Department for Energy Security & Net Zero

The ability of BECCS to generate negative emissions

Task and Finish Group Report

August 2023

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Executive Summary

The context

The UK Government (HMG) is committed to decisive action to cut emissions across the economy, to achieve a target of net zero emissions by 2050. To complement these efforts the Climate Change Committee (CCC) has been clear[1] that Greenhouse Gas Removal (GGR) methods will be required to offset residual emissions in sectors that are difficult to decarbonise completely.

The UK has set the ambition of deploying at least 5 Mt/yr of GGR by 2030, in line with CCC and National Infrastructure Commission assessments, potentially rising to 23 MtCO_2/yr by 2035.

Bioenergy with carbon dioxide (CO_2) capture and storage (BECCS) is a potentially important option in delivering GGR at scale in the UK in a meaningful time frame. However, owing to concerns surrounding its ability to deliver net removal CO_2 from the atmosphere, it is sometimes considered to be a controversial GGR pathway.

This report focuses on the carbon dynamics of BECCS, with the aim of establishing an evidence-based position on the validity of BECCS as a GGR option, and to address some of the key concerns raised.

The outcome of the discussions will be used to inform the government position on BECCS and why/how it is being prioritised as a use for biomass in meeting net zero.

This report will not discuss in detail the factors affecting biomass sustainability that do not directly relate to carbon, e.g., biodiversity, social, water impacts. These have been reviewed as part of the Biomass Strategy. The report is focused on BECCS applications which utilise forest biomass.

About the Task and Finish Group

The Department for Energy Security and Net Zero (DESNZ; formerly known as the Department for Business, Energy and Industrial Strategy, BEIS) convened a bioenergy and carbon capture and storage (BECCS) Task and Finish Group ('The Group') with the aim of understanding:

- Can biomass be a carbon neutral feedstock?
- Can BECCS result in the net removal of CO_2 from the atmosphere and its permanent geological storage?
- Will BECCS, as is being proposed in the UK context, result in the permanent net removal of CO_2 from the atmosphere?

[1] CCC (2019) Net Zero – The UK's contribution to stopping global warming.

- What are the key social barriers to delivering BECCS?
- What is the opportunity cost of not delivering BECCS?

Over the course of four months, the department engaged with 11 experts from a range of institutions, along with government officials, in a number of group meetings. The Group's members represent industry, academics, the financial sector, non-governmental organisations, the legal sector, representative organisations, and HMG science advisors and policy officials.

This report elaborates on the discussions and presentations from the group meetings. It is not intended to be a definitive summary of issues related to BECCS and does not constitute the official government position.

The role of the Group is advisory and, whilst they have been actively consulted throughout and have reviewed this report, they have not been asked to endorse its contents.

Key messages / recommendations

1. Whilst there are some challenges the group has not identified any insurmountable scientific barriers to the net removal of CO_2 from the atmosphere and subsequent permanent geological storage via BECCS when carried out in accordance with existing biomass sustainability criteria and via sustainable supply chains.

2. In principle, forests can be managed to supply biomass at scale and over relevant time periods, and the ability of the Carbon Capture and Storage element of the value chain to deliver was not contested.

3. The issue is primarily one of choice in terms of how the integrity of the biomass value chain is managed, regulated, and maintained and across national and international boundaries. Forest biomass can be robustly and reliably monitored with currently available technologies and carbon stock monitored by a modest extension of normal forest management practices. A practical framework for monitoring impacts of biomass extraction on carbon stocks in forests is feasible and could be developed. It is imperative that regulatory and independent auditing practices be transparent and verifiable.

4. Notwithstanding, public opinion remains divided on the issue of GGRs in general and BECCS in particular. In many respects, this appears to be an issue of understanding and perceptions of risk of, e.g., mitigation deterrence, potential competition with land for food, exacerbating deforestation. Improving assessment and monitoring methods and the transparency of accounting, reporting, and independent auditing will be of paramount importance in this effort.

5. There is a substantial opportunity for the UK to develop a leadership position in the range of technical, commercial, legal, financial, and policy "know-how" associated with the delivery of sustainable BECCS/GGRs. If the UK chooses not to pursue GGRs and BECCS we miss out on these innovation and associated export opportunities, in addition to increasing the costs of delivering net zero. However, it is imperative that

existing regulation/certification practices be carefully evaluated, with any weaknesses addressed.

Introduction

Delivering Net Zero

For the UK to reach net zero emissions in 2050, Greenhouse gas removals (GGRs) will be required to balance residual emissions from some of the most difficult to decarbonise sectors, such as industry, agriculture, and aviation. Analysis from the Climate Change Committee (CCC) supports this position.[2]

Development of UK greenhouse gas removal (GGR) policy

The portfolio of GGR methods is rapidly evolving, however most engineering-based approaches are at an early stage of commercial development and have not yet been deployed at scale in the UK. HMG is already rolling out nature-based solutions, whilst in parallel supporting innovation and commercial development of more nascent technologies. For example:

- In June 2020, the government announced up to £100m for Direct Air Capture Research & Development. In November 2020, Phase 1 of the Direct Air Capture and other GGR Innovation Programme was launched, seeking to pilot feasible GGR approaches at scale as well as improve our understanding of governance and ethics of GGRs.
- The £50m Woodland Carbon Guarantee, which aims to accelerate planting rates and develop the domestic market for woodland carbon for the permanent removal of carbon dioxide from the atmosphere.
- Work on developing Carbon Capture, Usage and Storage (CCUS) infrastructure that will be essential for the deployment of BECCS and DACCS is progressing. This includes a £20 billion commitment for early deployment of CCUS through the establishment of four clusters by 2030, with the first two in the mid-2020s.

HMG is also exploring the longer-term policy support that could be needed to enable a market for GGRs and accelerate the development and deployment of less mature technologies. It is important to recognise that the different GGR pathways have wide ranging longevity of carbon storage, from relatively short (agriculture and woodland and commercial forestry on a timescale of years to decades) to near permanent storage (bioenergy CCS), and that more work is needed to understand the value of these carbon flows.

Task and Finish Group Output

The DESNZ Chief Scientific Advisor (CSA) commissioned a Task and Finish (T&F) group to "*establish a scientific position on the validity of BECCS as a greenhouse gas reduction option, and address some of the key concerns raised on BECCS, particularly from BECCS options*

[2] CCC (2019), Net Zero – The UK's contribution to stopping global warming.

that utilise forest-derived biomass." The group did not cover the factors affecting biomass sustainability that do not directly relate to carbon (e.g., biodiversity, social, water impacts) as these have been considered as part of Biomass Strategy.

The group was convened by Prof Niall MacDowell from Imperial College London (on secondment into DESNZ) and chaired by Paul Monks, the DESNZ CSA. Over three sessions the group sought to consider:

1.Is biomass, in principle, a carbon neutral feedstock? And therefore, can BECCS result in the permanent net removal of CO_2 from the atmosphere?

2.How can the government address concerns raised over forest-derived biomass, or are there areas that need further exploration?

3.Will BECCS, as is being proposed in the UK context, result in the permanent net removal of CO_2 from the atmosphere?

The following topics emerged as key discussion points and were explored in detail, both in meetings of the Group and in follow up stakeholder one-to-ones with Prof. MacDowell. This report seeks to summarise and elaborate on what was discussed. It does not constitute an official government position but has been used to inform the Biomass Strategy and wider BECCS policies.

This section:

1. Sets out how forest biomass to BECCS value chains work.
2. Assesses the potential carbon removal efficiency of BECCS as envisioned in the UK, and places this in the broader context of the GGR landscape.
3. Sets out how forest management can supply sustainable biomass for use as a BECCS feedstock.
4. Discusses public acceptability concerns.

How BECCS works

First proposed in the mid-1990s[3], BECCS relies upon the thermo- or biochemical conversion of biomass to supply an energy service, and the addition of CO_2 capture and storage (CCS) to recover biogenic CO_2 and geologically sequester it, thus permanently removing it from the atmosphere. As illustrated in Figure 1 below, BECCS can use a variety of biomass feedstocks, from dedicated energy crops to waste-derived biomass, and agricultural and forest residues. The biomass conversion process can include combustion, gasification, digestion, or fermentation to deliver electricity, heat, liquid or gaseous biofuel, or hydrogen.

