stack emissions") which are released when woody biomass is burnt for energy as well as upstream biogenic CO_2 emissions.

The IPCC explicitly warns against representing biomass energy as producing zero emissions and researchers point out the time lag associated with biogenic emissions and the re-growth of forests can be significant - especially given the short timescales needed for rapid decarbonisation. Conversion of land with high carbon stocks for bioenergy leads to very long carbon payback periods making them less effective at delivering timely greenhouse gas mitigation.

For these reasons, any framework for prioritising biomass feedstocks should incentivise those that have short payback periods (i.e. exclude systems that rely on stemwood).

Shifting contexts: the "best" option will change over time

Finally, the sustainability of the supply of a biomass source will change over time. Feedstock sustainability assessments need to be updated regularly and plans should anticipate changes in supply, competing uses over time, climate change adaptation and resilience. Building an energy system around current 'sustainable' supply and use of biomass could potentially lock-in the energy system into an undesirable pathway in the long term.

RENEWABLE ENERGY SOURCES

Biomass is now a major source of renewable energy

The UK uses a variety of sources including plant biomass, landfill gas and wood waste

Currently, all bioenergy sources make up 11% of the total UK primary energy supply. Since 2010 there has been a reduction in the reliance on oil and coal - with a slight increase in gas use. Over this period, we have also seen a growth in bioenergy supply (albeit modest in terms of the overall supply). Primary electricity - including nuclear, solar, wind and hydro grew by 25% over this period.

In 2020, solid biomass contributed 33% of total renewable energy use, with approximately two-thirds being used in electricity generation and the remaining to produce heat (see Figure 1, right, which shows biomass sources considered in this report highlighted in dark blue on the left hand side). It is worth noting that biomass contributes a much larger share of primary energy supply due to significant conversion losses when combusting biomass for electricity generation.

Figure 1: UK renewable energy flow chart, 2020

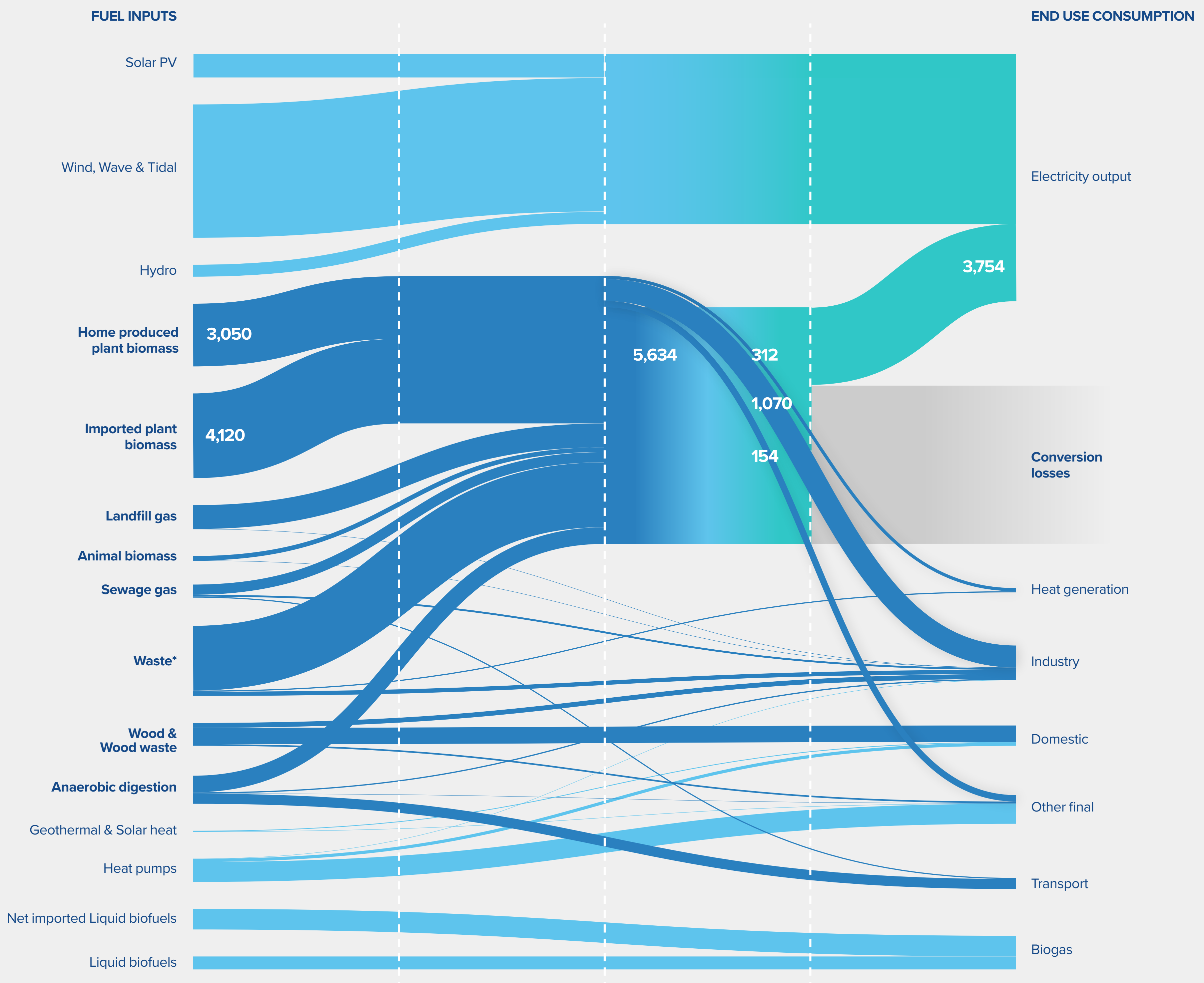


Diagram adapted from BEIS (2021a) Digest of UK Energy Statistics Annual data for UK, 2020
**Original waste figure adjusted to represent biodegradable fractions only in this chart*

