FORESIGHT TRANSITIONS

climateworks FOUNDATION

ATKINS

Member of the SNC-Lavalin Group

Authorship

Lead Author and Analyst:
Richard Heap, Foresight Transitions

Oversight and Strategic Guidance:
Mark Workman, Foresight Transitions & Imperial College.

Advisor:
Steve Hall, University of Leeds

Advisor:
Harry Armstrong, Nesta

Acknowledgements

The report was made possible with the support from ClimateWorks Foundation. Additional support with the publication was provided by Atkins.

The authors would like to extend a special thanks to Andy Gouldson and the Leeds Climate Commission, West Yorkshire Combined Authority, Leeds City Council, and the Imperial College MSc students who contributed to the analysis. And, to all who helped with the stakeholder mapping and contributed through the workshops and interviews, recognising that many were interviewed in confidence and unattributed.

About Foresight Transitions

Foresight Transitions was set up in 2017 and provides bespoke analysis based on fundamental research around financial modelling, user perceptions and experiences, technological development and regulatory and policy risks in possible futures accommodating for deep uncertainty.

We also offer a unique level of research to assist decision making under deep uncertainty across the technology transitions, resource systems, environmental and climate change issues.

Disclaimer

Imperial College London

UNIVERSITY OF LEEDS

climateworks FOUNDATION

ATKINS
Member of the SNC-Lavalin Group

There is a growing interest in Greenhouse Gas Removal (GGR) as businesses, industry, local authorities and individuals come to terms with what net-zero carbon emissions means.

CONTENTS

GLOSSARY

AONB	Area of Outstanding Natural Beauty – a designated land use defined by legislation
BECCS	Bio-Energy with Carbon Capture and Storage
BECCU	Bio-Energy with Carbon Capture and Utilisation
CAP	Common Agricultural Policy – European agricultural support policy
CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal, see also GGR
DACS	Direct Air Capture and Storage
DACU	Direct Air Capture and Utilisation
ELMS	Environmental Land Management Scheme – proposed new UK legislation to replace EU Common Agricultural Policy
GGR	Greenhouse Gas Removal, also commonly referred to as Carbon Dioxide Removal or Negative Emission Technologies
NETS	Negative Emission Technologies, see also GGR
SSSI	Site of Special Scientific Interest – a designated land use defined by legislation

EXECUTIVE SUMMARY

Even with aggressive mitigation effort achieving the Paris climate ambitions of remaining below 1.5°C means the UK will need a portfolio of GGR techniques to draw down about 100 million tonnes of CO_2 per year by 2050. Globally the GGR economy needs to become a multi giga-tonne scale sector. At present, the combined global negative emissions stand at less than a few thousand tonnes per year.

New global industries will be created, expanding rapidly to reach the scale of some of the world's largest activities, such as the oil and gas sector and agriculture, in the next 30 years. Deploying carbon removal technologies at this rate and scale will raise significant social, cultural and environmental issues in the local communities and regions. However, it is widely recognised that the governance frameworks to enable this transformation and ensure its appropriate use are fragmented and inadequate.

This project explores what deploying the various carbon removal options will look like on the ground to understand the implications from the bottom up. It sought to:

- Explore how participation and social co-production influence social legitimacy of carbon removal technologies and the implications for governance.
- Build a database of non-financial values for deploying each option.
- Map the complex value-chains for the options for the region.
- Develop a participatory engagement toolbox and lessons learnt from the bottom up study.

Using Yorkshire, in the United Kingdom, as a case study, the project undertook over 100 interviews with the communities, stakeholders and interested parties to generate an evidence base of the attitudes and responses to local deployment of carbon removal options. It also undertook two participatory workshops with over 30 participants with broad representation.

The approach is as important as the issues

The values and perspectives that will arise from deploying the multiple carbon removal technologies will need to be negotiated and addressed for each location and region. It is imperative that these new technologies are evaluated from a variety of framings and viewpoints rather than purely a technical and least cost basis in order to gain approval. Perspectives are already becoming polarised. Evidence from forestry already shows that societal aspects will define the potential scale at which the technologies will be deployed.

