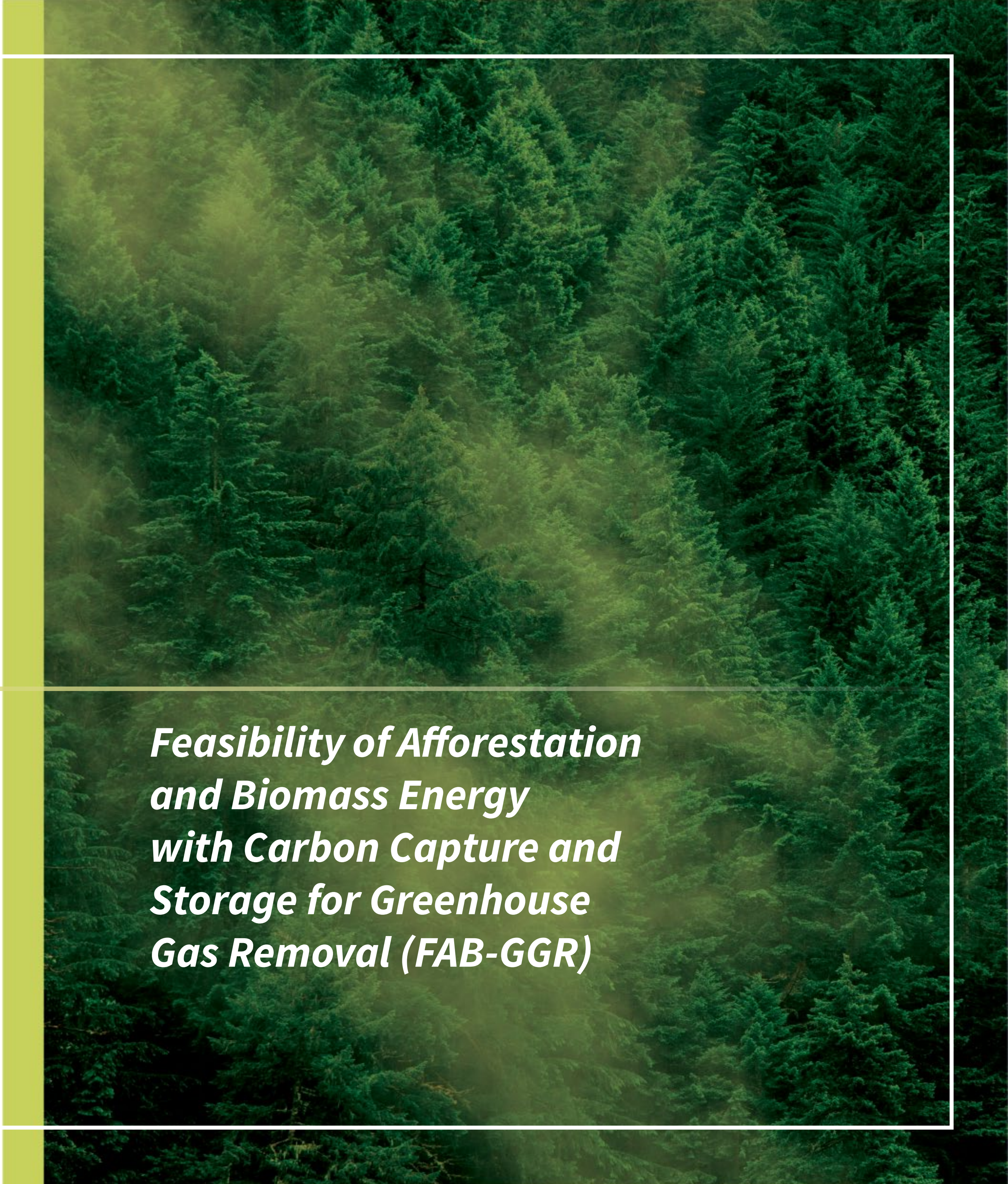
GREENHOUSE GAS REMOVAL
RESEARCH PROGRAMME

UK GGR Research Programme
Policy Brief



Feasibility of Afforestation and Biomass Energy with Carbon Capture and Storage for Greenhouse Gas Removal (FAB-GGR)

Summary

Forest planting and bioenergy with carbon capture and storage (BECCS) are two of the more common approaches to greenhouse gas removal (GGR) found in future paths to net zero. Expectations around what they can deliver are high. In its sixth Carbon Budget, the Climate Change Committee (CCC) suggests that in the UK, the removal of 53 Mt CO_2 will be required per year by 2050 using BECCS, and up to 15 Mt CO_2 removed per year by afforestation (Climate Change Committee, 2020).

To ensure these two GGR approaches can feasibly deliver, policy must be guided by research into the factors that influence the amount and permanence of the removal, and evidence-based insight into possible knock-on effects that might counteract overall impact.

The FAB-GGR project is the first interdisciplinary assessment of feasibility in the UK of greenhouse gas removal (GGR) by BECCS and large-scale tree planting.

Its research shows that the effectiveness of removal by BECCS is influenced by the type of biomass that is used and where this biomass is grown. Similarly, afforestation depends not only on the type of forest but also the location of where it is grown. Looking at the bigger picture, feasibility depends on land availability and impacts from any resulting land use change. Overarching these aspects of viability are factors around supply chains, storage capacity, public involvement in decisions and how these GGR approaches fit within the context of decarbonisation strategies, both nationally and globally.