BIOENERGY GROWTH

Bioenergy supply has more than doubled since 2010

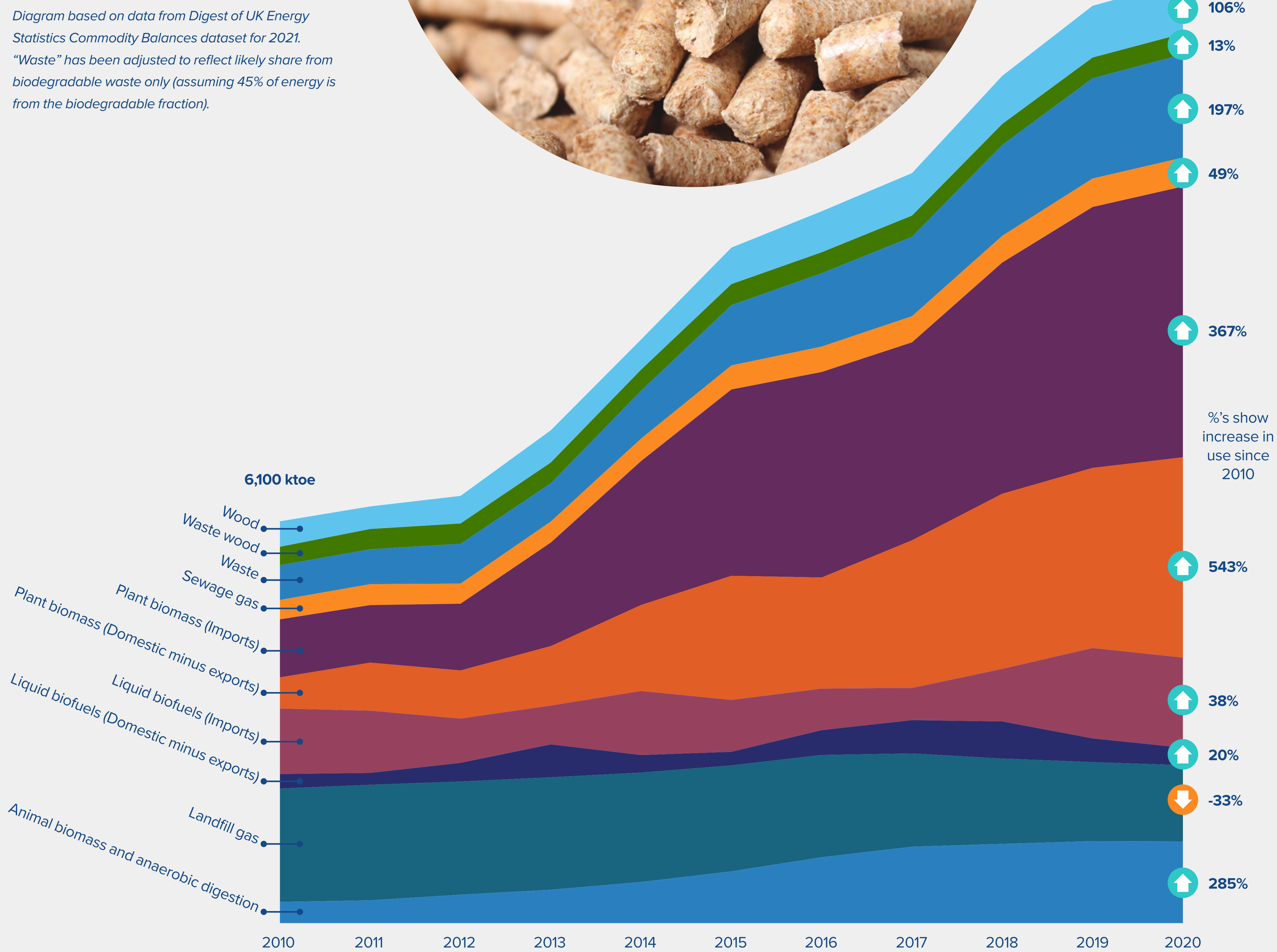
Most of the growth was from the combustion of domestic and imported plant biomass in electricity generation

Between 2010 and 2020 the primary supply of bioenergy more than doubled from c. 6,000 kilotonnes of oil equivalent (ktoe) to more than 14,000 ktoe (see Figure 2, right). Most of this growth was from increases in domestic and imported plant biomass (wood pellets produced from forestry systems).

Over the same time period there was also notable growth in energy from waste and anaerobic digestion of animal waste. Only landfill gas reduced in importance.

Figure 2: Change in bioenergy sources, 2010-2020

Diagram based on data from Digest of UK Energy Statistics Commodity Balances dataset for 2021. "Waste" has been adjusted to reflect likely share from biodegradable waste only (assuming 45% of energy is from the biodegradable fraction).