How the issues are addressed is as important as the issues themselves. Other sectors have already shown that failure to invest time and effort into early engagement with local communities around large infrastructure proposals can lead to disruption, for example, onshore renewables and fracking. Building public trust will be vital, requiring a proactive, participatory approach that works with the local communities and national publics to develop solutions and realise opportunities. Existing frameworks are inadequate.

The lack of awareness and understanding of CDR amongst the public is a substantive risk to deployment. Uncertainty about new technologies undermines social acceptance and questions the motives of the developers. Provision of open and honest information, combined with a participatory approach, will allow a more informed debate of the issues. Developers along with national and local governments need to raise awareness and build capacity to allow engagement on the carbon removal as a matter of priority.

[1] 1000 Million tonnes

Recommendations

Embed participation into governance

Government departments for energy, industry, transport and aviation, agriculture, food and land use, and environment[2] should adopt an Anticipatory Governance approach to the development and deployment of carbon removal and achieving the net-zero target. A proactive and participatory approach to public engagement will identify issues early, allowing a balanced consideration of concerns and opportunities. This will inform the governance frameworks that will be needed.

- **Carbon Dioxide Removal is integral to achieving the net-zero target, but a clear understanding is needed of the role it will play in abating climate change and how it integrates with reducing emissions.** Clear definitions will be needed for how removals and GGR options should be incentivised and supported and who will be able to access them.
- **Strategic guidance and governance are needed on how GGR integrates with other policy priorities particularly agriculture, biodiversity, and energy.** Developments will be contested with decisions and trade-offs between the objectives made at a local level. They will need to integrate with top down strategic guidance and scientific input.
- **Local and regional authorities will need to value carbon removal and sequestration and integrate it into local and regional development plans, to avoid conflicting objectives.**
- **A proactive participatory approach should be integrated into planning law, with clear guidance for developers and local authorities on how public engagement should be undertaken. Integrating procedural justice into proposals is fundamental to social legitimacy.** Planning law is the primary point of engagement, but current specifications do not promote building public trust.

Raising awareness is a priority for participation

- **Technology developers, along with central and local governments, should focus on raising awareness and understanding of carbon removal and the options.** This capacity building is essential to enable more informed decision making.
- **A national level discussion led by leading government departments[2], is needed to explore the assumptions about carbon removal and its role in mitigating climate change.** Multiple dimensions need to be explored using a range of tools and media and informed by national, regional and local perspectives. National discussions should inform the strategic governance frameworks.
- **Technology development and demonstration should incorporate local engagement to enhance the technical and commercial learning.** Local engagement would identify issues that affect deployment and potential new commercial opportunities.

Strategy and implementation agency

- **Establishing an independent Agency with responsibility for carbon removal should be a high priority. It should oversee the development of a carbon removal strategy, manage its implementation and monitor its impact.** Stimulating deployment will require a coordinated effort across local and national government with broad engagement and participation from industry, civil society and the wider publics.
- **The Agency would report to Government and interact internationally to harmonise policies and standards.**

[2] In the UK this is Business, Energy & Industrial Strategy (BEIS), Department for Transport (DfT), and Department for Environment, Food & Rural Affairs (DEFRA)

CONTEXT

In May 2019, the UK Committee on Climate Change (CCC) released a report outlining pathways to reduce emissions, with the aggregate goal of 'net zero' emissions in the UK by 2050. Established natural ways of removing CO_2 and less established Greenhouse Gas Removal (GGR) options are included to achieve emissions reductions. The report proposed that over 50MtCO_2 would need to be captured and stored in 2050 via engineered removals. Meanwhile, established land-based removals could increase the net forestry sink to over 22 MtCO_2 per year by 2050. In relative alignment with scenarios presented by the Energy Transitions Commission, a variety of land based and engineered GGR methods are considered necessary to abate emissions from the **'harder to abate sectors such as industry, freight transport and aviation'.**

The UK has enshrined the net-zero emissions target into legislation, meaning that GGR will likely be part of the government's strategy to achieve a net zero carbon reduction. The frameworks needed to govern GGR and the issues that need to be addressed are not well understood. GGR technologies will be deployed extensively across the landscape, affecting a wide range of local communities. However, little is known about how local communities will respond. If new technologies are to gain approval, it is imperative they are evaluated from a variety of framings and viewpoints, rather than purely a technical and least cost basis.