[3] Herzog, H. J., and Drake, E. M., "Carbon dioxide recovery and disposal from large energy systems", Annu. Rev. Energy, 1996, 21, 145–166

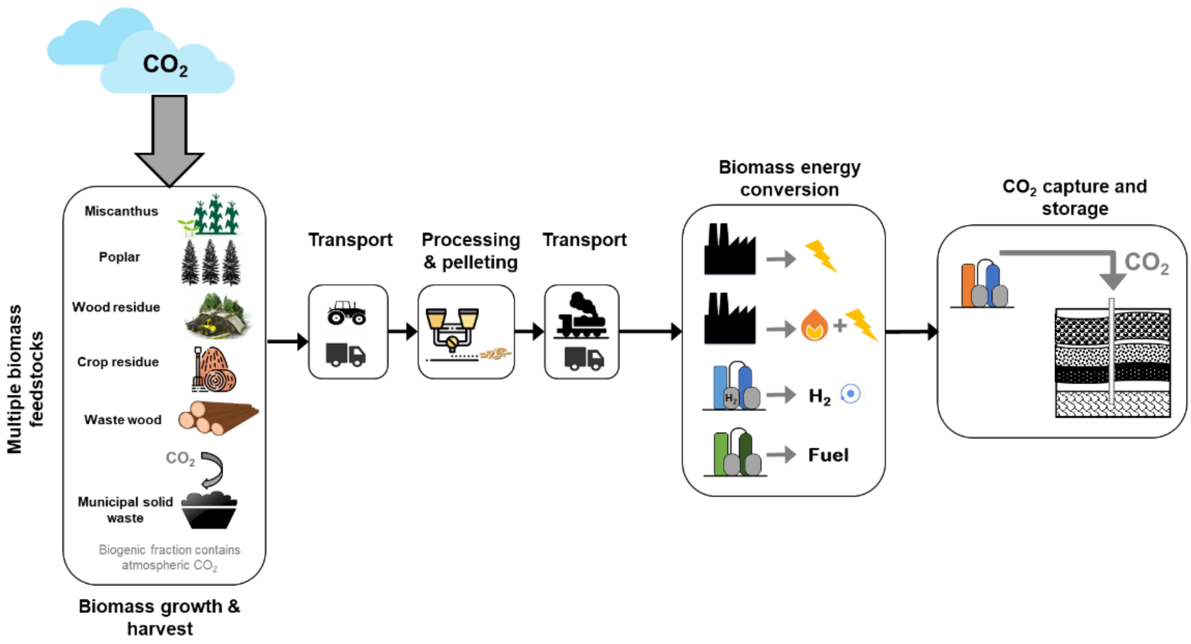

Figure 1: Illustrative flow diagram of an archetypal bioenergy with CO_2 capture and storage (BECCS) value chain. The initial cultivation and growth of the biomass absorbs CO_2 from the atmosphere. It is recognised that waste-derived biomass is also a potential feedstock. This biomass is subsequently harvested, processed into a fuel-grade material, and transported to a BECCS facility. The biomass can be converted via a range of processes to produce heat, power, transport fuels, or hydrogen. The resulting CO_2 is then captured and transported to a geological store.

However, BECCS is susceptible to upstream carbon leakage, primarily associated with the cultivation, harvesting, processing, and transport of biomass. It is therefore important to quantify and minimise carbon leakage across the biomass supply chain.

An illustrative calculation of carbon removal efficiency is presented in Figure 2 below. Whilst drying of the material can be an important source of carbon leakage, as is the extent of carbon capture at the BECCS facility (90% capture is assumed in the example below), there is no one dominant source. In practice, representative carbon removal efficiencies for BECCS are anticipated to be between 65 – 85%, as a function of CO_2 capture rate, supply chain, and supply chain logistics.

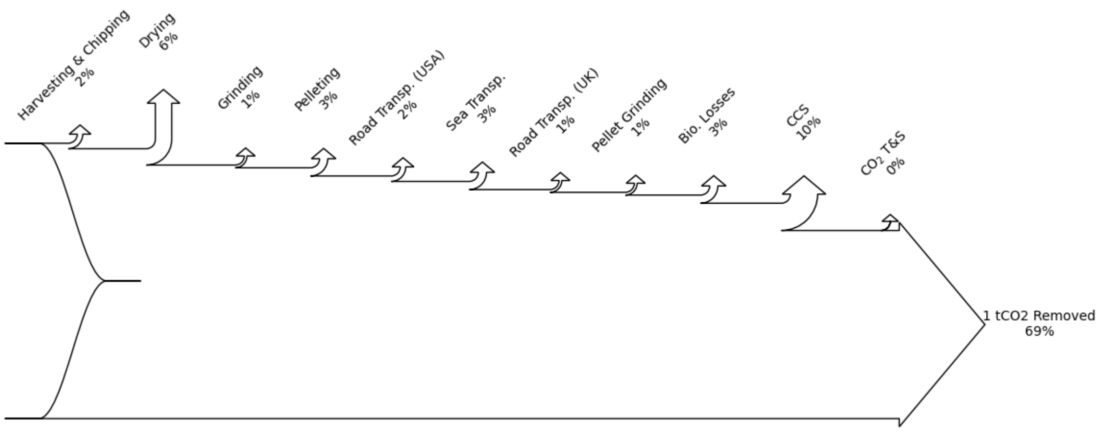

Figure 2: Illustrative carbon removal efficiency diagram for a UK BECCS project using biomass imported from the USA. This example assumes 90% CO2 capture at the BECCS facility. This calculation was performed using the MONET framework[5].

The sample calculation shown here assumes a 90% CO_2 capture rate at point of use. It is recognised that substantially greater capture rates are viable[4], and the overall removal efficiency can be increased if greater capture rates are used. Beyond that, many of the key sources of carbon leakage in BECCS can be expected to reduce in line with the decarbonisation of the broader energy system. This calculation was performed using the MONET framework[5]

It is important to note that the carbon removal efficiency of a given BECCS pathway is a strong function of the amount of permanently sequestered CO_2 per unit biomass consumed. For example, in the case of biofuels, e.g., biodiesel or ethanol, a substantial amount of biogenic carbon is retained in the fuel, and only 20 – 30% of the biogenic carbon is available for capture and sequestration[6]. Thus, as discussed by Patrizio et al,[7] the optimal BECCS pathway is economy dependant and a function of what service is most important to that economy at that time – carbon avoidance via low carbon energy production, or carbon removal. It ought to be noted that, at a global scale, the carbon removal service appears to be most important[8] and thus this ought to be borne in mind in a policy context.

[4] Feron, P., et al., (2019), "Towards Zero Emissions from Fossil Fuel Power Stations", Int J GHG Con.
[5] Fajardy, M., Mac Dowell, N., (2017), "Can BECCS deliver sustainable and resource efficient negative emissions?", Energy & Environ. Sci.
[6] Fajardy, M., Koberle, A., Mac Dowell, N., Fantuzzi, A. (2019), "BECCS deployment: a reality check", Grantham Institute Briefing Paper No 28.
[7] Patrizio, P., Fajardy, M., Bui, M., and Mac Dowell, N., (2021) "CO_2 mitigation or removal: The optimal uses of biomass in energy system decarbonization", iScience
[8] Fajardy, M., Morris, J., Gurgel, A., Herzog, H., Mac Dowell, N., Paltsev, S., (2021), "The economics of bioenergy with carbon capture and storage (BECCS) deployment in a 1.5 C or 2 C world", Global Environmental Change

Further, in addition to BECCS Chiquier et al.,[9] evaluate a set of archetypal Carbon Dioxide Removal (CDR) pathways; afforestation/reforestation (AR), biochar, direct air capture of CO_2 with storage (DACCS) and enhanced weathering (EW).

Through a series of thought experiments, considering different climates and forest types for AR, land types, (e.g., impacting biomass yield and (direct and indirect) land use change, and biomass types for BECCS and biochar, capture processes for DACCS, and rock types for EW,) Chiquier et al. evaluate carbon removal efficiency.

They find that AR can be highly efficient in delivering CDR, up to 95–99% under optimal conditions. However, regional bio-geophysical factors, such as the near-term relatively slow and limited forest growth in cold climates, or the long-term exposure to natural disturbances, e.g., wildfires in warm and dry climates, could substantially reduce the overall CO_2 removal efficiency of AR.

It is important to stress that AR is an important but special case in terms of sources of forest biomass. In the near to medium term, the bulk of forest biomass will come from existing managed forest areas.

Conversely, where the CO_2 is permanently geologically stored in, e.g., a saline aquifer, BECCS delivers immediate and permanent CDR, but its CO_2 removal efficiency can be significantly impacted by any negative impacts on carbon stocks and carbon sequestration associated with (direct and indirect) land use change, and thereby could be significantly delayed, or negated.

Biochar achieves low CDR efficiency, in the range of 20–39% when it is first integrated with the soil, and that regardless of the biomass feedstock considered. Moreover, its CO2 removal efficiency can decrease to -3–5% over multi-century timescales, owing to the decay of biochar.