Taking Miscanthus as an example, the project has researched scaling up the growth of this biomass grass and demonstrated that yields vary (Shepherd et al., 2020) but, at best, it can only produce a fifth of the CCC estimates of what is expected from BECCS in the UK. And this will depend on availability of land, impacts of land use change and acceptability. Research investi-

TABLE OF CONTENTS

gating the GGR potential of two options in the UK – using wheat straw as a fuel with carbon storage to produce combined heat and power (CHP), and hydrogen production using waste wood with carbon storage – estimated that the two systems together could achieve 4.6 Mt of CO_2 per year. This was dependant on using all the national wheat straw (based on 2017 data) and waste wood (based on estimates from 2013-2061) that is available for biomass production in the UK (Almena et al., 2022).

These findings highlight the technical challenges for just two options of BECCS. In addition, if the nested factors from type of biomass to geographical location to societal and global context, are not considered in the deployment of both afforestation and BECCS, then they will be more unlikely to meet their CO_2 removal expectations. A combination of different BECCS pathways will be necessary to reach net-zero targets (Almena et al., 2022). New policy incentives and business models will need to guide their development and these must consider the multifaceted nature of GGR approaches and the many inter-dependent factors that influence their feasibility. The development and implementation of BECCS and afforestation must be done responsibly with community engagement.

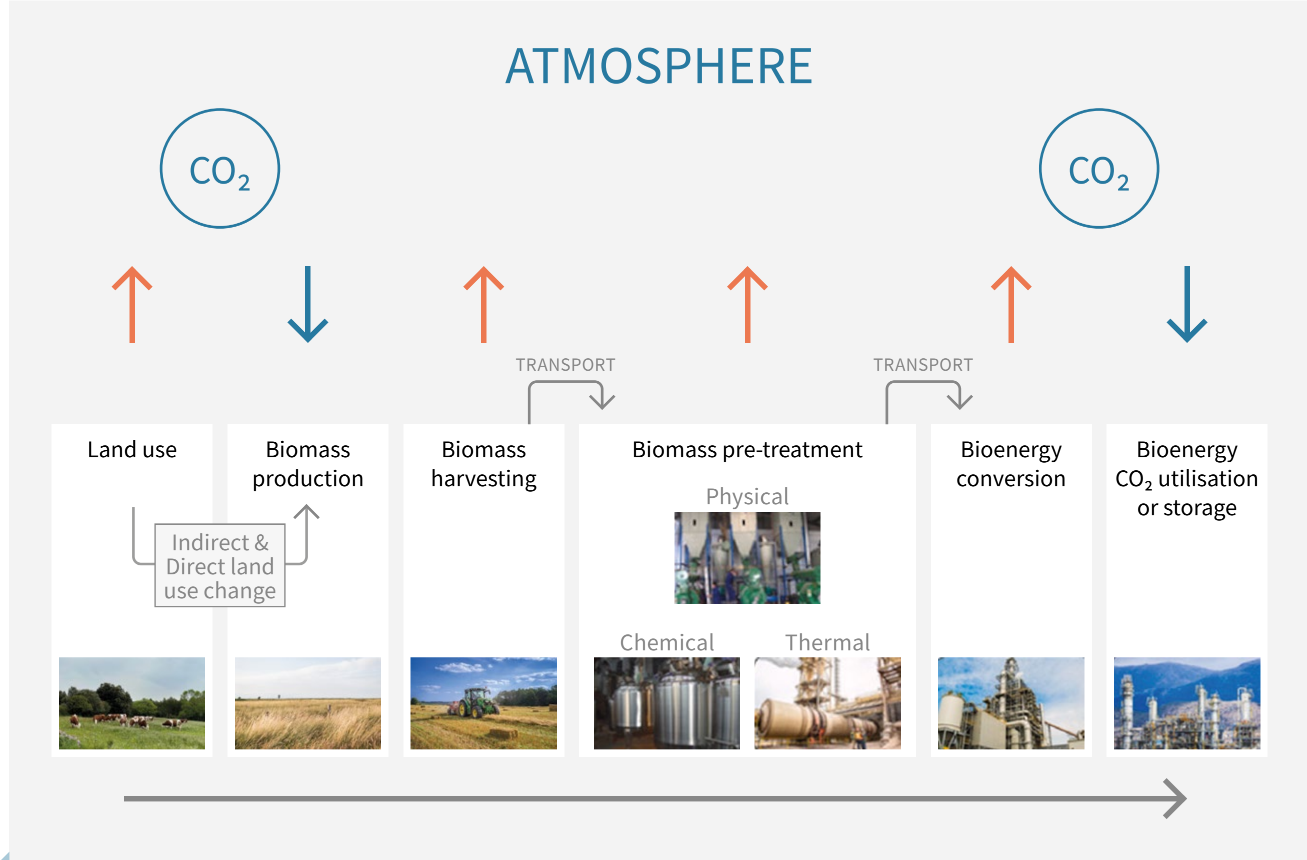


FIGURE 1: **BECCS supply chain. The resulting balance of CO_2 sinks (blue arrow) and sources (red arrow) will determine the net-negative emission potential of the system (adapted from Almena et al., 2022).**