A proactive, participatory approach to engagement with local communities will identify the issues to inform the governance frameworks. How this is done is as important as the issues themselves; focussing on procedural justice will build trust and enable social legitimacy. This bottom up assessment of GGR options will identify the non-financial values, map value chains, and create insights into local business models. Focussing on this form of socio-legitimacy will not only help mitigate the negative externalities of GGR but can also engage local enterprises and open up opportunities to new commercial models and innovation. Enabling this to happen will require the oversight of a bespoke body and the idea of a national Agency reporting to government should be explored.

SUMMARY

There is a growing interest in Greenhouse Gas Removal (GGR) as businesses, industry, local authorities and individuals come to terms with what net-zero carbon emissions means. As the costs and difficulty of decarbonising parts of industry, transport, and heat demand, are revealed attention is shifting to how to address them using negative emission technologies, which remove greenhouse gases from the atmosphere (Figure 1).

However, there are diverging views about the role of GGR and which techniques should be used, as well as the costs and effectiveness.

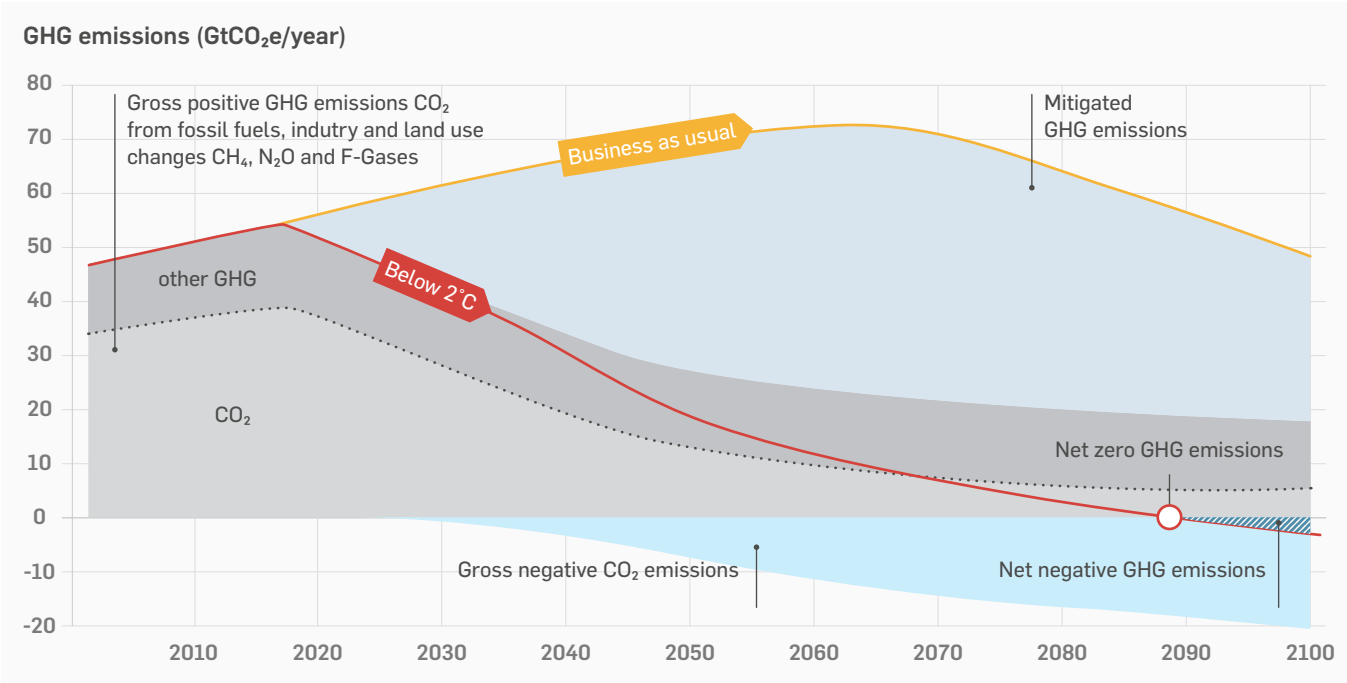
Of equal concern is how little is known about the impacts on local communities and how they will respond to large-scale deployment of GGR, even for familiar sectors like forestry and land management.