Finally, as with BECCS, DACCS and EW can deliver permanent CO_2 removal, but their CO_2 removal efficiencies are substantially characterized by the energy system within which they are deployed, in the range of -5–90% and 17–92%, respectively, if currently deployed.

Is biomass a carbon neutral feedstock?

Currently bioenergy in the UK primarily relies upon biomass supplied from managed forests in North America and it is likely that BECCS deployment will also mainly use the same feedstock. The discussion within the T&F Group thus predominately focused on this context.

Hence, the balance of this section will focus on sourcing biomass in this context, though evidence from other parts of the world will also be incorporated where relevant.

There was relatively little discussion on the sustainability of dedicated energy crops, e.g., Miscanthus or switchgrass, or the use of biogenic wastes or agricultural residues. It is therefore

[9] Chiquier, S., Patrizio, P., Bui M., Sunny, N., and Mac Dowell, N., (2022) “A comparative analysis of the efficiency, timing, and permanence of CO_2 removal pathways”, Energy Environ. Sci.

proposed that these areas be the subject of future T&F Group efforts. However, whilst this future work will provide more detailed information on these areas, it is not anticipated that they alter the conclusions of this current contribution.

As a first step in determining whether and how biomass supplied from forests can be carbon neutral, a clear definition is needed for what we mean by 'carbon neutral biomass'. The definition assumed in this report is given in Box 1, and some immediate implications are considered.

Box 1. What is 'carbon neutral biomass?'

The term 'carbon neutral' is not well defined and not always helpful in discussions about biomass sustainability. However, it is in common use, and, for the purposes of this report, the term is used to refer to situations in which biomass is produced from forests, for use as timber or other biobased products or to produce bioenergy, by managing forest areas purposefully to avoid negative overall impacts on carbon stocks and carbon sequestration rates. To be consistent with the IPCC definitions of carbon neutrality and net zero CO_2 emissions, this means the rate of carbon sequestration in the forest needs to at least match the rate that would occur currently in the vegetation and soil of an equivalent area of intact unmanaged land at the same location. (Note that this carbon sequestration rate, which is excluded from "anthropogenic CO_2 removals" by the IPCC, may be small relative to other anthropogenic disturbances at an individual location, but is highly significant when integrated globally.)

Based on the above definition and the conditions specified, it may be stated at the outset of this discussion that:

- Biomass derived from deforestation will never meet the above conditions
- Biomass harvested from previously intact, unmanaged and relatively undisturbed forests with high carbon stocks is very unlikely to meet these conditions
- Conversely, biomass supplied by creating new forest areas on non-forest land, or actively restoring degraded forests, can often meet these conditions, as long as tree planting on land with high soil carbon stocks is avoided and that risks of indirect land use change are mitigated.
- The grey area is where management is changed in forests that are already under management for wood supply, with the aim of 'mobilising' higher levels of supply. It is suggested that biomass can be produced through sustainable forest management in ways that ensure carbon is removed from the atmosphere overall during tree growth and harvesting, and appropriate sustainability and carbon assessment systems can and should be put in place to make sure that is achieved. These issues are discussed further in this report.

Forest biomass supply

There are between 310-325,000,000 hectares of natural and planted forests and woodlands in the USA[10]. Approximately 67% of this area can be legally harvested but annually only 2% of this area is subject to cutting and removal[11]. US forest area corresponds to 3.07 - 3.24 million square km[12]. US forest area corresponds to more than 12 - 13 times the total area of the UK.

Figure 3: Map of US forest cover

The subtropical area in the south-eastern US, known as the nation's "wood basket" is the most productive forest land areas[13].

The 1964 Wilderness Act created the National Wilderness Preservation System which currently accounts for approximately 405 million hectares (~ 404,685 km2, or 1.66 UKs). Designated wilderness areas protect a broad range of "NO CHANGE – Wilderness Map" ecosystems. Each wilderness area is managed by one of four federal agencies – the US Forest Service, the Bureau of Land Management, the US Fish and Wildlife Service, and the National Park Service.

The majority of forest land in the US is privately owned. Some data from the Congressional Research Service are presented in Figure 4.

[10] Congressional Research Service, US Forest ownership and management, 2021 https://crsreports.congress.gov/product/pdf/IF/IF12001

[11] Carlos Rodriguez Franco & Jennifer Conje (2022) The Evolution of the Dialogue and Perspectives on Sustainable Forest Management with Special Emphasis on the United States of America, Journal of Sustainable Forestry, DOI: 10.1080/10549811.2022.2059687

[12] https://forest-atlas.fs.fed.us/index.html

[13] https://forest-atlas.fs.fed.us/grow-ecological-divisions.html

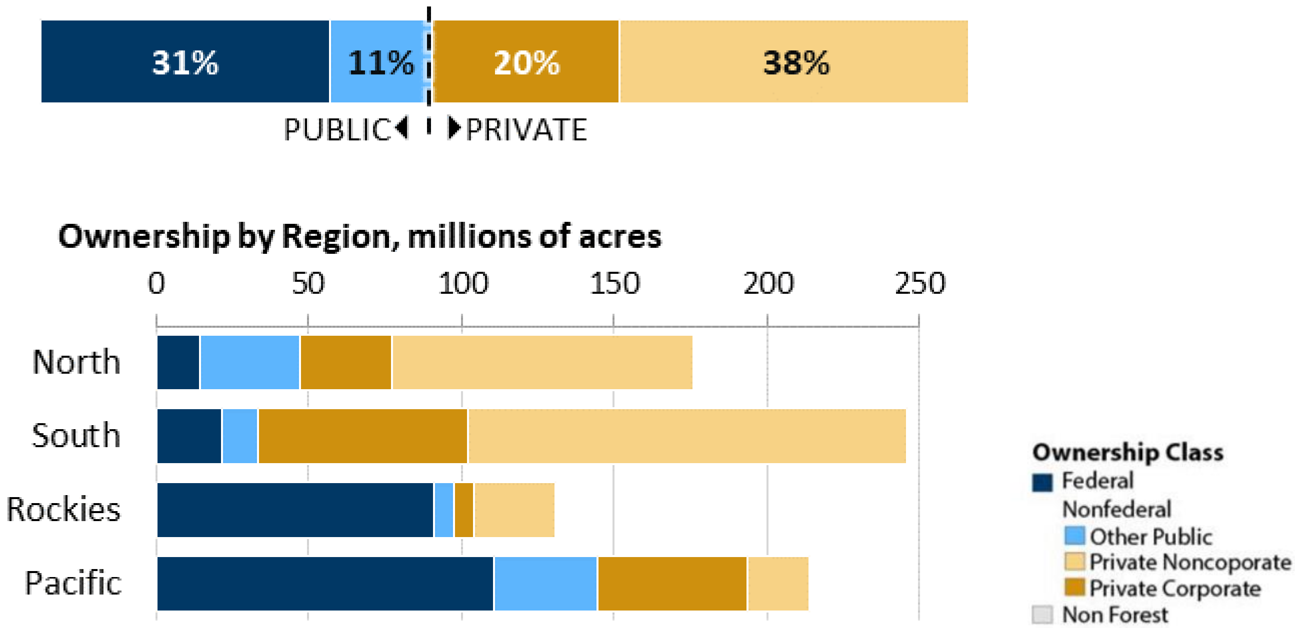

Figure 4: Forest ownership in the US, data from 2021.

Of the private owners, the largest group is families and individuals, collectively referred to as "family owners." Approximately eleven million of them collectively own approximately 38% of US forest area. Corporate owners own a further 20 percent. The "other" private owners, including conservation organizations, clubs and associations, own the balance. In general, owing to, e.g., SFI certification requirements, biomass is primarily sourced from the corporate landowners.

Private forest owners seek to derive an income from their land through a combination of harvesting timber for wood products, and also recreation, e.g., hunting licenses.

There are approximately 100 million hectares of forest in the US south, 86% of which is privately owned and managed as working forests. These forests produce approximately 18% of the world's pulpwood, and 7% of industrial roundwood. This activity supports > 1.1 million jobs and generates > $53 billion in income[14]. If these forests were to be taken out of active management, this loss of employment and GDP would need to be accounted for and compensated accordingly.

Certification of biomass sustainability

Delivering BECCS at the scale required to meet the UK's anticipated GGR targets will require a reliable supply of biomass. In order for this to deliver sustainable negative emissions, the biomass supply must itself meet the highest sustainability standards.

In principle, a variety of waste, forest, and herbaceous biomass sources can be used for BECCS, owing to the incumbent supply chains in the UK, this report focuses on forest biomass.