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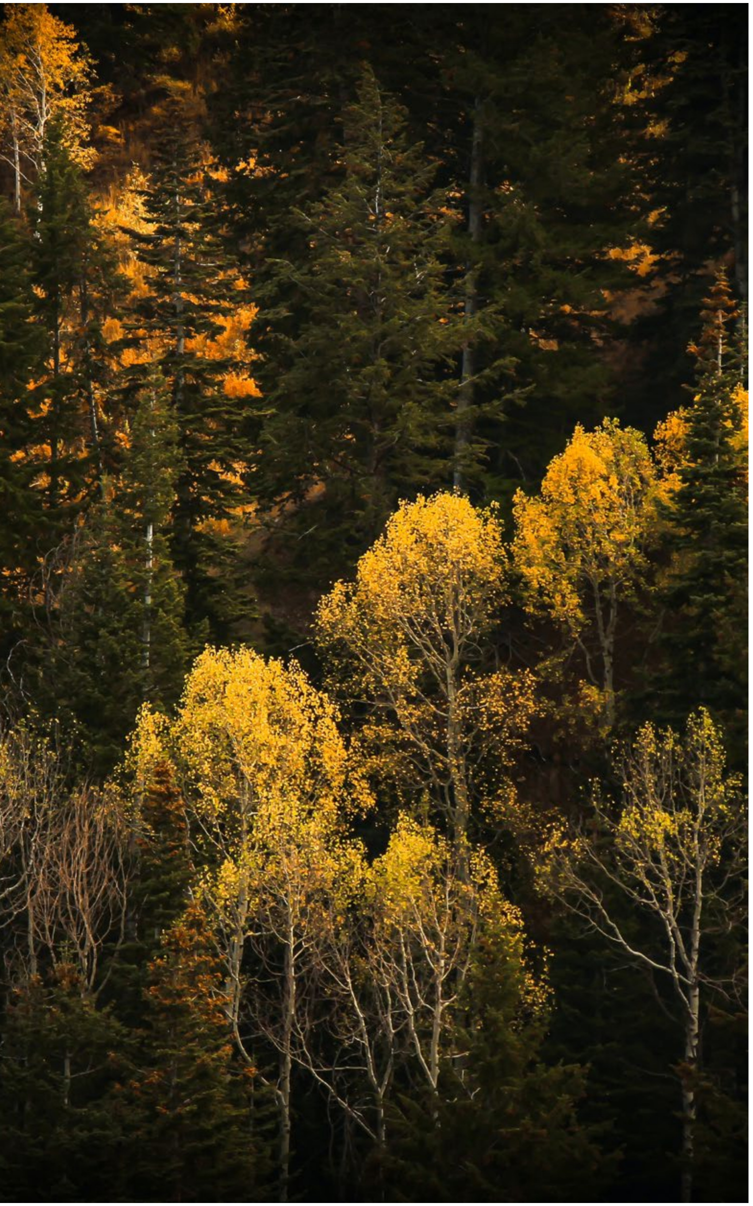


Recommendations

Afforestation should be part of wider strategies around climate change and biodiversity, with the use of mixed forests and native species. Business models to incentivise BECCS and afforestation should consider multiple objectives and co-benefits beyond cost and carbon removal. It is essential to incorporate these real-life complexities of implementation to enable these GGR practices to work sustainably.

GGR is limited by land availability. Deployment of BECCS and afforestation in the UK should consider policies around land use change and how these affect the ability of these approaches to remove CO_2.

For BECCS to deliver CO_2 removal, the development of a network for CO_2 transport and storage is essential. Research is needed to help clarify what the infrastructure will look like for different regions and what this will require in terms of costs and public engagement.

Public discussion around BECCS and afforestation as GGR practices is currently limited. Better understanding of how the public conceptualises tree-planting and how communities are currently engaged in this area will help develop more informed approaches and harness existing motivation.

Engagement with local communities, including farming and landowning communities, is central to ensuring the environmental, technical and social success of afforestation. Responsible development is key for both BECCS and afforestation, and assessments should incorporate pathways for public involvement.

Better understanding of how the public conceptualises tree-planting and how communities are currently engaged in this area will help develop more informed approaches

1. Trees: where and how they are grown

Trees can be planted in a variety of ways (see box 1). The type of tree and where it is planted contribute to how much carbon can be stored and for how long. Research has shown that tree species and previous land use both influence levels of carbon sequestration in the soil (Guo et al., 2021).

Forest management is also instrumental to carbon storage. Trimming, replanting and harvesting can enable more sustained CO_2 removal, whilst forest by-products can be used for timber or bioenergy. Research has indicated that CO_2 removal is greater in slow growing forests with longer rotations compared to faster growing forests with shorter rotations, and the maximum climate benefit is delivered at a different point in time for different forest systems (Röder et al., 2019).

Involving local communities to provide insight on the connection to trees and opinions on how trees should be used can help ensure any afforestation is embedded in society

2. The multifaceted nature of forests: perceptions and values

According to research with stakeholders from UK business, policy and civil society, afforestation is considered to be the most feasible and cheapest form of GGR (Clery et al., 2021). Research on social media has found that tree-planting is a popular subject of discussion in the public domain compared to other forms of GGR. However, the awareness is not ostensibly around forestry as a GGR approach but around tree-planting for conservation and recreation with some consideration towards offsetting carbon. Debates on social media around afforestation and GGR remain distinct conversations (Waller et al., 2020).

Forestry is not only a means to remove CO_2 but provides other functions (or ecosystem services) such as biodiversity conservation, flood mitigation, recreation space and human wellbeing (Clery et al., 2021; Forster et al., 2020). Views on the inherent value of forests, apart from CO_2 removal, must be considered in GGR deployment.