Afforestation, for example, will lead to wholesale changes to landscapes affecting the land use, agriculture, and the local communities within them. This drive for rapid land use change to tackle climate change will require a balance to be struck between priorities such as the biodiversity crisis, regional flood risks and local economic and cultural interests.

How these issues are addressed will have a significant impact on the rate and scale of deployment of land based GGR technologies.

Proactive engagement with local communities and interested parties will help anticipate the issues, allowing deployment proposals to adapt and appropriate governance structures to emerge. Participation will engender trust and enable the proposals to be regarded as socially legitimate.

Figure 1. A global emission trajectory for staying below 2°C of global warming *(Source UNEP 2017)*



Experience in other sectors has shown that failure to invest time and effort into good engagement with local communities around large infrastructure proposals can lead to disruption, for example, onshore renewables and fracking. This emphasis on process is lacking in the current legal requirements for engagement.

A more strategic, anticipatory approach is needed than has been used to date. This approach needs to convene the various interests and explicitly address these issues face to face, to build trust, social legitimacy, and new institutional capabilities. Working across sectors and interests a co-productive approach will raise understanding, inform the development and design of the proposals, so as to overcome the barriers to GGR. It can also help realise any opportunities it might bring to the communities.

Scale of GGR required in a short timeframe

Achieving the Paris climate ambitions of remaining below 1.5°C means that, even with aggressive mitigation effort, the UK will need a portfolio of GGR techniques to draw down about 100 million tonnes of CO_2 per year by 2050, and beyond. Globally the GGR economy could reach the giga-tonne scale, requiring industries two to three times the size of the current oil and gas sector. At present, the combined global negative emissions effort is less than a few thousand tonnes per year.

The rate of development and scale up of new infrastructure and industries will be substantial. With a limited amount of time and space to develop and deploy GGR options any delay risks constraining these options, at the time when we might need them most.

However, the governance frameworks to ensure the appropriate use of these new industries, and enable this transformation, are fragmented and inadequate. Without this there is a risk that demand for GGR will outstrip supply, leading to socially unacceptable practices and putting at risk the objective of achieving net-zero. Development of the governance frameworks should be informed by the issues emerging from early engagement, as tested in this project.

The tendency to regard engagement as a means to deal with negative externalities and a hurdle to deployment needs to shift to one where it adds value and can enable opportunities. Engaging local enterprises can lead to new commercial opportunities and innovation.

Understanding the opportunities and challenges and how to enable or resolve them will give a clearer picture of the potential role that GGR will play in mitigating climate change.

The project

This project sets out to explore what deploying the various GGR options would look like on the ground and understand the implications from the bottom up. Using the Yorkshire region in the United Kingdom as a case study, it sought to identify the interested parties and stakeholders and explore how enhancing participation in decision making could facilitate socially legitimacy.

The project considers five main GGR options: Afforestation, Bioenergy with CCS (BECCS), Direct Air Capture, Biochar and Enhanced Weathering (see Annex A). It also notes the role of other nature-based solutions including peatland restoration and protection. Scenarios for how each option might be deployed in the Yorkshire region are used to inform the engagement (see Annex D).

An extensive literature review combined with interviews was used to identify the governance aspects for the GGR technologies and create local scenarios. Local networks and stakeholder mapping were used to identify a broad range of stakeholders and interested parties. Over 100 interviews were conducted to identify the issues and perspectives along with the underlying governance needs. A workshop, focussed on afforestation, explored the specific issues. A follow-up co-production workshop prioritised the main challenges and identified enabling actions. In total over 30 local organisations and stakeholders were engaged in the workshops.