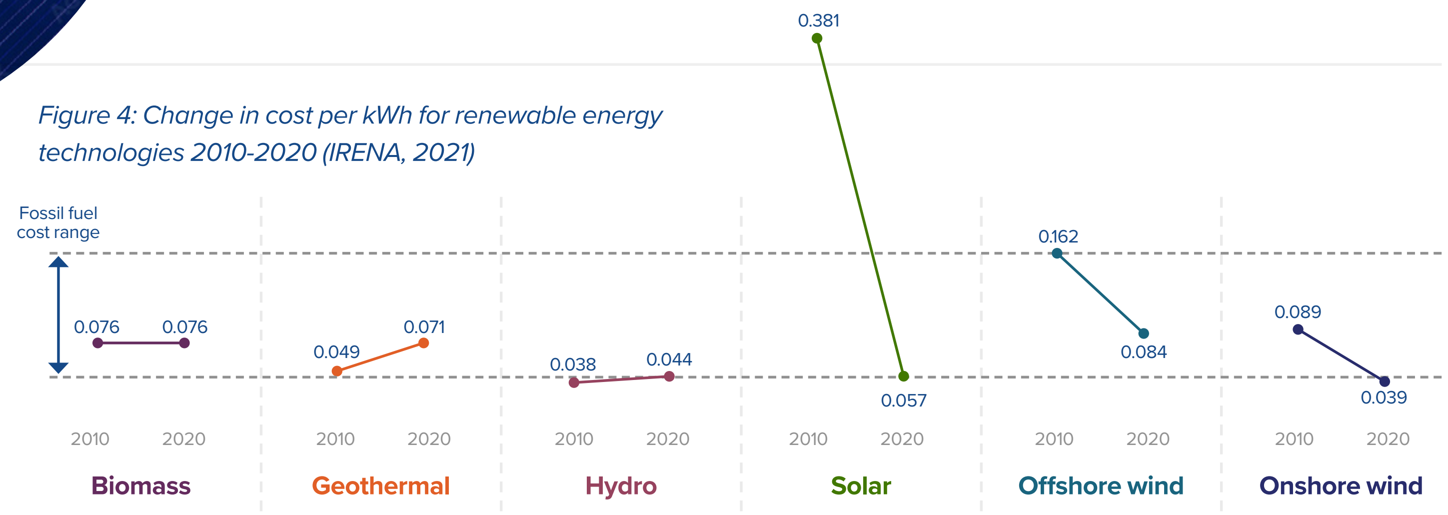


A DECADE OF CHANGE

The shifting energy and climate context affecting biomass

Five developments since 2011 impacting the case for biomass

Figure 4: Change in cost per kWh for renewable energy technologies 2010-2020 (IRENA, 2021)

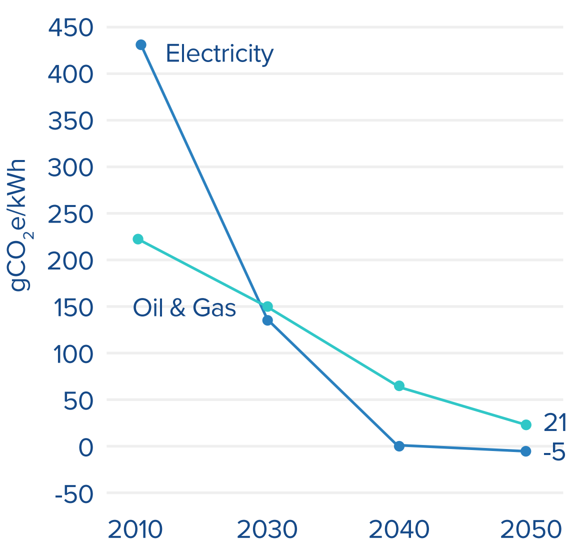


Deep decarbonisation needed in the short term

The science regarding the need to decarbonise the economy rapidly and deeply by mid-century has strengthened (IPCC, 2022). Ultimately energy systems need to decarbonise by >90% to be considered sustainable (see Figure 3).

Sustainable biomass should deliver energy in line with carbon intensities that are aligned to 1.5°C emissions pathways (see Figure 3 below). Those emissions reductions should be delivered as quickly as possible i.e., they should have a short ‘carbon payback period’.

Figure 3: Paris-aligned electricity and fuel carbon intensities (Transition Pathway Initiative, 2022)



‘Net zero’ and ‘negative emissions’ in focus

Since 2011, the concept of “net zero” has become established in policy and corporate climate commitments. The adoption of the net zero concept has focused attention on carbon dioxide removals (CDR) and associated ‘negative emissions technologies’ - ranging from existing “nature-based solutions” (such as afforestation/reforestation) to emerging carbon capture and storage (CCS) technologies.

Most emission pathways that are compatible with the temperature goals of the Paris Agreement are heavily reliant on negative emissions technologies, especially biomass energy with carbon capture and storage (Gough et al 2018).

Carbon dioxide removal has now become the third ‘use’ of biomass alongside energy and biomaterials. The implication of this trend is that BECCS could become the primary rationale for promoting biomass-based energy as arguments over its energy security, climate mitigation and energy storage benefits fall away due to the performance and availability of other renewable alternatives. This is despite significant concerns over CDR technologies (EASAC, 2022).

Cost and availability of competing technologies

There have been significant reductions in the price per kWh of renewable energy technologies (see Figure 4, above). Between 2010 and 2020, solar PV cost per kWh fell by more than 80%. It is expected to halve again by 2050 (Energy Transitions Commission, 2021).

Since 2010, biomass energy costs per kWh have remained the same. Some researchers see this trend continuing, with many current applications of bioenergy being uncompetitive against clean electrification options (Energy Transitions Commission, 2021).

In addition to cost reductions in competing power generation technologies, the last ten years have seen a similar revolution in battery storage technologies that is likely to further disrupt power system planning and influence the relative attractiveness of biomass (Reid et al 2020).