Research with stakeholders from UK business, policy and civil society suggests that a mix of planted tree species, rather than monoculture plantations, are socially preferred and could maximise biodiversity benefits in local areas (Clery et al., 2021). Involving local communities to provide insight on the connection to trees and opinions on how trees should be used can help ensure any afforestation is embedded in society.

Types of tree planting

BOX 1

URBAN TREES AND WOODLAND – Areas of green cover in towns and cities, ranging from trees in streets and gardens to woods

FORESTS – Large areas covered mostly by trees and undergrowth

AGROFORESTRY – Integration of trees in the agricultural landscape, in fields and hedgerows

AFFORESTATION – Creation of forest on areas not naturally forested in recent times

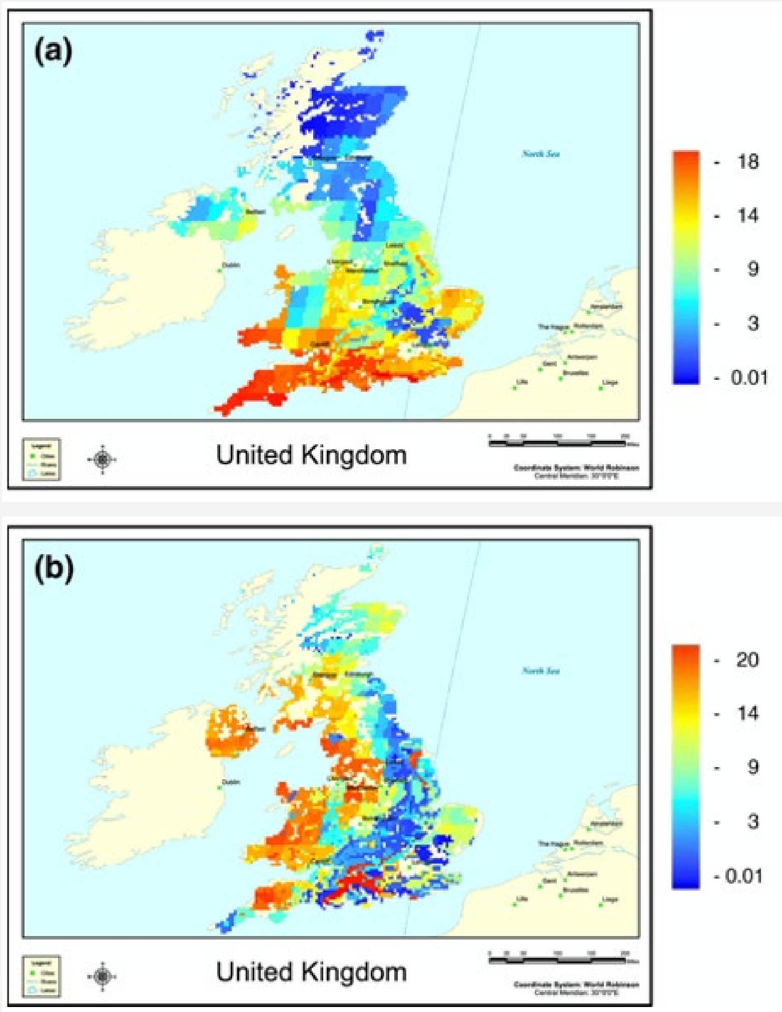
REFORESTATION – Re-creation of forest on a previously forested area

3. Limits of land availability on GGR effectiveness

The amount of land available for afforestation or growing biomass for BECCS is a key limiting factor for GGR in the UK. For BECCS, different biomass feedstocks, such as wood pellets, grasses or short rotation coppice, yield different levels of carbon removal. Researchers on the FAB-GGR project have estimated how much CO_2 the giant grass Miscanthus could sequester in the UK (see box 2).

BOX 2

Taking Miscanthus x giganteus as an example of a biomass energy crop, research on scaling up its growth has shown that yields vary (Shepherd et al., 2020) (see figure 2) but average about 12 tonnes per hectare per year, providing an estimated aggregated carbon sequestration rate for the UK of 10.5 Mt CO_2 per year from the atmosphere using land for BECCS crops modelled in the Integrated Assessment Model (IAM) for the SSP2 scenario. This land use would be equivalent to the conversion of 10% of UK's arable land and 10% of UK's grasslands to Miscanthus x giganteus. This is only a fifth of the Climate Change Committee estimates of what is expected from BECCS in the UK.



Historical climate (1960-1990)

Future 2°C climate (2090-2099)

FIGURE 2: **Yield of Miscanthus in dry matter in tonnes per hectare per year for 1961-1990 under historic climate conditions (a) and 2090-2099 under representative concentration pathway (RCP) 2.6 that requires zero emissions by 2100 (b). In (b) the pattern was predominantly influenced by projected soil water deficit with future rainfall patterns projected to be higher in the west of the UK (adapted from Shepherd et al., 2020).**