Findings

The project found that the scale and breadth of each GGR technology means there will be are a wide range of parties that will have interests and concerns. Any process will need to balance national and local interests.

Social attitudes and perspectives are altered by proximity to any development. For example, whilst tree planting may be widely regarded as positive, large swathes of forests across landscapes do not always fit with local cultural identity and farming practices. With land use being an important factor in GGR, local concerns about distributional burden between regions may be balanced with other factors such as job creation. Similarly, large industrial clusters forming around Carbon Capture Utilisation and Storage (CCUS) infrastructure may provide local employment but be resisted by national interests on the basis of their feedstock, trust in the operators, or in the science behind geological storage.

i) What will deployment of GGR look like?

A key finding is the limited awareness and understanding of the range of GGR options, even amongst those professionally engaged with climate change mitigation. With many of the GGR options yet to be demonstrated, much of the knowledge is held by the developers, and has yet to find a series of outlets trusted by each stakeholder.

Understanding the potential impacts of the options, without any real-world examples, requires generating a representation of the technology. Framing becomes important as specific aspects of the techniques can easily become associated with existing concerns, which may or may not be helpful.

This work discovered a clear divergence of views about the various GGR options including which ones might be acceptable in any region. This study examined one region to see how much agreement existed; even the need for GGR was far from agreed.

Participants challenged the assumptions used in the national and international scientific modelling, and, as many of the options have yet to be demonstrated at scale, uncertainty was cast over the available performance data and costs.

There was broad-based agreement that GGR should be reserved to address only the 'residual', hard or expensive to treat, emissions. A key priority, from the interviews, is the need for a strategic level framework, to set out how this will be determined and implemented, to ensure GGR is not used for "mitigation avoidance".

ii) Complexity

A common factor to all the GGR options is that the value stack[3] for each is complex, aligning financial and non-financial benefits to support proposals. The value chains also cross several economic sectors so investors building business cases will need to gain new confidence and capability in those which they are likely unfamiliar with, for example, farming and land use sectors, agricultural policy and energy markets.

The scale and extent of some GGR options means trade-offs between non-financial values, such as biodiversity and aesthetic and cultural perceptions are unavoidable.

This complexity is illustrated by afforestation, which, outside of Scotland, is struggling to find available land for tree planting. The GGR scenario developed for Yorkshire would see a doubling of tree cover, a five-fold increase above current regional programmes for flooding alleviation and planting of a new National Forest. This will require building skills and capacity and ensuring future markets for timber, to secure the carbon indefinitely.

iii) Recognising non-financial values

The Northern Forest is an ambitious plan to substantially increase tree cover across the North of England, currently one of the least forested areas of Europe. However, current programmes are already struggling to meet their goals, constrained by the availability of land due to regulatory, commercial, cultural and social constraints.

[3] A Value Stack considers the various revenue streams and factors in how the additional diverse non-financial values can affect and determine the overall benefit.

These constraints include Sites of Special Scientific Interest (SSSI) and archaeological significance, as well as Area Plans that define permitted activity, such as National Parks and Areas of Outstanding Natural Beauty. Landowners and tenant farmers in this research raised concerns about long-term contracts for tree planting and liability and ensuring the permanence of the woodland, which will require an incentive mechanism that addresses the lock-in and long-term business models.

These stakeholders also highlighted the cultural aspects of changing their farming practices and business models, which, for some, was their personal and family's identity. It would also require retraining. Even with substantial assistance and transaction costs covered, landowners were reluctant to commit to planting new woodland.

Forestry and carbon removal will need to fit in with the wider landscape design and management which includes addressing the biodiversity crisis and flood alleviation. However, planting broadleaf woodlands comes with a lifetime maintenance cost, whereas the most cost-effective option for carbon removal is fast-growing coniferous plantations. Dense coniferous plantations, however, offer little value for biodiversity. Strengthening of the evidence base for carbon sequestration rates and capacity of different species, planting regimes and soils will be needed to inform decision making.