For these reasons it is likely biomass will rely on market demand created by policy (Vivid Economics, 2019). Overall, land-intensive bioenergy systems face a significant risk of being seen as a ‘legacy’ fuel by 2050 – and so it will be critical to avoid physical, institutional, and behavioural lock-in when setting biomass policies in the 2020s.

Rise of the circular economy principles

Since 2011 the concepts of the ‘circular economy’ and the ‘bioeconomy’ have gained significant policy and private sector interest. Circular economy principles promote the use of renewable materials and seeks to keep them circulating in the economy.

Satisfying global material use alone in 2050 could use all available sustainable biomass – even after assuming a significant reduction in biomaterials demand through recycling, re-use, etc. (Energy Transitions Commission, 2021).

Given that competition for renewable materials is likely to increase in the coming decades, it will become increasingly important to prioritise the recycling and reuse of biomaterials – and clearly establish energy recovery as the least desirable option (Terlouw, T 2021).

The quantity of bioenergy we use will depend, in the end, on the priority given to energy uses versus other products obtained from these finite resources. Sustainable biomass for energy should only be from those sources with low risk of competing against alternative uses - both food and non-food. Even though this concept is not new the principles need to be more actively supported by policymakers to ensure alignment across different policy areas.

Energy security and independence concerns

The case for biomass has been partially made, in the past, on the potential for it to contribute to a country’s energy security, particularly in the context of energy baseloads and the intermittency of some other renewables like solar and wind (Scope, 2015).

Russia’s invasion of Ukraine has put the topic of food and energy security firmly back on the agenda of business and policymakers.

In the context of discussions on energy security and import dependence, it is worth noting that the UK has a comparatively poor domestic biomass resource-base compared to its relative share of global GDP and energy demand. It is logical to assume that this will place constraints on the degree to which domestic bioenergy sources can offer significant energy independence benefits. It should also be noted that any effective ‘security’ measures must rely on mitigating climate change: the expansion of highly emitting fuel sources would endanger long term national security even if energy demands are met in the short term.

BIOENERGY WITH CARBON CAPTURE AND STORAGE (BECCS)

BECCS could become the main case for expanding biomass use

However, rather than framing the technology as ‘needed’ to reach climate goals we need to establish what can be sustainably supplied within ecological limits

Bioenergy Carbon Capture and Storage (BECCS) is the capture and permanent sequestration of biogenic CO_2 when biomass is processed for energy (e.g., combusted within a power plant). BECCS can theoretically result in net negative greenhouse gas emissions when the amount of CO_2 extracted from the atmosphere (and the permanent storage) exceeds emissions from the whole life cycle of BECCS systems and feedstocks.

Despite this potential, the IPCC’s AR6 Working Group II highlighted major risks of bioenergy and BECCS, such as threats to biodiversity, water, food security and livelihoods.

Within our framework we acknowledge BECCS as a potential end-use technology for biomass and one which could drive significant increase in demand for biomass. However, we argue that – beyond improving the carbon balance of some feedstocks – a sustainable supply of a biomass resource must be assessed independently from its end use. Rather than framing these technologies as ‘needed’ to reach climate goals we need to establish what can be sustainably supplied within ecological boundaries and then work to meet temperature goals by other means within these constraints (as we do on a number of other sustainability issues, such as human and animal welfare). This principle is supported by NGOs and international climate experts - for example, the IPCC states that “pathways that feature low energy demand show the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and SDGs (very high confidence)”.

While some level of atmospheric carbon removal is necessary and can be achieved in synergy with other social and environmental goals, the deployment of negative emission technologies at a large scale is subject to several uncertainties and constraints, including potential adverse effects on the environment and trade-offs with other Sustainable Development Goals.

For this reason, we recommend the establishment of clear ‘quotas’ or a ‘land budget’ for land-intensive bioenergy technologies, such as BECCS. This is the only way to ensure that bioenergy carbon capture and storage does not transgress ecological limits. The use of quotas for high risk biomass sources is explored in the next section.

Current approaches to defining biomass sustainability in policy

Biomass sustainability is already assessed within various policy areas. An example of this is the approach taken in the UK’s Renewables Obligation laws. The Renewables Obligation and versions in devolved administrations are designed to incentivise large-scale renewable electricity generation in the UK. For example, all solid biomass and/or biogas stations ≥1MW must report against and meet “land” and “greenhouse gas” criteria to be eligible for Renewables Obligation Certificates. For woody materials the land criteria could be met by sourcing materials produced using the Forest Stewardship Council (FSC) certificate scheme, Programme for the Endorsement of Forest Certification (PEFC) certification scheme, the Sustainable Biomass Program (SBP) or by bespoke evidence compiled by the generator. For non-woody materials the feedstock must not have been sourced from several types of land that have high conservation or carbon stock value (e.g., land that was primary forest any time after 2008). The greenhouse gas criteria set thresholds of environmental performance that different feedstocks must meet, but this only covers the greenhouse gases generated in transport and processing of the material, not biogenic emissions released when it is combusted. By limiting sustainability criteria to LCA-type indicators and basic land exclusions/management requirements, current approaches to defining biomass sustainability do not consider broader system risks and impacts such as land and resource competition.

METHODOLOGY

Framework for assessing and managing biomass sustainability risk

A consistent approach to ranking land, resource and climate mitigation risk

A framework for rating biomass sustainability was developed that draws upon the findings and conclusions outlined in previous sections. Rather than relying on a preference expressed via a hierarchy or by using a limited number of life-cycle based indicators to assess sustainability we propose an approach that assesses biomass sustainability risk and then uses the results of this assessment to identify differential controls for each feedstock based on their risk level.