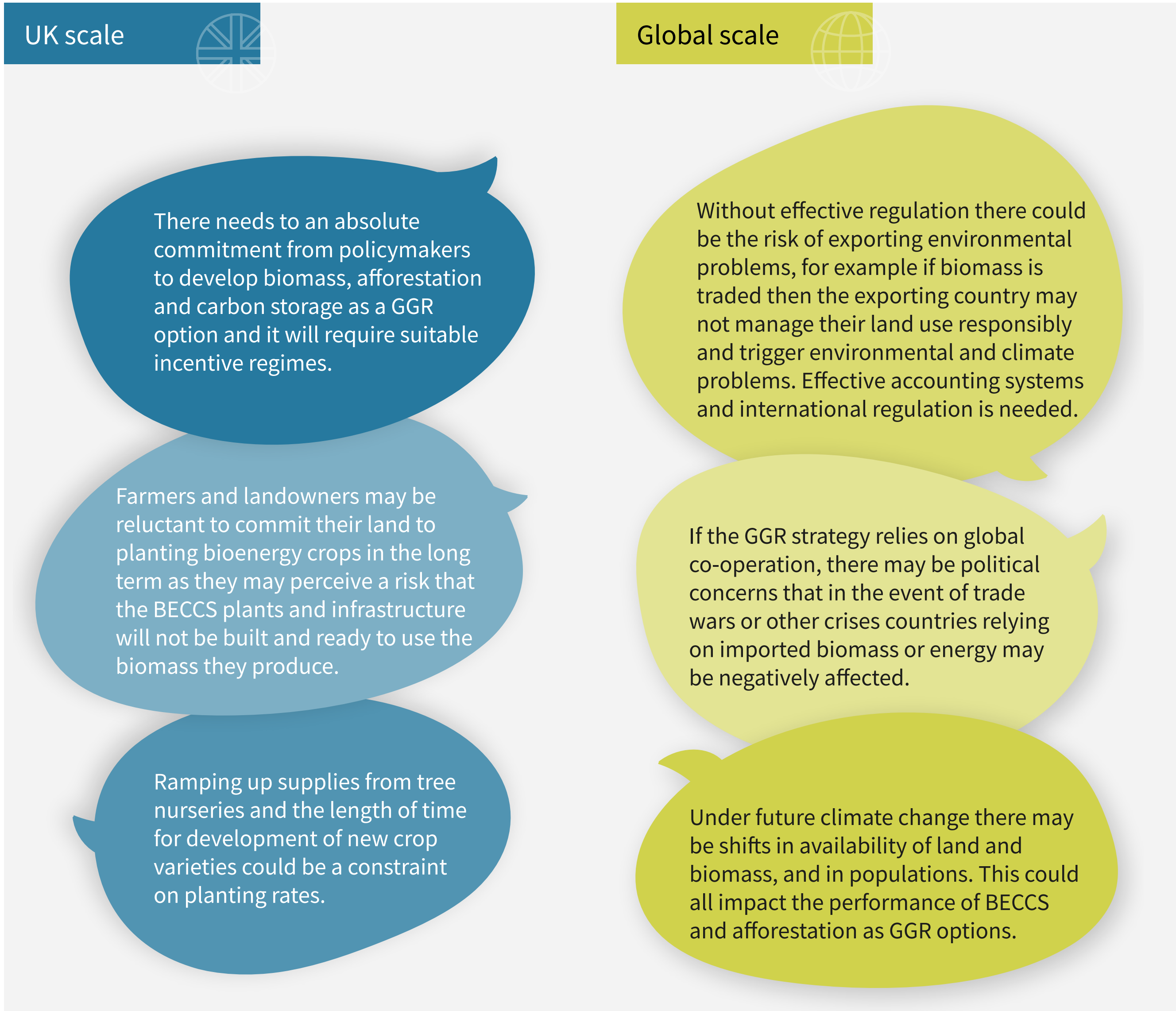
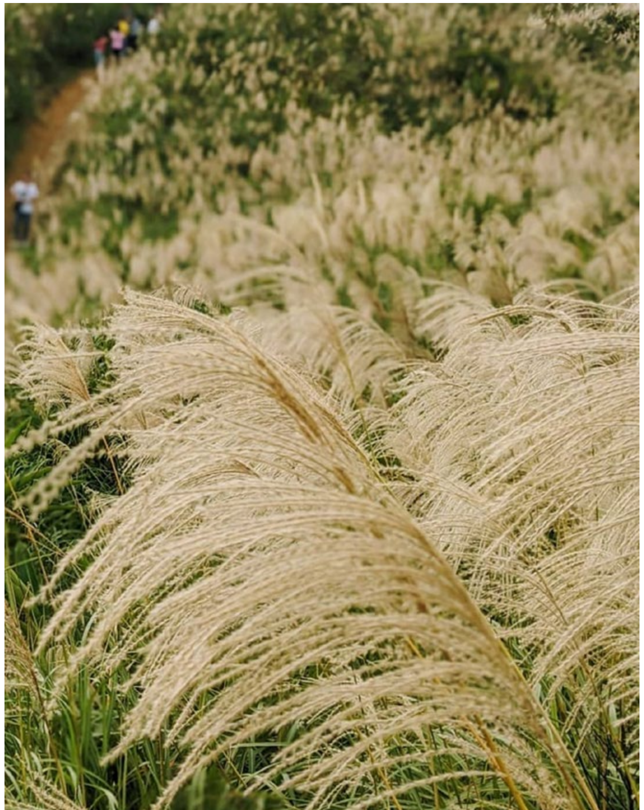


FIGURE 3: **Examples of pinch points in scaling up BECCS and afforestation at a UK scale and a global scale based upon quotes from stakeholders.**

The research assumes that scaling up will be possible on the land identified as suitable for this crop.

In reality, there is evidence that the amount of land available for bioenergy or afforestation in the UK depends on several interconnected constraints within societal systems, such as land tenure and diet, as well as policy effectiveness (Clery et al., 2021) (see figure 3). These must be considered in any estimate of land availability.