The need for a strategic framework for land management was emphasised. A framework that can align economics, policy, and regulation to allow business models to capture value from land use change / tree planting. However, to do this will require a wider discussion and debate across society about choices for land use and landscapes; a debate which is becoming increasingly polarised.

Given the scale of change that is envisaged, this cannot be done through a simple consultation. It is critical this polarisation is addressed in open public fora. It will require a more deliberative approach that builds a social understanding of the issues.

Recommendations

The use of GGR to help address climate change will have a transformative impact on mitigation strategies. It will also require the creation and rapid expansion of new industries.

However, there are fundamental gaps in the governance frameworks for GGR at a strategic level and at a local level.

The government departments for Business, Energy and Industrial Strategy (BEIS), Transport (DfT) and Department for Environment, Food and Rural Affairs (DEFRA) should adopt an Anticipatory Governance approach to the development and deployment of Greenhouse Gas Removal and achieving the net-zero target. This will help identify and inform the development of the governance frameworks that will need to be put in place.

- **Greenhouse Gas Removal is integral to achieving the net-zero target, but a clear understanding is needed of the role it will play in abating climate change and how it integrates with reducing emissions.** Perspectives are already becoming polarised. Proactive and participatory engagement will allow issues to be identified in advance and a balanced consideration of any concerns and opportunities.
- **Strategic guidance and governance are needed on how GGR integrates with other policy priorities particularly agriculture, biodiversity, and energy.** This will need to integrate learning from local developments with top down strategic guidance and scientific input. The issues identified at a local level highlight where GGR deployment will be contested by other policy objectives and incentives.

- **A proactive participatory approach should be integrated into planning law, with clear guidance for developers and local authorities on how public engagement should be undertaken. This will integrate procedural justice into the development of GGR proposals which is fundamental to social legitimacy.** Planning law is currently the primary point of engagement for GGR, but its current vague specifications do not promote procedural justice and social legitimacy, which risks projects being disputed and delayed.

Multiple issues will arise when GGR technologies are deployed into local communities and regions. These will define the scale and rate at which the technologies will be deployed. How these perspectives are addressed is as important as the issues.

- **Local and regional authorities will need to value carbon removal and sequestration and integrate it into local and regional development plans, to avoid conflicting objectives.**
- **Technology developers along with central and local governments should focus on raising awareness and understanding of GGR and the technologies. This capacity building is essential to enable more informed decision making.** Few people are aware of GGR technologies, which will reduce the value of the insights that can be gained by developers when presenting project proposals. Proactive engagement will help raise awareness and build the understanding and capacity.
- **A national level discussion led by BEIS, DfT and DEFRA, is needed to explore the assumptions about GGR and to understand the role of the different options in mitigating climate change.** This should explore the multiple dimensions that will need to be considered and be informed by local perspectives. National discussions should be used to inform the development of the strategic governance frameworks. A range of tools and media have been developed to enable this.

Demonstration projects for emerging GGR technologies should incorporate local engagement e.g. BBSRC GGR Demonstrator project. While the focus is often on technical and commercial learning, local engagement would identify wider issues that could affect commercial deployment, which could be incorporated into the design. It could also identify new opportunities. The technologies would benefit from wider awareness and understanding, which would raise their legitimacy.

Current governance frameworks for GGR are fragmented, with some clear gaps that need to be addressed. Stimulation of the development and deployment of GGR, whilst avoiding undermining efforts to mitigate emissions, will be essential, together with managing the wider impacts of deployment.

- Developing these frameworks is urgent and the **establishment of an independent body with responsibility for GGR should be a high priority.**
- **A GGR Agency is proposed that would oversee the recommendations outlined above with responsibility for the development of GGR strategy, manage its implementation and monitor its impact.** It would oversee the engagement and participatory activities required to deliver successful outcomes. Agency stakeholders would include public-private enterprises, local communities, developers, industry, civil society and NGOs and policy makers.
- **The Agency would report to Government through the three departments of BEIS, DfT and DEFRA.**
- **The Agency would interact internationally to harmonise policies and standards,** including with the European Commission and EU regulatory frameworks post-Brexit.