The framework consists of a set of qualitative and quantitative criteria that can be applied consistently to all feedstock types. The criteria presented in this report could be further developed and refined if adopted by government and industry. The approach focuses on scoring feedstocks against the four areas of concern flagged in our research (see table, right). Namely that more sustainable biomass can be defined as material that exhibits the following characteristics: has low land competition risk; has low resource competition risk; delivers additional sustainability benefits (or avoids other sustainability risks); delivers high climate mitigation effectiveness over a short time horizon.

Criteria and description	High (3)	Moderate (2)	Low (1)
Land competition risk The degree to which feedstock production drives additional land use and so risks (indirect) land use change	Feedstock is primary economic output of land-based production system	Feedstock is by-product or residue of land-based system. Product has economic value.	Feedstock is waste product of land-based system – or not derived from land-based production system. Feedstock has no economic value to producer
Resource competition risk Degree to which feedstock is used by competing industries and sectors	Feedstock is input to significant and/or rapidly growing non-energy sector use (e.g., construction, bioplastics, pharmaceuticals, etc.)	Feedstock is used by non-energy sector – however these are relatively low economic value	Biomass is not currently used by other non-energy sector as input
Wider sustainability risk Degree to which feedstock production impacts on biodiversity and other environmental and social development goals	Feedstock production or use negatively impacts on other sustainable development goals (e.g., biodiversity, air pollution, local communities)	Feedstock production has negligible additional environmental of social impacts	Feedstock production has potential additional sustainable development benefits
Climate mitigation risk Degree to which feedstock carbon intensity aligns with Paris Agreement transition over short term.	Carbon intensity not aligned to 2°C or 1.5°C energy pathways (> 20.3gCO_2e/MJ) or has long term biogenic carbon payback (i.e., >=20 years)	Carbon intensity aligned to 2°C emissions pathway for 2050 (20.3gCO_2e/MJ) and biogenic CO_2 has short- or medium-term pack back (<20 years, > 5 years)	Carbon intensity aligned to 1.5°C emissions pathway for 2050 (5.9gCO_2e/MJ) and biogenic CO_2 has short payback (i.e., < 5 years)

Fifteen feedstock types assessed ...

Short rotation forestry Trees that have reached a size of typically 10-20 cm diameter at breast height. This usually takes between 8 and 20 years.
Stemwood The wood of the stem of a tree. Includes wood in main axes and major branches. See note below on 'whole tree thinnings'.
Landfill gas Gas that is produced under anaerobic conditions in a landfill from breakdown of biodegradable waste materials.
Renewable fraction of wastes The fraction of energy produced from waste incineration that can be classed as renewable (i.e. the organic element).
Biogas from food waste Food that was originally meant for human consumption but for various reasons is removed from the human food chain.
Waste wood Wood, which is not virgin timber (that is, wood that has been used for any purpose) and associated residues such as off-cuts.
Biogas from sewage sludge Sewage sludge is a semi-solid residual, or by-product, arising from the treatment of municipal wastewater.
Biogas from livestock manures Mostly derived from animal faeces, urine. Normally blended with straw and energy dense inputs e.g. maize silage.
Arboricultural arisings The cut wood left after tree surgery or conservation-management activities. May be left on site, burnt, chipped, logged, etc.
Sawmill co-products Sawmills recover ~50% of the input material as sawn product, with the balance being coproduct (bark, sawdust, and woodchip).
Forestry residues Forestry residues are a by-product from forest harvesting- consisting of branches, leaves, bark, and other portions of wood.
Dry agricultural residue Agricultural residues from crop production - most frequently straw in the UK
Marine resources Macro-algae could also be used in anaerobic digestion plants to produce biogas for combustion or production of biomethane
UK perennial energy crops Crops which are grown for combustion. Species such as willow and poplar to 'grassy' energy crops such as Miscanthus.
Biogas from crops A plant grown for use in the generation of energy or the production of fuels such as bioethanol.

Thinnings: an 'edge' case requiring careful controls

Whole tree thinnings are included in the 'Forestry residues' category rather than 'Stemwood'. While thinning can be beneficial for biodiversity and an inevitable co-product of a well managed forest system, there is evidence that bioenergy demand can stimulate excessive thinning and have a negative climate impact (e.g. Brack D. et al., 2021; Buchholz et al. 2021; SELC, 2022). For this reason, it is critical that the definitions and requirements set for forestry residues and thinnings mitigate the risk of their unsustainable use.

RESULTS

Fifteen types of biomass feedstock were ranked from low to high risk

A wide variety of risk levels and issues were identified by applying the consistent scoring methodology

The application of the risk scoring approach resulted in a range of feedstock sustainability risk ratings – from low to high (see table, right). The lowest risk feedstocks were landfill gas and renewable fractions of waste. The highest risk feedstocks were stemwood combustion and biomass from crops. High scores were due to land and resource competition risks posed by these feedstock types. A detailed summary of one of the feedstock scores – dry agricultural residues – is shown in the table below. On first view, agricultural residues such as straw might be considered a waste and so present negligible sustainability risk if used for energy production. However, straw is a co-product of crop production and can have significant commercial and practical value to farmers. Additional demand for straw for bioenergy use is therefore likely to lead to some additional pressure on land use.

These residues can also be used as inputs to other processes higher up the circular economy hierarchy e.g., fodder for animal feed, animal bedding, and soil improvement. If residues are used for bioenergy, then this will result in replacement of these materials with inputs from other sectors.

Removal of residues can also result in wider environmental impacts. For example, straw removal can lead to higher aquatic eutrophication, due to nitrate leaching and emissions from the manufacturing process of the compensating nitrogen fertilisers.