4. Comparing BECCS and afforestation: efficiency, ecosystem services and feasibility

There are many different forms of BECCS (and types of tree planting) that vary in both the feedstocks they use (wood pellets, straws or bioenergy crops) and what type of energy they provide (electricity, a transport fuel or hydrogen). There will likely be competition between forestry and bioenergy crops (Albanito et al., 2019; Donnison et al., 2020; Shepherd et al., 2020) and trade-offs between different uses of land. For example, forests take decades to reach their full CO_2 sequestration potential, whilst BECCS facilitates CO_2 removal during processing.

Research from the FAB-GGR project in the UK suggests that larger scale BECCS facilities are more efficient, both for GGR and energy production (see box 3) (García-Freites et al., 2021). However, choosing the best options will strongly depend on the decarbonisation pathway that the UK takes and how our energy system develops in the future. For example, combined heat and power can offer a solution for decarbonising heat if the infrastructure is in

Different UK BECCS options to remove 20 $MtCO_2$

BOX 3

FAB-GGR researchers used process modelling and lifecycle assessment to identify the GGR potential of three BECCS supply chains. Results depend on specific assumptions but the general trends hold (Garcia-Freites et al, 2021).

10 — 620MW

large power plants (620 MW) using sawmill residues from USA

32 — 20MW

small combined heat and power plants (20MW) using Miscanthus

18 — 232MW

advanced facilities (232MW) that make hydrogen to generate electricity using willow

This result for how many facilities would be needed to remove 20 $MtCO_2$ is not limited by domestic biomass availability. However, using as much national sustainable resources as possible is still preferrable. Scaling down and decentralisation could improve the flexibility and functionality of bioenergy processes to reach more resources (Almena et al., 2022).

The results show that BECCS can deliver effective GGR, but that the potential of the different BECCS supply chains can vary significantly and each presents its own challenges. Prioritising GGR penalises biomass-to-energy yield and, therefore, BECCS economic performance, which could lead to less attractive commercial activities and hinder investment.

Policy frameworks can be effective drivers to endorse BECCS development at this stage, by seeking future improvements in efficiency that can allow this technology to deliver removal alongside higher bioenergy and GGR rates (Almena et al., 2022). To do this, evaluation must go beyond carbon performance and consider specific engineering, economic, social and policy challenges and trade-offs as well as how BECCS approaches will fit with future decarbonisation strategies and energy systems.

place, whereas if hydrogen becomes dominant in the decarbonisation of transport, then BECCS facilities that make hydrogen could become more feasible.

Forests have an inherent value beyond CO_2 removal and, although BECCS removes more carbon than afforestation, the growth of trees has more co-benefits such as biodiversity and human wellbeing. These must be considered in decision-making and when incentivising GGR.

Stakeholder research indicates that successful GGR implementation will require novel business models for carbon removal to manage incentives and reimburse multiple objectives and co-benefits beyond carbon removal and cost. The form of these incentives will have implications for farming and landowners, which in turn will affect the feasibility of GGR approaches (Forster et al., 2020). All this must be considered in how we approach BECCS and afforestation as GGR techniques.

There is a need to ensure that sustainable biomass production, land availability and carbon, capture and storage (CCS) networks are in place for GGR supply chains, particularly in terms of CO_2 transport and storage. Alongside these practical issues, more responsible development will help anticipate possible future consequences of GGR and shape responses to public values and societal concerns (Waller et al., 2020).

Social media analysis indicates that GGR is not being discussed in public and media debates and more effort is needed to engage with stakeholders and communities to ensure successful and resilient policies.

There is a need to ensure that sustainable biomass production, land availability and carbon, capture and storage networks are in place for GGR supply chains

5. Global feasibility of GGR

GGR is a global approach and should be evaluated at a global scale. The Intergovernmental Panel on Climate Change scenarios which are used to explore how temperature targets can be achieved are not able to account for some real-world aspects that have been identified as influential in the success of GGR. These include political will, public responses and international disputes. These must be considered alongside the biophysical and technological aspects.

While social acceptability is not explicitly represented in the models, it is crucial and potentially unpredictable in the context of the rapid expansion of a new technology on a very large scale. Two key factors affecting public responses are scale – with smaller scale operations more likely to be accepted – and early public and community involvement in planning and consultation.

5. 1 Assessing the global yields of bioenergy crops

Understanding the yield of bioenergy crops (biophysical potential) at the global level is vital to understanding how much BECCS can be expected to deliver in terms of CO_2 removal. Integrated Assessment Models (IAMs) have specific assumptions about the type of biomass used for bioenergy, the availability of CO_2 storage capacity, future diet and land use trends, the development of a large-scale biomass energy market and the contributions from other technologies to decarbonising the wider energy system.

Research investigating a low emission scenario in which half the biomass supply was derived from crop and forestry residues found that global biomass supply is likely to be sufficient to meet 1.5 or 2 °C targets. However, for this to happen it must be combined with deep cuts in emissions and strong governance over the land used for bioenergy crops, i.e. not causing deforestation or threatening food supply (Vaughan et al., 2018).

In certain dry regions, such as East Africa and dryer parts of Brazil, the projected yield of bioenergy crops varies substantially (Littleton et al., 2020; Shepherd et al., 2020), suggesting that more heat- and drought-resistant crops will be needed to ensure a less variable yield. Planting the right crops in the right place together with decarbonisation of our current energy systems will be required to achieve a sufficient global bioenergy supply to meet climate targets (Zhang et al., 2020; Zhang et al., 2019) - but there are no guarantees that the amount of biomass required will be available.