Climate change will introduce new challenges at a very large scale.

01.

Meeting the Paris Agreement ambitions of below 2°C will require rapid technical and societal effort to make deep cuts in emissions. Most analyses indicate that global greenhouse gas emissions will need to reach zero, at some time between the middle and end of this century, or within the next 40 years if we are to achieve the 1.5°C target. Zero emissions will require either eliminating all emissions or removing carbon dioxide and other greenhouse gases from the atmosphere to offset emissions from hard to decarbonise sources, to achieve 'net zero'.

1.1.

The need for greenhouse gas removal

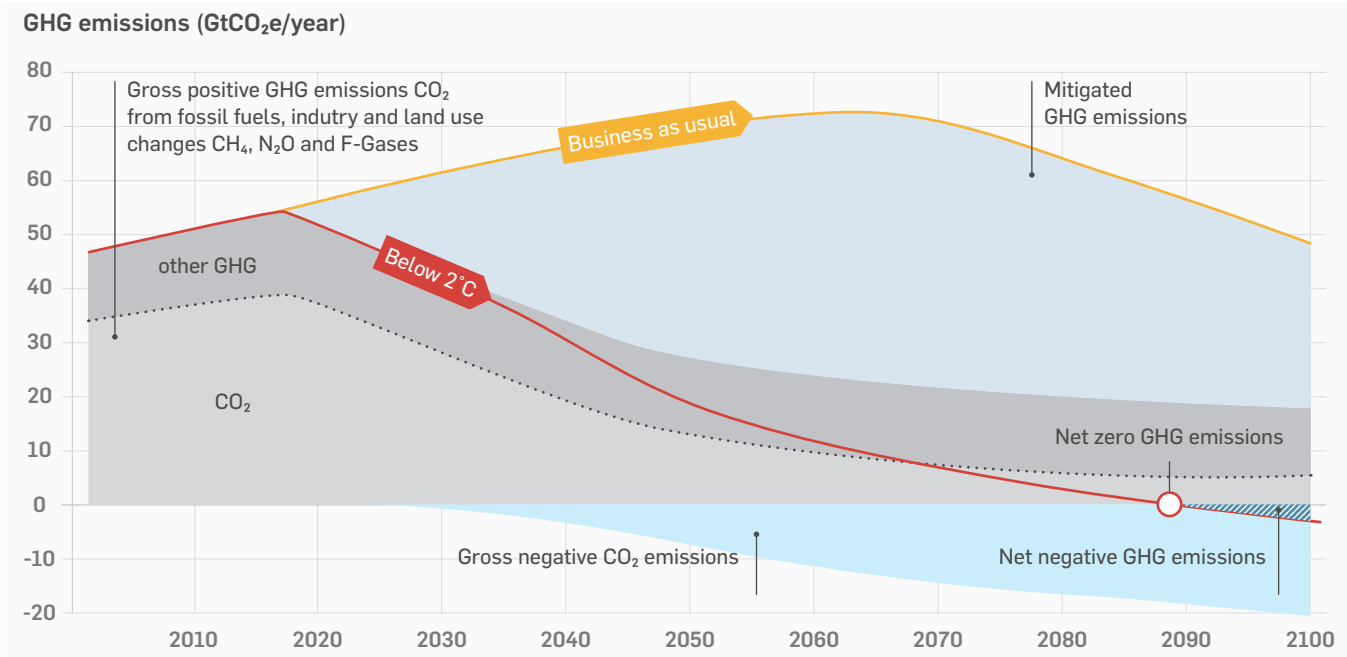
In May 2019, the UK Committee on Climate Change (CCC) released a report outlining pathways to achieve 'net zero' emissions in the UK by 2050.