[14] https://southernforests.org/services

Managed forests can produce a range of types of biomass for a variety of purposes. The primary wood products of managed forests are high-value timber which can be used for construction, or the production of wood-based panels, pulp, and paper products. Forest management is also intended to maintain and enhance natural forest capital, avoid, and minimise degradation of this capital via disease, pests, fire, etc. A by-product of this activity is the availability of biomass in the form of, slash (tops and branches), dead, damaged, or diseased/infested biomass. If this low value material is not removed from the forest and disposed of, the material will decompose producing a combination of CO_2 and CH_4 and may also present a fire risk as well as hindering replanting and future removals.

In many regions of the world, there are extensive existing legal and regulatory frameworks covering the management of forests independent of climate ambition, with widely varying levels of compliance and enforcement. In the USA, forest management is within the purview of the US Department of Agriculture's Forest Service[15] and is underpinned by, inter alia, the National Environmental Policy Act of 1969, Clean Air Act of 1970, Clean Water Act of 1972, Endangered Species Act of 1973, National Forest Management Act of 1976. In Canada, similar laws apply, with key laws including the Forestry Act and Timber Regulations, First Nations Land Management Act and National Parks Act[16]. There are analogous frameworks in place in other regions.

The incumbent legal and regulatory system is an overlapping framework of mutually reinforcing laws and standards that are independently audited and enforced.

In addition to these legal and regulatory frameworks, there are a number of independent, non-governmental organisations, such as the Sustainable Forestry Initiative (SFI) [17] and the Sustainable Biomass Program (SBP) [18], which aim to ensure that biomass use is sustainable. Of these, the SBP participated in this T&F Group, and a concise description of their approach is presented here.

[15] https://www.fs.usda.gov/about-agency/regulations-policies/laws-regulations
[16] https://www.nrcan.gc.ca/our-natural-resources/forests/sustainable-forest-management/canadas-forest-laws/17497
[17] https://forests.org/

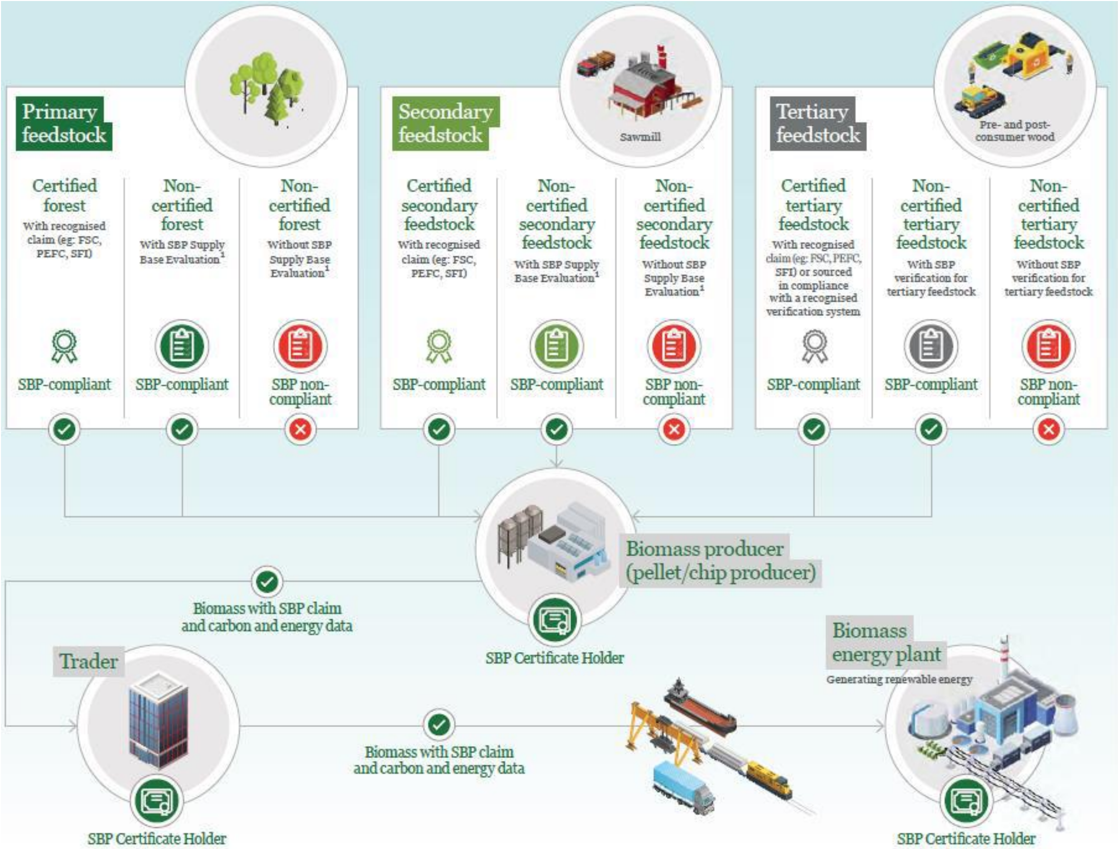

Figure 5: Illustration of SBP value chain

SBP is an independent non-profit, multi-stakeholder certification scheme, specifically focused on woody biomass used in the provision of heat and power services. End-users, i.e., the consumers of the biomass use SBP certification to demonstrate compliance with national legal and sustainability requirements for woody biomass. Importantly, SBP certificate holders are independently audited by Control Union, Preferred by Nature, DNV-GL, and SCS Global Services.

In 2021 the UK/EU consumed ca. 16.45 Mt of SBP certified woody biomass. Of this, 6.6 Mt was produced in Europe, 6.95 Mt was produced in the US, 1.6 Mt in Canada, 1.25 Mt in Russia, and 0.3 Mt in the rest of the world.

Under SBP, there are three types of certificate holder; producer, trader, and end-user. At the end of 2021, there were 353 certificate holders across 33 countries, 281 of whom were producers, 62 were traders, and 10 were end-users. Each step of the supply chain must be certified in order for an SBP claim to be valid. This is illustrated in Figure 5.

The SBP certification process is further illustrated in Figure 6 below.

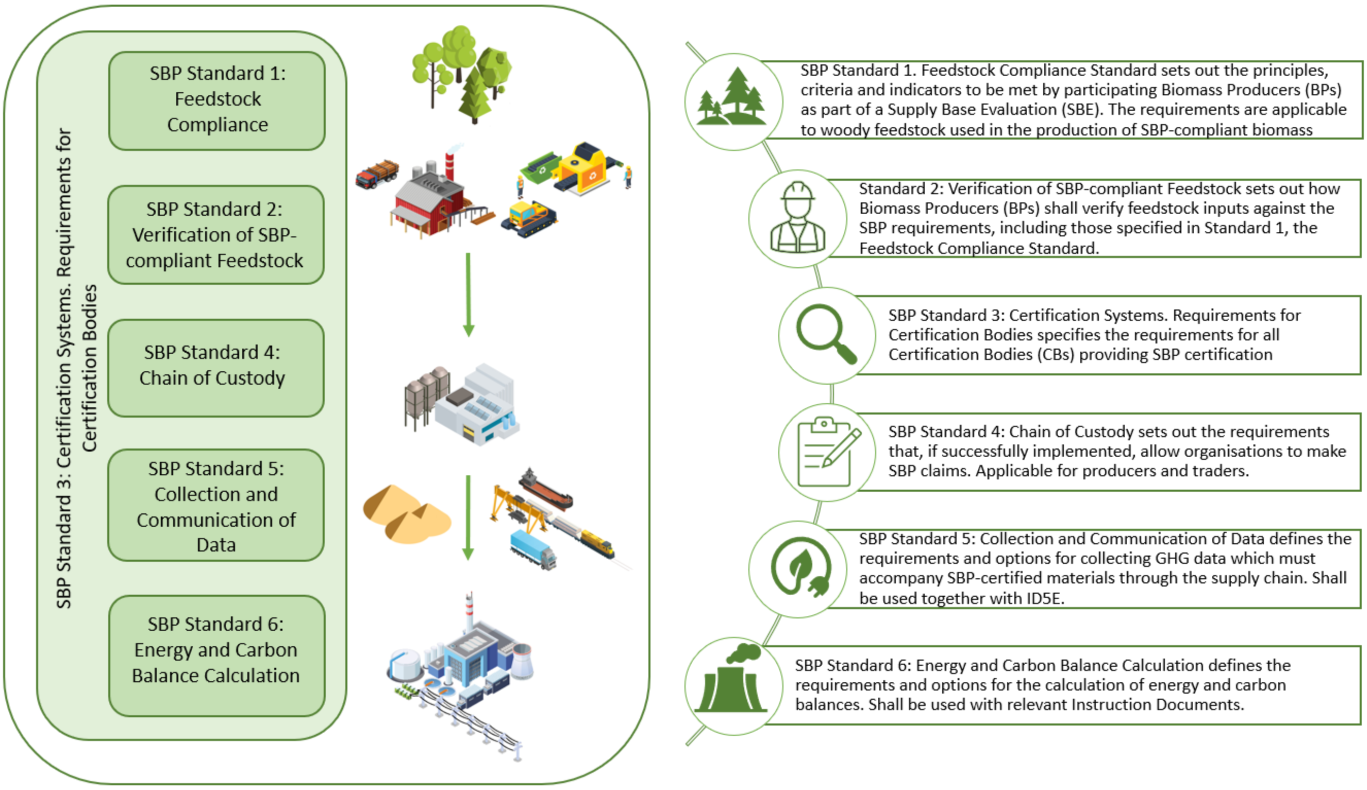

Figure 6: SBP normative framework

Sourcing biomass for bioenergy

As discussed extensively by Cowie et al.[19], and references therein, forests are not harvested for bioenergy products alone. Biomass for bioenergy is usually a by-product of sawlog and pulpwood production for material applications – this material flow is illustrated in Figure 7.