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5. 2 Incorporating the indirect effects of BECCS at a global level

Biomass is not only used in BECCS but it is also needed globally for food supply and as a renewable energy source. Land use policy must be part of any GGR strategies, but currently there are multiple initiatives and overlapping policy frameworks which impact land-based carbon removal. These need to be co-ordinated for verified GGR.

Land use change resulting from conversion to growing bioenergy crops may reduce the carbon removal or lead to net carbon emissions from the BECCS supply chain. This may be directly through deforestation or indirectly through planting on high carbon soils (Harper et al., 2018; Littleton et al., 2020; Shepherd et al., 2020). On the other side of the scales, global efforts to reforest and restore degraded forests could recover close to half of the carbon already lost from ecosystems by 2100 (Littleton et al., 2021).

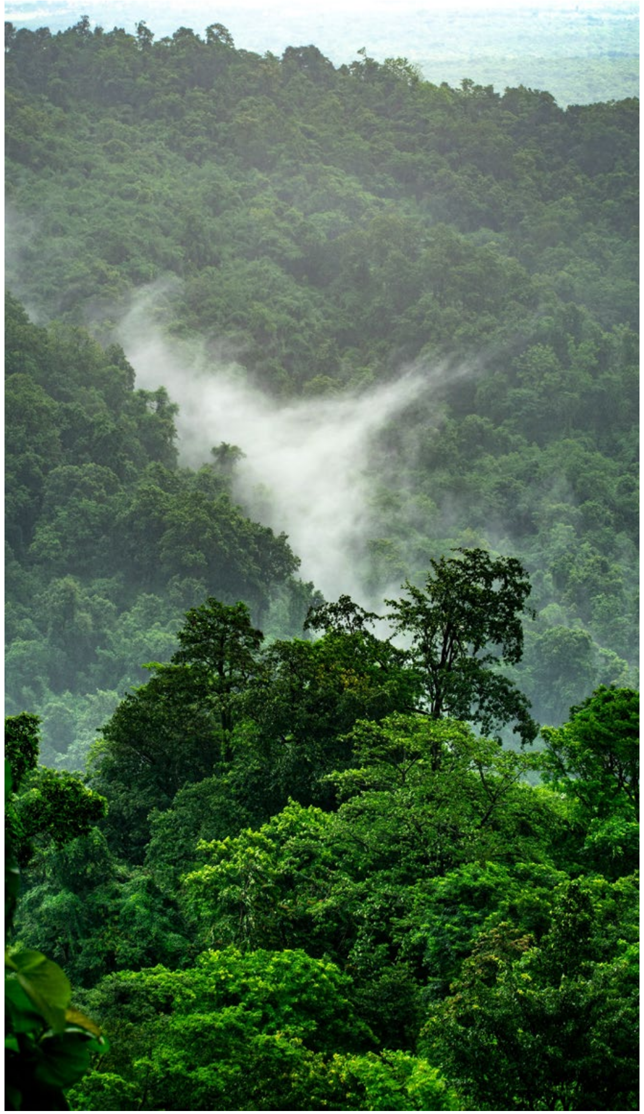
Land use change resulting from conversion to growing bioenergy crops may reduce the carbon removal or lead to net carbon emissions from the BECCS supply chain

Financing suitable BECCS and afforestation approaches whilst delivering co-benefits such as biodiversity, soil health and energy provision is a key goal for policy makers and landowners globally (Clery et al., 2021; Forster et al., 2020; Gough & Mander, 2019).

5. 3 Evidence for the global feasibility of GGR

Research from the FAB-GGR project suggests that we need to think critically about the evidence for the feasibility of GGR. Societal resistance to the development and deployment of GGRs is likely to emerge if large scale afforestation and BECCS fail to address issues of responsibility and public accountability for GGR (Waller et al, 2020). This conversation is not currently happening in the public domain and it needs to be instigated, curated and incorporated into action.

The global-scale roll out of GGR supply chains will require cooperation between countries (Clery et al., 2021). Verification of carbon removals must take into account the diversity of GGR supply chains (Almena et al., 2022) and consider what is the most appropriate metric to use. Measurement of the amount of CO_2 removed must include carbon losses from land conversion, particularly of high-carbon land areas such as those with high-carbon soils or tropical rainforests (Harper et al., 2018).



Verification of carbon removals must take into account the diversity of GGR supply chains and consider what is the most appropriate metric to use

Next steps

When assessing the feasibility of afforestation and BECCS, the focus should not be just on technical and biophysical aspects, but must also consider the potential impact of broader public values and societal concerns. Engagement with local communities will be needed before large new forests are planted to maximise the social and environmental success of these approaches. The next stage of trialling GGR should assess the best way to incorporate engagement. Social science will play an integral role.

GGR is limited by land availability and should only be used to compensate for those human activities that cannot physically and technically be decarbonised. Otherwise, it may deter mitigation of avoidable emissions. Future research and trials should investigate how to prevent the use of GGR to offset emissions that could be reduced in other ways.

There is a balance to be struck between facilitating faster planting rates, through changes to regulation and new incentives, and preventing inappropriate tree planting, which could jeopardise support for greater afforestation rates. How to reach this balance needs to be investigated in the next stage of assessing GGR techniques.