The life cycle emissions of straw (excluding biogenic CO_2) range from 6 to 18gCO_2e/MJ. This is classed as aligned to a 'Well Below 2°C' carbon intensity for the energy sector. The feedstock has the benefit of having a very short biogenic CO_2 cycle (i.e. CO_2 is sequestered and used within months).

Overall, the considerations above placed agricultural residues in the 'high risk' group. This means they warrant tighter controls in their use for bioenergy, as excessive consumption could have significant unintended consequences.

Example: Dry agricultural residues (e.g. straw)

Land competition risk	Straw is a co-product of crop production and can have significant commercial and practical value to farmers. Additional demand for straw for bioenergy use likely to lead to some additional pressure on land use	2
Resource competition risk	Residues can be used as inputs to other processes higher up the circular economy hierarchy e.g., fodder for animal feed, animal bedding, and as soil improvement . If residues are used for bioenergy, then this will result in replacement of materials with inputs from other sectors	2
Wider sustainability risk	Straw removal can lead to higher aquatic eutrophication, due to nitrate leaching and emissions from the manufacturing process of the compensating nitrogen fertilisers. Removal of residues therefore risks wider environmental impacts.	3
Climate mitigation risk	Life cycle emissions range from 6-18gCO_2e/MJ. This is classed as aligned to 'Well Below 2C° carbon intensity for energy sector. The feedstock has benefit of being very short cycle biogenic carbon dioxide emissions.	2
Total score		9

Risk ratings of all biomass types

Feedstock	Land risk	Resource risk	Other SDG risk	Climate mitigation risk	Total score	Rank	Risk rating
Landfill gas	1	1	1	2	5	1	Low
Renewable fraction of wastes	1	1	1	2	5	1	Low
Biogas from food waste	1	2	1	1	5	1	Low
Arboricultural arisings	1	2	2	1	6	4	Moderate
Sawmill co-products	1	2	2	1	6	4	Moderate
Marine resources	1	2	2	2	7	6	Moderate
Waste wood	1	3	2	1	7	6	Moderate
Biogas from sewage sludge	1	2	2	2	7	6	Moderate
Forestry residues	2	2	2	1	7	6	Moderate
Biogas from livestock manures	2	2	2	2	8	10	High
Dry agricultural residue	2	2	3	2	9	11	High
UK perennial energy crops	3	2	2	2	9	11	High
Short rotation forestry	3	3	2	2	10	13	Very high
Stemwood	3	3	2	3	11	14	Very high
Biogas from crops	3	3	2	3	11	14	Very high

USING THE BIOMASS RISK FRAMEWORK OUTPUTS IN POLICYMAKING

Applying differential controls to biomass feedstocks based on their sustainability risk level

Using quotas, production standards, transparency and emissions thresholds to ensure land use and resource risks are adequately managed in the long term

Ensuring an appropriate level of bioenergy use will require a novel mix of policies and incentives that encourage appropriate utilisation in the short term but minimise lock-in in the longer term (Reid et al 2020).

We recommend using a framework such as the one presented on the previous page to enable differentiated controls on feedstocks that present different sustainability risks.

Having assessed the relative risk of different feedstocks we have grouped them into three categories: very low/low risk; moderate risk; high/very high risk. Each of these will call for different types of general and feedstock-specific policy responses (see table on opposite page).

For the highest risk feedstocks, feedstock use quotas are needed. These are limits set by policymakers on total land areas and/or tonnages of materials that can be used in the UK energy system. These should be informed by an assessment of UK land use that balances competing uses, such as nature, food, and materials production. As the UK has been a global leader on national carbon budgeting through the work of the Climate Change Committee, there is an increasingly urgent need to develop a similar UK-level 'land budget' for enabling policymakers across government to balance competing land use priorities. Setting quotas in this way is a key means of limiting the potential for energy technologies to drive unsustainable resource use (Kalkuhl, M., et al 2012).

For moderate and high risk feedstocks there is also a need for feedstock-specific production standards and greater transparency. Feedstock-specific requirements will need to be included to mitigate broader environmental and social risks e.g., setting quantified limits on the proportion of crop residues that can be removed from agricultural land to ensure risks of soil depletion or water pollution are minimised. This would also include requirements on excluding biomass from protected areas, etc. In addition to feedstock-specific production standards much greater transparency and due diligence is needed on the nature of moderate and higher risk feedstocks (in particular where there is the potential for feedstocks to be assumed to be a waste or residue, when in fact they are the primary output of a production system e.g., forestry residues could be stemwood).

Finally, carbon intensity performance thresholds should be used on feedstocks of all risk levels to drive decarbonisation of the UK energy system. Specific carbon intensity thresholds should be aligned to 1.5°C-aligned emissions pathways for the energy sector.