Logs that meet quality requirements are used to produce high-value products such as sawn wood and engineered wood products such as cross laminated timber, which can substitute for more carbon-intensive building materials such as concrete, steel and aluminium.

Residues from forestry operations, e.g., tops, branches, irregular and damaged stem sections, and wood processing residues, e.g., sawdust, bark, black liquor are major sources for bioenergy.

Part of the forest biomass used for bioenergy comprises roundwood (also referred to as stemwood), such as stems from forest thinning (See Box 2). As noted by Cowie et al., roundwood was estimated to contribute around 20% of the feedstock used for densified wood pellets in the United States in 2018.

[19] Cowie, A. L., et al., (2021) “Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy”, GCB Bioenergy

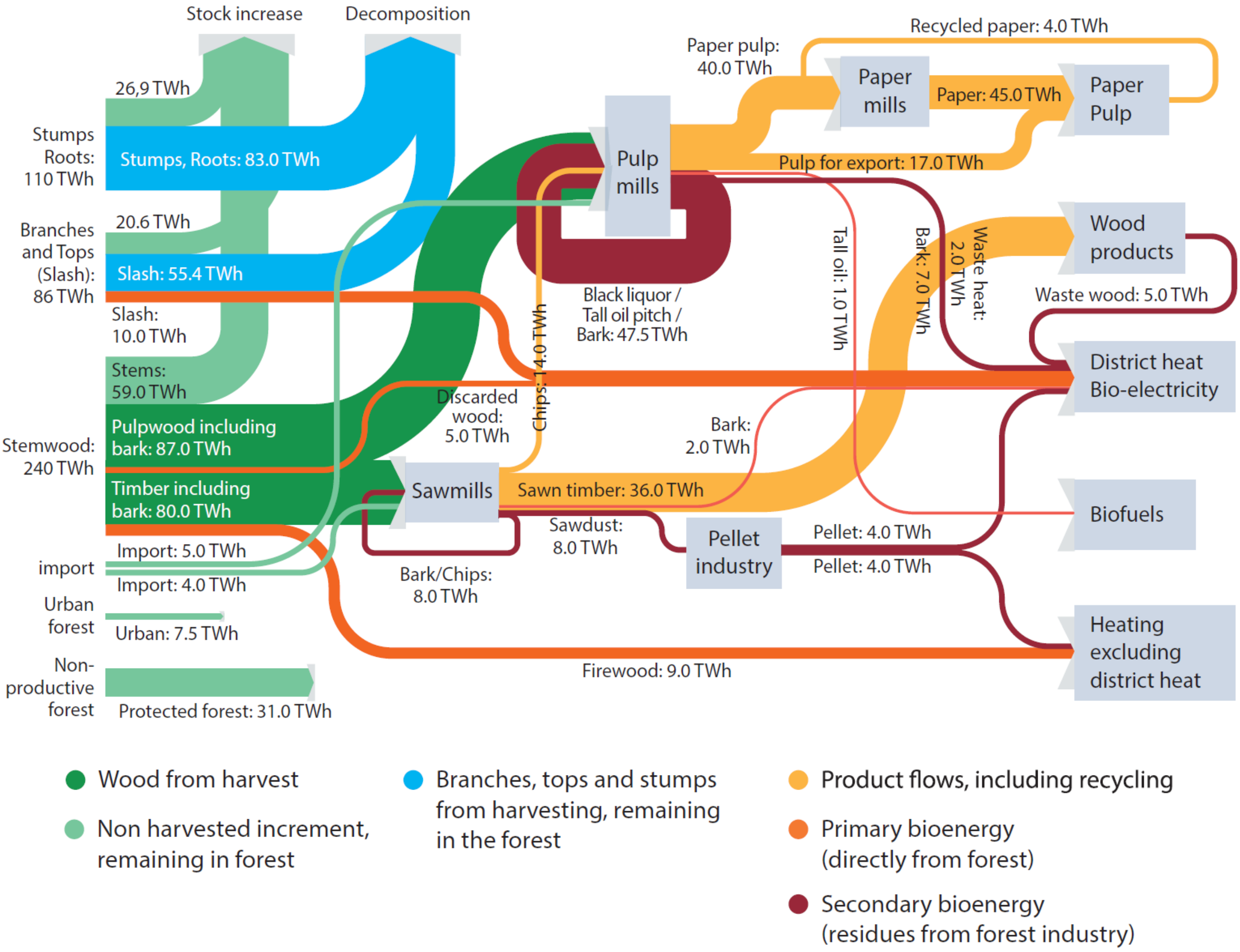

Figure 7: Biomass and energy flows from Swedish forests

Box 2. Thinnings, wood pellets and carbon stocks

"Thinning" is a forestry operation that involves felling a proportion of the trees forming a stand within a forest, whilst leaving the remainder with more room to grow. The trees cut down in these operations are known as "thinnings". The principal aim of thinning is to remove weak, defective and/or invasive trees, thereby improving the quality of the remaining stand. However, sometimes a forest owner may preferentially remove the highest quality trees, leaving behind the poorer ones, to maximise the financial returns from the operation. This kind of activity, sometimes known as "high-grading", is not normally supported in sustainability standards addressing forest management.

Thinning operations may be carried out at different stages in the life cycle of a stand of trees. Early on, very small thinnings that have no appreciable stemwood may be removed in recently planted or regenerating stands, to avoid significant overcrowding that would stifle all tree growth. Later on, in older stands, quite large trees may be harvested, to provide a range of wood products, whilst avoiding fully clearfelling a complete stand of trees. The sizes of thinnings can therefore vary considerably, which has a significant bearing on their suitability for different end uses:

- Very small thinnings are only useful for making wood chips and wood pellets

- Younger thinnings, with smaller stem diameters, can be used for 'lower value' products including paper, particleboards and wood pellets, with possibly some of the larger diameter stemwood could produce lower value sawn wood products, notably pallets
- Thinnings with bigger stem diameters, usually from older stands, can supply sawlogs, suitable for making higher-value sawn wood products including structural timber, whilst the smaller diameter parts of these trees (the top ends of their stems) can be utilised for the lower value products identified above.

A growing market for bioenergy such as wood pellets is likely to have variable effects on forest management and carbon stocks in forests. On the one hand, it may encourage more extensive and frequent thinning of stands, which is likely to diminish the total carbon stocks across the affected forest landscape. On the other hand, markets for bioenergy can enhance the value of small trees, boosting the economic value of forest stands, thereby encouraging landowners to retain their existing forests, instead of converting them to other more lucrative land uses (such as growing crops), which would lead to an even more significant loss of carbon stocks. A growing demand for wood pellets is very unlikely to compete for wood that is normally used for high value products such as structural sawn timber, because the value of these products is so much higher, and this is very likely to remain the case. There may be some competition from wood pellets with other the sectors using the lower value, smaller diameter stemwood. However, markets for wood pellets may also sustain forest industries (and the forests supplying them) in some regions where paper and particleboard industries are already in decline. An improved value for smaller and lower-quality thinning's could also reduce the motivation for high-grading forest stands when thinning them.

The relationship between forest carbon stock and biomass production

One of the common concerns about using forest biomass for bioenergy purposes is that the harvesting of biomass from the forest will reduce the carbon stock. This is often expressed as "*it takes seconds to cut down a tree but decades to replace it*".

The following thought experiment, taken from Matthews, 2020[20], illustrates an example of how the gain and loss of carbon when an individual tree, or stand of trees, is grown and felled needs to be considered in the broader context of many trees, and many stands of trees, growing as a population across a whole forest.