There are a number of policies that will affect UK land use and the UK's ability to deliver up to 53 Mt CO_2 removed per year from BECCS and up to 15 Mt CO_2 removed per year by afforestation. How these policies will incentivise or discourage BECCS and afforestation must be considered as we look to scale up these GGR approaches.

The development of a network for carbon dioxide transport and storage is essential for BECCS to deliver removal. Alongside assessing the efficacy of the technologies, we must assess the necessary logistics for them to be delivered and to be effective.

Questions for next generation of research projects to address

BOX 4

- How best can we engage with communities to ensure BECCS and afforestation projects incorporate public views and values into the development and implementation of these GGR approaches?
- What infrastructure and logistics need to be in place to enable the necessary CO_2 transport and storage for large scale BECCS?
- How can we ensure appropriate planting of the right tree in the right place alongside sustainable land use, whilst also facilitating faster planting rates to meet afforestation targets?
- What is the current understanding of BECCS and afforestation in the public domain and how can we harness the existing desire to support tree-planting whilst ensuring it is done in a sustainable way?

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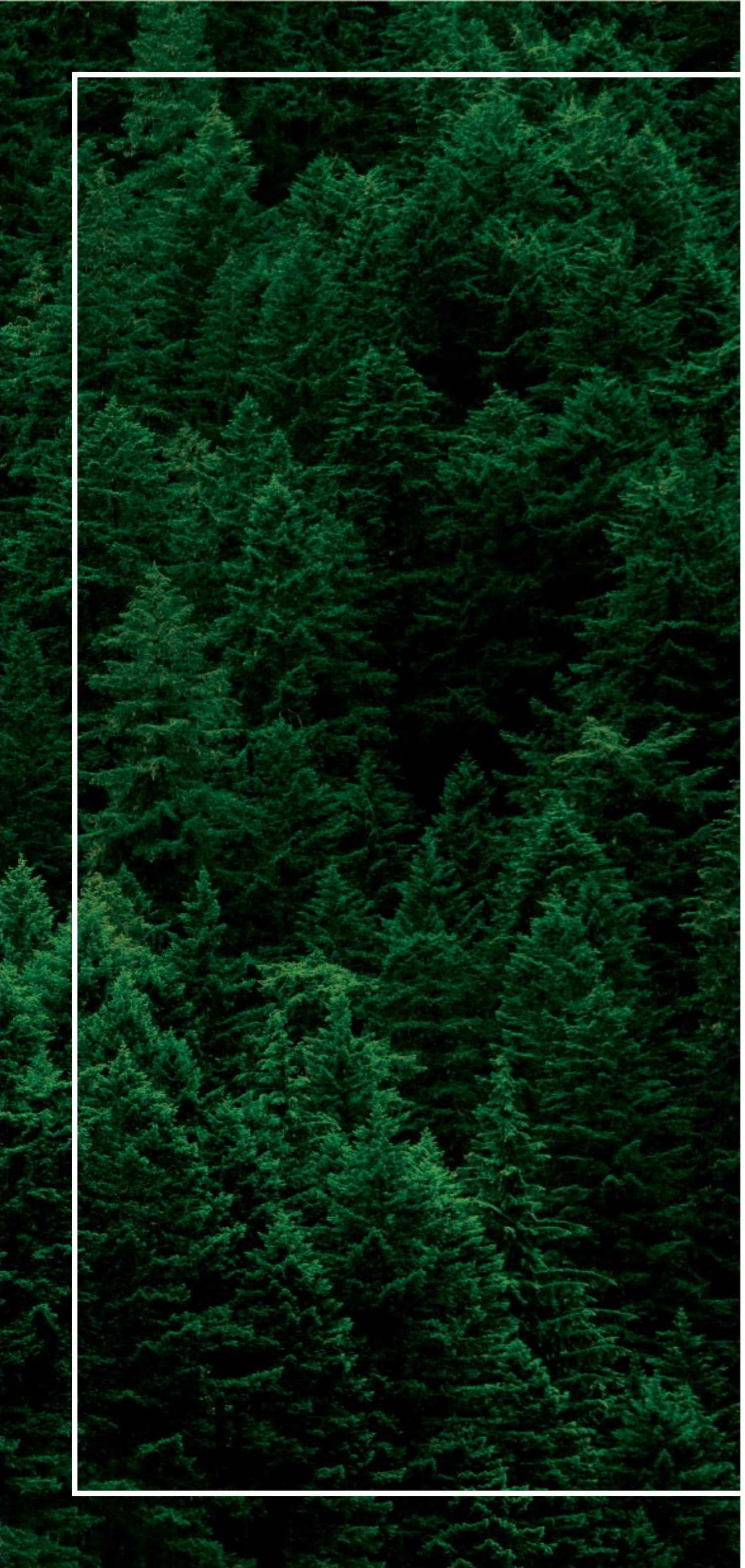
About the programme »



About the programme

The Greenhouse Gas Removal research programme aims to improve our knowledge of the options for removing carbon dioxide and other greenhouse gases from the atmosphere. Through eleven component research projects it addresses the environmental, technical, economic, governance and wider societal aspects of such approaches on a national level and in an international context to inform implementation of climate policy pathways that include large scale removal of carbon dioxide.

Feasibility of Afforestation and Biomass Energy with Carbon Capture and Storage for Greenhouse Gas Removal (FAB-GGR) is one of eleven components. This policy brief was created in collaboration with Dr Nem Vaughan, Dr Diarmaid Clery and Dr Anita Shepherd, and with contributions from all the project members.

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