Policy implications of feedstock risk levels

Feedstock risk level	Description	Feedstock use quota or budget	Production standards & transparency	Carbon intensity threshold
Very low / Low	 Growth in these feedstocks will have no additional land use pressure. They do not compete with other non-energy sectors and have limited environmental/ social issues through their use *Example: Renewable fraction of wastes*			✓
Moderate	 Growth in these feedstocks will have some limited additional pressure on land use and materials can often compete with some, relatively low value, non-energy sectors. Additional feedstock-specific environmental or social risks may need to be mitigated. *Examples: Sawmill co-products; forestry residues*		✓	✓
High / Very high	 Growth in these feedstocks is highly likely to drive additional land use, they have strong competition for resources and frequently have longer carbon payback times or wider sustainability risks. In theory these feedstocks could drive significant land use. *Examples: UK perennial energy crops; Stemwood*	✓	✓	✓

DOMESTIC-SOURCED BIOMASS AVAILABILITY

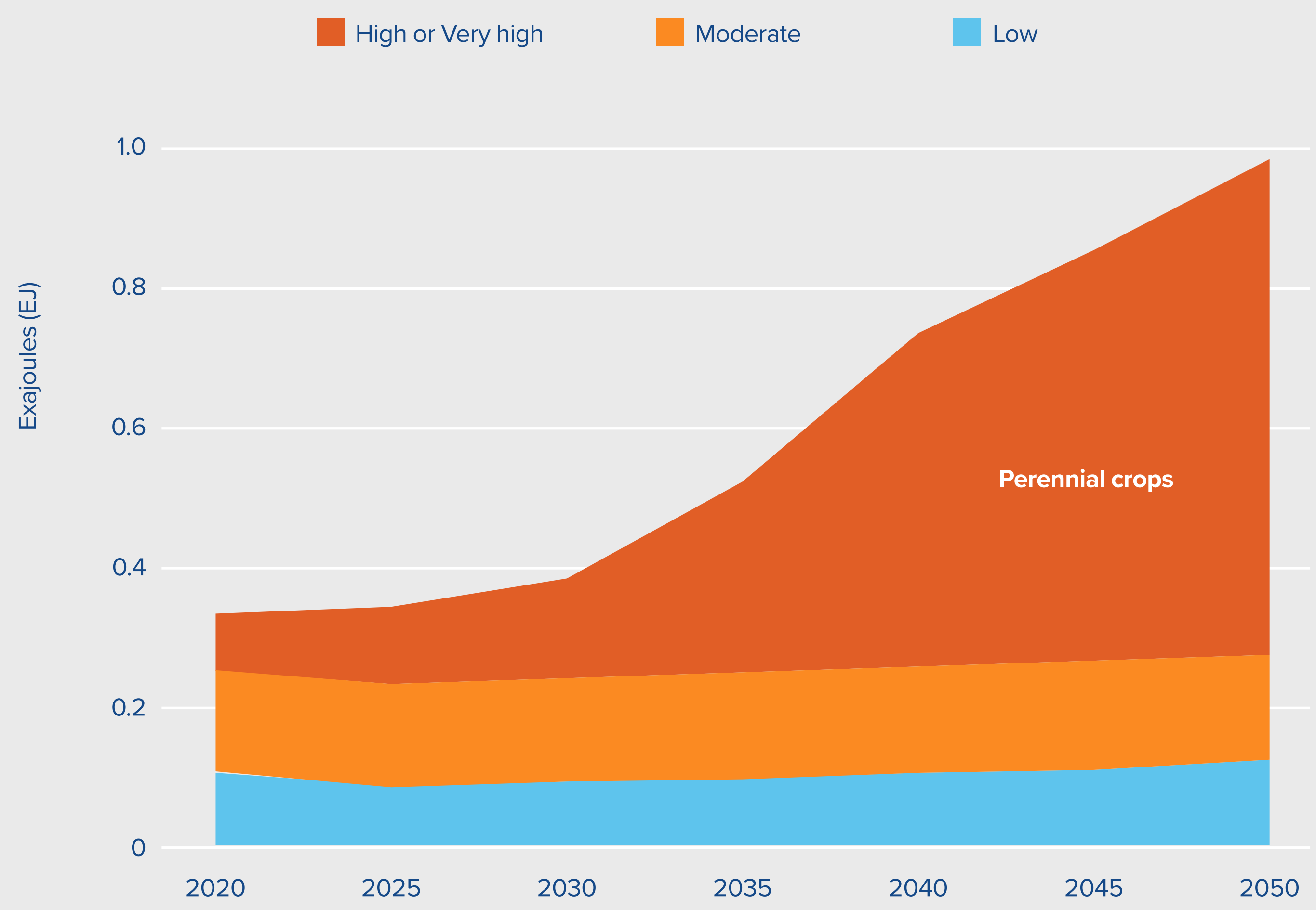
Low and moderate risk biomass could supply 4% of primary energy in 2050

Availability of the most sustainable feedstocks is unlikely to increase over the next thirty years

Based on the feedstock scores developed above, and availability data from the BEIS UK and Global Bioenergy Resource Model (Ricardo, 2017), it was possible to explore the likely availability of feedstocks of different risk levels between 2020 and 2050 (see Figure 5). Low or moderate risk biomass stay relatively stable over the period (c. 0.27EJ in 2030 and 0.29EJ in 2050). The increase in high-risk biomass from 2030 reflects the potential for growth in UK perennial crops in the Ricardo scenario used in this study.