Consider the establishment of a 5,600-hectare forest formed of 56 stands of Sitka spruce. Each stand has an area of 100 hectares, with typical UK growth rates in Britain assumed. The forest is managed with clear-felling on a 56-year rotation. As illustrated in Figure 8, when the forest is first established, the forest carbon stock and associated carbon sequestration rate is negligible.

[20] Matthews, R., 2020, ERAMMP Report-36, Annex-4: Climate Change Mitigation https://erammp.wales/en/r-forest-evidence

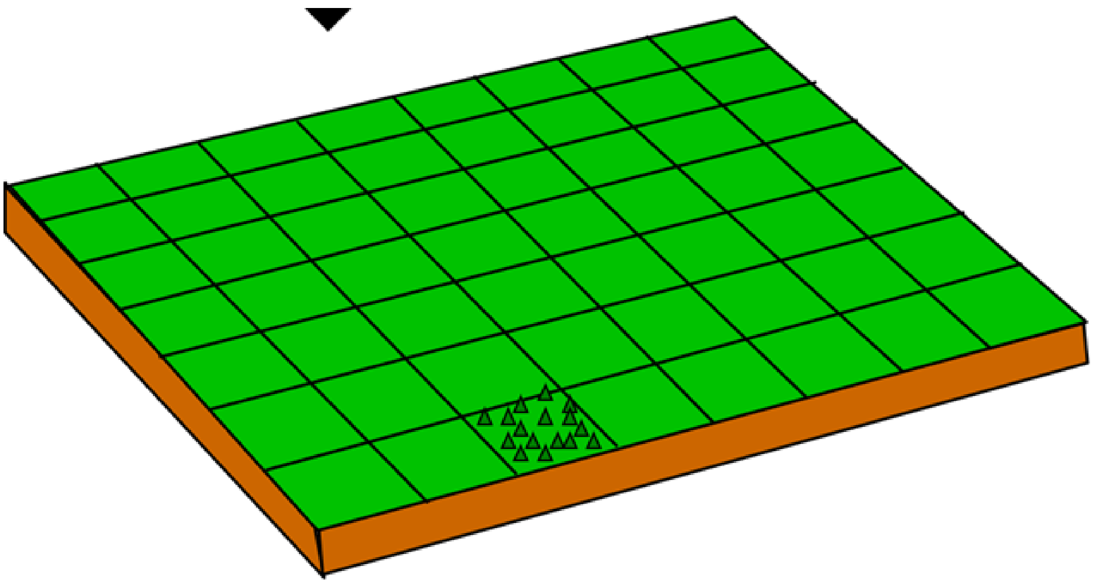

Figure 8: When the first area of forest is first established, the carbon stock, and associated carbon sequestration rate, in trees is negligible.

After, say, a decade, the standing carbon stock across the landscape will have increased to 1.0 ktC (1 thousand tonnes of carbon), and the carbon sequestration rate will have increased to 0.3 ktC/yr. This is illustrated in Figure 9.

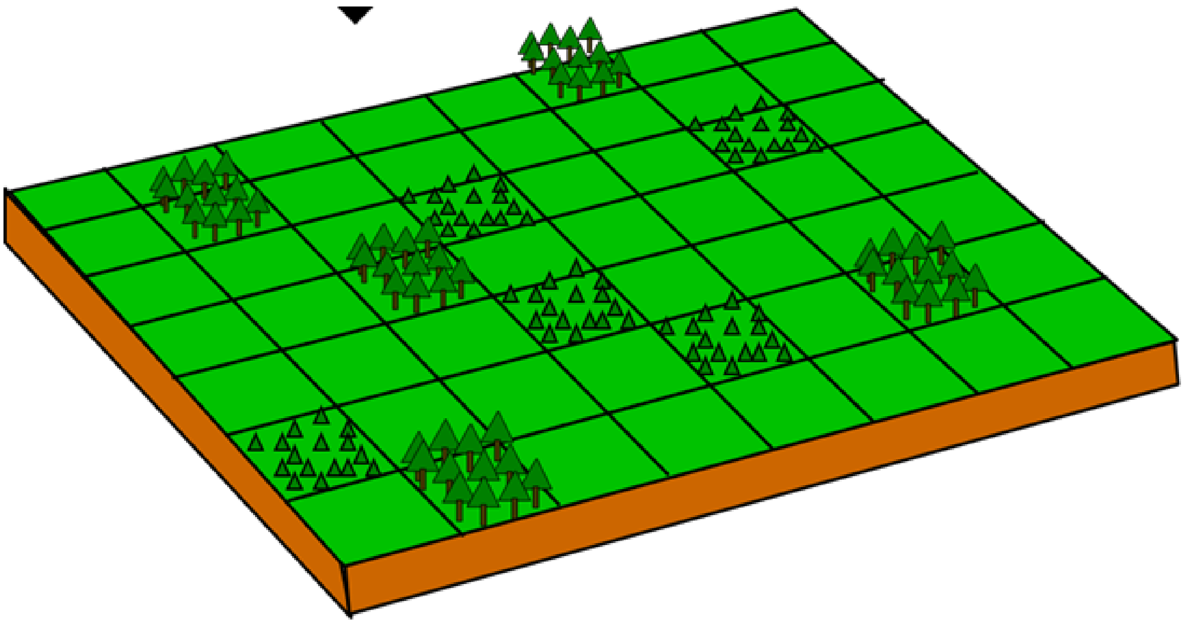

Figure 9: Sitka spruce forest one decade after establishment. An increasing number of stands have been planted, and they are each at a different stage of the growth curve.

This trend will continue for several decades as the forest matures, with the standing carbon stock of the landscape where the 5,600-hectare forest is being created increasing to 309 ktC. The overall carbon removal rate also increases over this period. By this stage, as illustrated in Figure 10, the forest has many distinct stands, each at different levels of maturity, with some closer to maturity, and others still in the establishment phase.

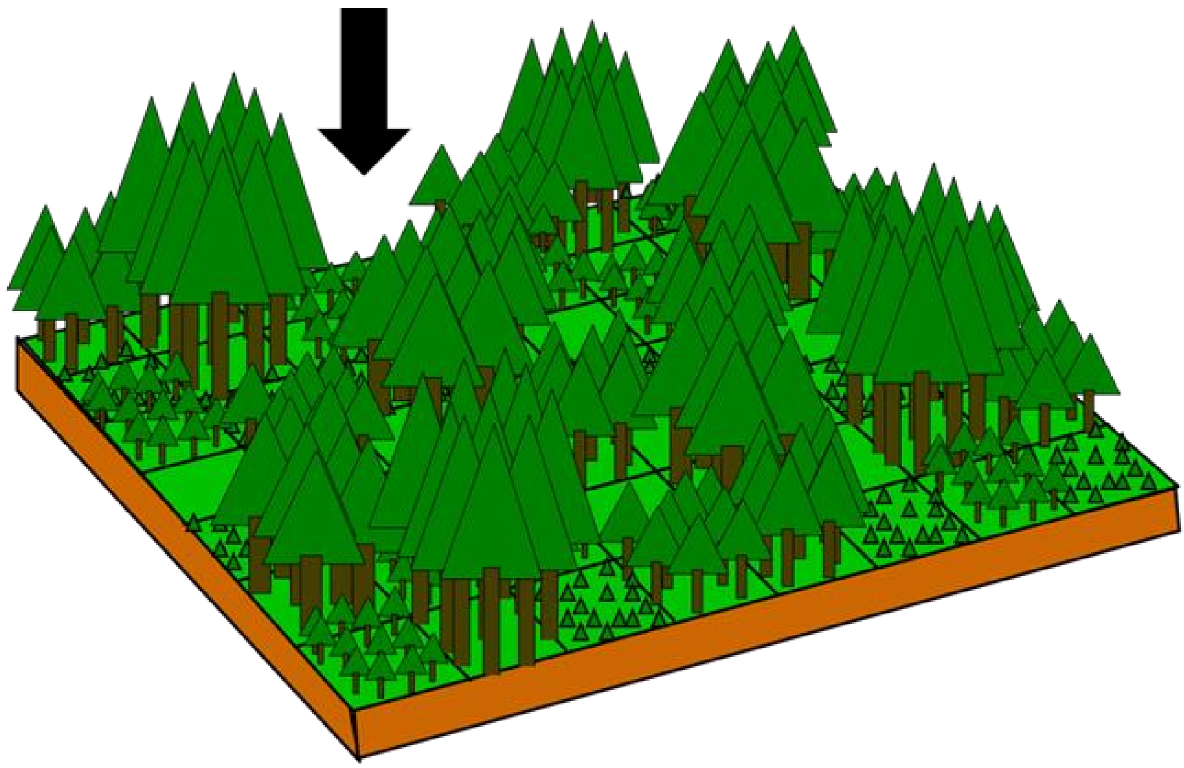

Figure 10: After several decades, the forest will be quite established, with a range of stands at varying levels of maturity.

Finally, after 56 years, the stands planted earliest are now fully mature, and are ready for harvest. Whilst the harvest of biomass from the forest inevitably removes carbon from the forest, this is compensated for by growth elsewhere in the forest. This concept is illustrated in Figure 11 below.

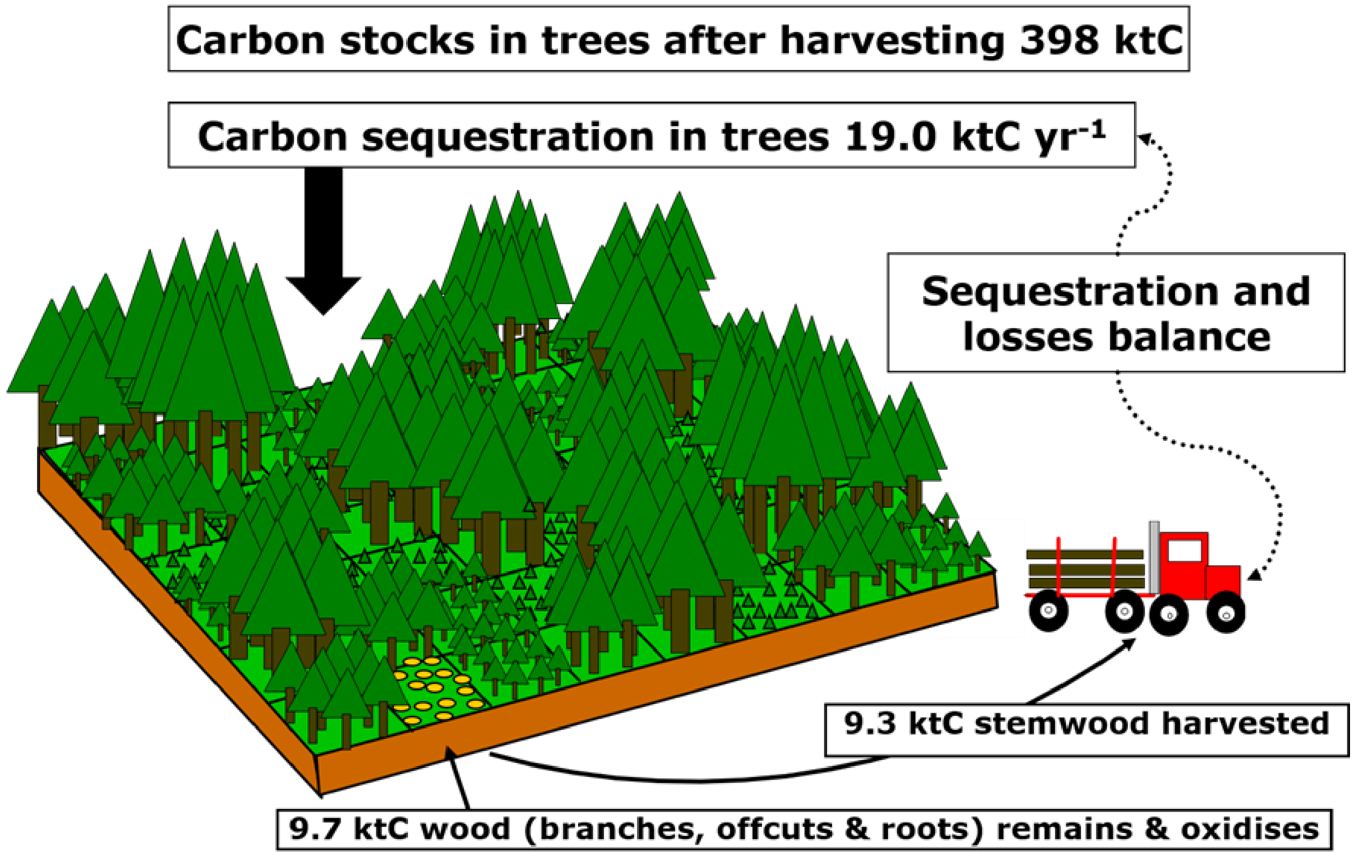

Figure 11: Sustainable harvest of biomass from the forest after 56 years of growth. The quantity of biomass removed from the forest landscape in year 56 (9.3 + 9.7 = 19.0 ktC) is compensated for by growth elsewhere in the forest landscape, so biomass removal and growth balance.

At the time the forest has reached the state shown in Figure 11, it is possible to produce biomass continuously that, when combined with BECCS, will deliver GGR indefinitely. An alternative might be to not harvest the trees at this point and allow the forest to develop without further intervention. However, this is not always a realistic scenario.

Ultimately, the land area can only carry so many trees, and beyond a certain point of growth, it will saturate with carbon, i.e., the total carbon stock in the managed forest approaches a maximum, and the rate of carbon removal, will tend to zero. If the forest is not managed, it could accumulate more carbon, but this may lead to stability problems, e.g., greater propensity for forest fires or windthrow. Thus, sustainable management of the forest can act as a carbon pump, avoiding carbon emissions via, e.g., the use of wood in construction, etc., and also removing carbon from the atmosphere via the use of bioenergy with CCS.

Thus, it is theoretically possible to manage forests such that they can produce biomass without having negative impacts on carbon stocks. In practice, it is also possible to identify situations where the growing stock of (i.e. standing stem volume) forests steadily increases, whilst annual harvests also increase over the same period. An increase in growing stock must mean that forest carbon stocks are also increasing. The question remains if this increase is a direct result of improved silvicultural practices or if there is another cause, such as the naturally occurring forest growth dynamics. Hence, the impact of the increasing rate of biomass supply on forest carbon stocks cannot be inferred simply from the fact that the carbon stocks are increasing. As partial evidence that forest management could be positively influencing forest carbon stocks, Dale et al. 2017[21] have shown that the area and growing stock of forests have expanded within land areas containing wood-pellet producing mills in the Southeast US since 2009.

In a further study, Kauppi et al[22] have presented a detailed analysis in the context of Nordic/Baltic states. These data are presented in Figure 12.

The work published by Kauppi et al., tested the assumption that there exists a trade-off between the timber harvested from existing forests and the stock of C in those forest ecosystems, asserting that both cannot increase simultaneously. They tested this assumption using detailed forest inventory data available from Finland, Norway, and Sweden, to analyse the development of gross annual increment (GAI)[23] and gross annual decrement (GAD) in these forests over time. These data spanned the period 1960 – 2017 and showed a negligible impact in the total area covered by forests in that region. Moreover, it was observed that, despite significant increases in timber and pulp wood harvests, the annual rate of increase of the forest C stock continued to increase over the study period. Over the study period, the C stock of the forest ecosystems in northern Europe increased by nearly 70%, while annual timber harvests increased at the about 40% over the same period. A key conclusion of this work is that improved forest management has allowed the forest C stock and biomass productivity in the study region to simultaneously increase. It is apparent from this analysis of forests in the Nordic/Baltic states that efforts have already been made to improve forest management in the last century, and biomass supply has also increased. Potentially, this suggest synergies between active forest management to enhance biomass supply and enhancement of forest carbon stocks. However, it could be questioned whether there is further potential to increase biomass supply in the region whilst continuing the maintain or increase carbon stocks. This question is pertinent given that, according to Figure 13, GAI has declined in the last few years of the study period (2015 to 2017), whilst the rate of wood harvesting (or GAD) has continued to rise. As a result, the margin between GAI and GAD appears to be starting to narrow, indicating that the rate of increase in forest stem volume growing stock is diminishing towards the end of the study period.

It is important to recognise that the availability of forest biomass is intertwined with the performance of the broader economy. Timber demand for, e.g., wood in construction, is impacted by recession – fewer houses being built results in reduced demand. This could, in

[21] Dale, V. H. et al., (2017), "How is wood-based pellet production affecting forest conditions in the southeastern United States?", Forest Ecology and Management

[22] Kauppi, P. E. et al., (2022), "Managing existing forests can mitigate climate change", Forest Ecology and Management

[23] GAI and GAD are statistics used in forestry, usually at large scales, as part of assessing forest health and vigour, the impacts of forest management (harvesting) and the extent to which management is 'sustainable'. GAI, or 'gross annual increment', usually represents the total annual growth of stemwood as measured using forest inventory methods (e.g. methods used by countries in National Forest Inventories), before subtracting any losses resulting from annual tree mortality or harvesting. GAD, or 'gross annual decrement', usually represents the total annual losses of stemwood resulting from tree mortality and harvesting. The difference between GAI and GAD represents the total change in stemwood volume stock in the forest area for which the statistics have been calculated. Stemwood volume GAI, GAD and volume stock change are very closely correlated with equivalent measurements for tree biomass and tree carbon stocks, which can be expected to follow very similar patterns of development.

principle, result in degraded forest management, leading to potential instability in the forest. Similarly, weather plays a role, e.g., severe storms in Sweden in 2005 damaged forests leading to a greater rate of harvest. More generally, other disturbances such as forest fires or pests/disease also impact the integrity of forest carbon stocks[24].