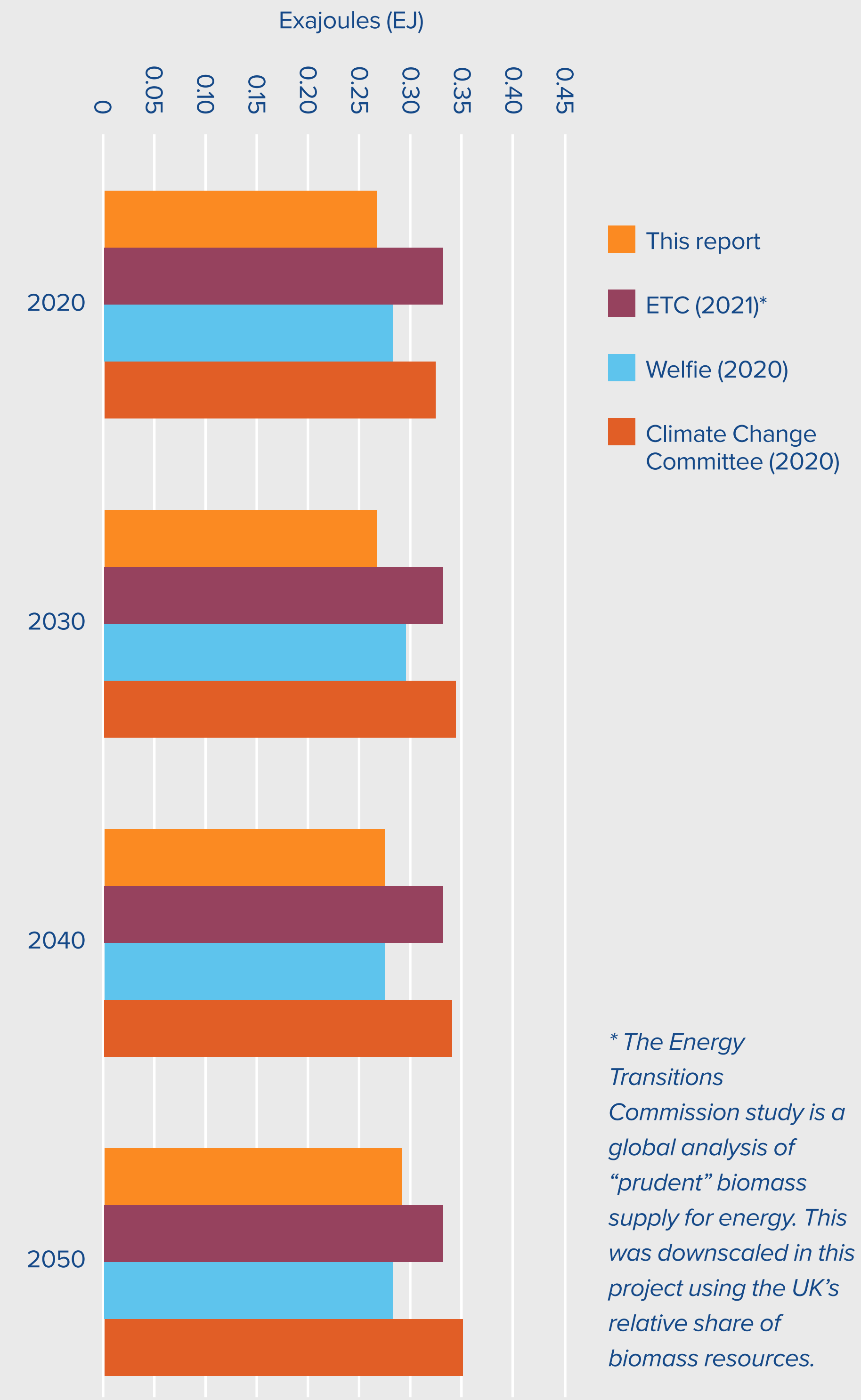
Comparing the low and moderate risk results in our study with comparable feedstocks in other data sources reviewed in this project we can see a reasonably good alignment both in terms of overall scale of low/moderate risk resource – and trends in production between now and 2050 (see Figure 6). These models show that low and moderate risk biomass could supply 4% of UK primary energy (assuming demand of 190 million tonnes of oil equivalent - or 8 Exajoules (based on BEIS 2022b).

Figure 5: Availability of low, moderate and high risk domestic biomass feedstocks between 2020 and 2050



Feedstock availability data from Ricardo (2017). Scenario parameters used: Central energy price scenario (£6/GJ); Easy and medium barriers overcome; Maximise production perennial energy crops; Continuing trends for international.

Figure 6: Low and moderate risk domestic biomass supply quantified in this report compared to three other notable UK and global datasets



** The Energy Transitions Commission study is a global analysis of "prudent" biomass supply for energy. This was downscaled in this project using the UK's relative share of biomass resources.*

Key recommendations

- The 2022 UK Biomass Strategy should seek to develop a risk-based biomass sustainability framework similar to the one presented in this report. It should be applied to all feedstock categories consistently and consider a much broader set of sustainability risks (in particular excessive land use and competition with non-energy users of biomaterials).

- For the feedstocks assessed as being 'highest risk' explicit usage quotas should be established to ensure that potential benefits are balanced against environmental and social risks. This could take the form of a UK 'land budget' to complement the UK carbon budget.

- Significant users of biomass should be required to report in detail on the precise nature of biomass being used, with greater chain-of-custody and transparency for feedstocks. Learnings from 'due diligence' requirements on deforestation within the UK Environment Act 2021 should be drawn upon to develop stronger requirements on due diligence of biomass feedstocks, so as to reduce risks identified in this report.

- The complete accounting of the greenhouse implications of biomass should be included within this framework – including full accounting of biogenic emissions. Feedstocks with long carbon payback periods and those that do not deliver energy aligned to sector 1.5°C emissions pathways should be not be incentivised.

- The Biomass Strategy should explicitly explore the potential of different biomass sources to deliver energy security and independence, reducing reliance on imports and our overseas footprint. Biomass systems that are highly dependent on imported raw materials are unlikely to deliver significant energy security dividends at the scales they are used, as well as posing significant challenges to sustainability monitoring.

- The government should seek to incentivise energy demand reduction as a priority, alongside innovation and research into new technologies that compete against biomass. Low carbon, sustainable negative emissions technologies should also be incentivised to avoid bioenergy carbon capture and storage overreliance.

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