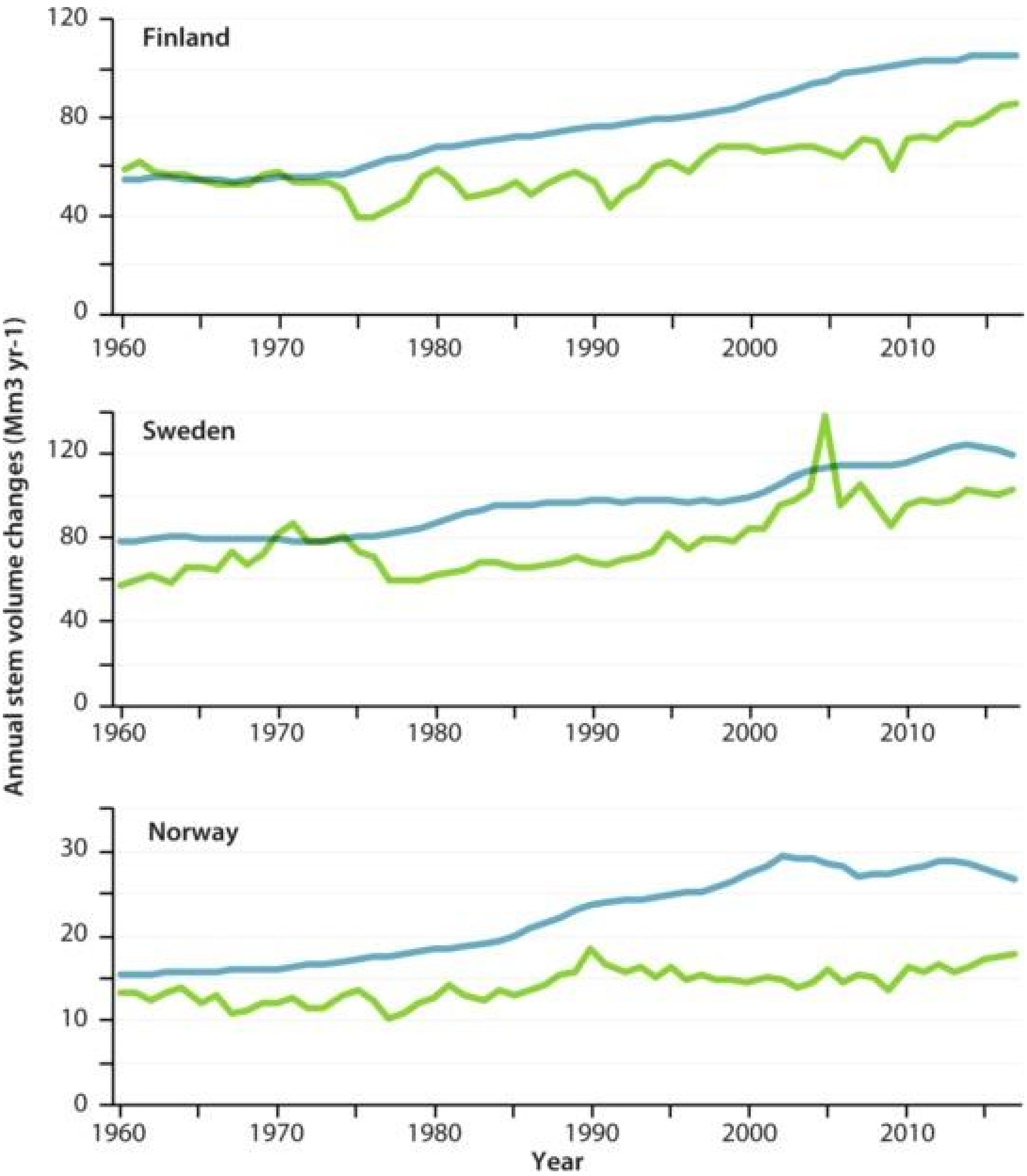

Figure 12: Gross Annual Increment (blue) and Gross Annual Decrement (green) over time for Finland, Norway, and Sweden on the productive forestland (from Kauppi et al., 2017).

[24] Chiquier, S., Fajardy, M., Mac Dowell, N. (2022), "CO_2 removal and 1.5° C: what, when, where, and how?", Energy Advances

Ongoing public acceptability concerns regarding BECCS

The foregoing notwithstanding, BECCS remains a persistently controversial pathway for removing CO_2 from the atmosphere. Work by the Green Alliance has identified four primary concerns that are associated with BECCS:

- Risk that poor quality carbon credits undermine growth in carbon removal markets.
- Concern that over reliance on GGR deters emissions abatement and undermines efforts to achieve net zero.
- The potential for the costs of engineered GGR to fall on the public owing to inefficient allocation of GGR capacity.
- GGR being deployed at such significant scale that it leads to negative sustainability impacts, and that cost pressures will drive practitioners away from sustainable best practice.

These are all entirely legitimate concerns, which must be carefully addressed.

It is important to recognise the need for robust and effective regulation/certification in this space. Ensuring a robust and transparent regulatory regime will help assuage at least some of the concerns described above.

There is also clearly a role for better public engagement and communication on this issue. Importantly, many of the concerns identified by the Green Alliance are policy choices – they are not inevitable, and can be avoided, or at least mitigated, with care. Based on what the T&F group has considered, within the scope of the group there are no insurmountable science-based obstacles to delivering BECCS at the levels of activity proposed by UK net zero ambitions.

Importantly, throughout the entire discussion, the operative word has been “choice”. The government can choose to support BECCS, or not. The government can choose to ensure a sustainable biomass supply chain, or not. But there are no avoidable scientific barriers.

Conclusions

The T&F group concluded that they had not identified any significant and insurmountable scientific barriers to the permanent removal of CO_2 from the atmosphere via BECCS with sustainable supply chains when well-regulated. It is important to recognise that there are substantial existing regulations that cover the cultivation and harvesting of biomass for bioenergy purposes, in addition to a range of industrial “best management practices”. These can be built upon to support and assure that biomass is supplied with small negative, neutral or positive impacts on carbon stocks. However, this relies on robust accounting standards which are not currently in place in many countries.

It is noteworthy that the preponderance of the discussion was on the sustainability of the biomass supply chain, with the only real discussion being around how this can be ensured and certified. The ability of the CCS element of the value chain to technically deliver was taken as read. However, it goes without saying that this is only possible in the context where CO_2 transport, and storage infrastructure is available.

The issue is primarily one of choice in terms of how the integrity of the biomass value chain is curated, regulated, and maintained. Thus, in delivering GGR via BECCS, it could be mandated that all biomass used be certified as compliant with, e.g., SBP or equivalent certification, with additional Monitoring Reporting and Verification for carbon stock impacts and the CCS element of the BECCS value chain. It will be important for an equivalent certification process to be established for other GGR pathways to ensure a level playing field, taking due consideration of other aspects such as the permanence of carbon dioxide storage.

Importantly, forest biomass can be robustly and reliably monitored with currently available technologies and carbon stock monitored by a modest extension to normal forest inventory practices. However, it is also vital to understand how changes in monitored forest carbon stocks are related to evolving management practices.

This notwithstanding, public opinion remains, at best, divided on the issue of GGR in general and BECCS in particular. In many respects, this appears to be an issue of understanding and perceptions of risk across a broad range of factors and geographies.

Anecdotal and systematic evidence suggests that improved forest management can lead to both an increase in standing forest stock and also forest biomass productivity. However, the challenge is to ensure that this continues to be the case going forward, if consumption of forest biomass is further increased owing to use of wood in construction, increased demand for bioenergy, and GGR. The onus is therefore on HMG to establish what represents minimum standards in sustainability and to demonstrate adherence to this when incentivising increased biomass use. Finally, it will be imperative that these standards are, in fact, practicable, and will not disincentivise the landowners from maintaining those forests. These points and those outside the scope of the T&F group have been explored as part of the Biomass Strategy.

Acknowledgements

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The following were members of the Task and Finish Group, who contributed to meetings, provided advice and information, and commented on this report. This does not, however, imply that the report received unanimous agreement or endorsement from all members.

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