A range of Greenhouse Gas Removal (GGR) methods will be needed (Figure 3) from natural ways of removing CO_2 to more novel technologies. At the global scale scenarios from the Energy Transitions Commission use a similar variety of land based and engineered GGR methods to mitigate emissions from the 'harder to abate sectors such as industry, freight transport and aviation'[4].

Cutting the emissions at the rate required to meet the targets will be challenging. For some sectors, the decarbonised alternatives are either expensive, currently unavailable, or difficult to deploy. In order to achieve the net-zero target, these emissions will have to be compensated for by removing CO_2 from the atmosphere.

As Figure 2 illustrates, even with aggressive emission reduction measures greenhouse gas removal will be needed ahead of achieving net zero. Even then, failure to cut emissions early enough, globally, will mean that net-zero may not be enough. The US National Academy of Sciences and European Academies Science Advisory Council[5] suggest removals will be needed at the rate of billions of tonnes per year, by the end of this century.

Figure 2. A global emission trajectory for staying below 2°C of global warming *(UNEP 2017)*



[4] ETC 2018 | [5] EASAC 2018

Text Box 1: Defining net-zero emissions and offsets

"Net-zero emissions" means that the total of active removals from the atmosphere offset any remaining emissions from the rest of the economy. Removals are expected to be important given the difficulty in entirely eliminating emissions from some sectors. *(Source: CCC 2019)*

There are several interpretations of offsets, but there are basically two main definitions: 1) Mitigation Offsets – an emitter can offset their mitigation effort by enabling another emitter to cut their emissions instead, where it is likely to be cheaper and/or easier , and they would have been unable to do so otherwise – thereby demonstrating "additionality"; 2) Emission Offsets– an emission to the atmosphere is offset by removing an equal amount from the atmosphere – the overall effect is "net-zero". The use of offset in this report will use the second definition.

Net-zero emissions means that all emitters, across the whole economy, will have to mitigate, removing the option of additionality. If an emitter is unable to cut their emissions, then the only way to achieve net zero will be to remove previous emissions from the atmosphere. "Offsets" must therefore be defined solely by emissions and not mitigation effort. Which emitters and technologies will be allowed to but "emission offsets" and how it will be determined is a vital part of the strategic governance.

Before the end of this century, analysis indicates that achieving the Paris climate targets of 1.5°C and 2°C will require global emissions to go net negative. This will mean that carbon dioxide and other greenhouse gases will have to be removed from the atmosphere faster thatn they are being emitted. This will be in addition to emission offsets.

Analysis of the IPCC scenarios indicate that GGR will need to remove up to 1,000 billion tonnes of CO_2 (1,000 $GtCO_2$) by 2100, reaching a rate of up to 20 billion tonnes a year, to have a 66% change of meeting the 1.5°C target[6]. This will require developing a global effort two to three times the size of the current oil and gas industry.

1.2.

Why develop GGR now?

Waiting to decide on GGR, based on how effective the mitigation effort has been, is not an option. As Figure 2 illustrates, greenhouse gas removal will be needed in the decades ahead of achieving net zero, as part of the mitigation effort.

The lead times for deploying the various technologies and developing the governance and incentives to enable them means that action is needed now to ensure they can achieve the scale required. Ramping up from a few 1,000 tonnes of CO_2 per year to hundreds of million tonnes in the UK by 2050 and billions of tonnes globally will require a major effort.

Interest in GGR is growing as businesses, industry, local authorities and individuals come to terms with what net-zero carbon emissions means (see Text Box 1). As the costs and difficulty of decarbonising parts of industry, transport, and heat demand are revealed, attention is shifting to how to use negative emission technologies to "offset" the emissions. This is compounded by varying interpretations of when net-zero will be required, with some working towards 2030 and others 2050. However, there is little awareness of the range of options available, beyond tree planting, nor of how they will be managed.

Governance frameworks will be needed for GGR to integrate it with mitigation efforts. Incentive and support mechanisms will be needed to aid development and deployment of the different options, along with regulations to manage the impacts. However, the current frameworks are fragmented, and do not address the cross-sector complexities of GGR, and the uncertainties and interactions that will arise during deployment.

[6] IPCC 2018

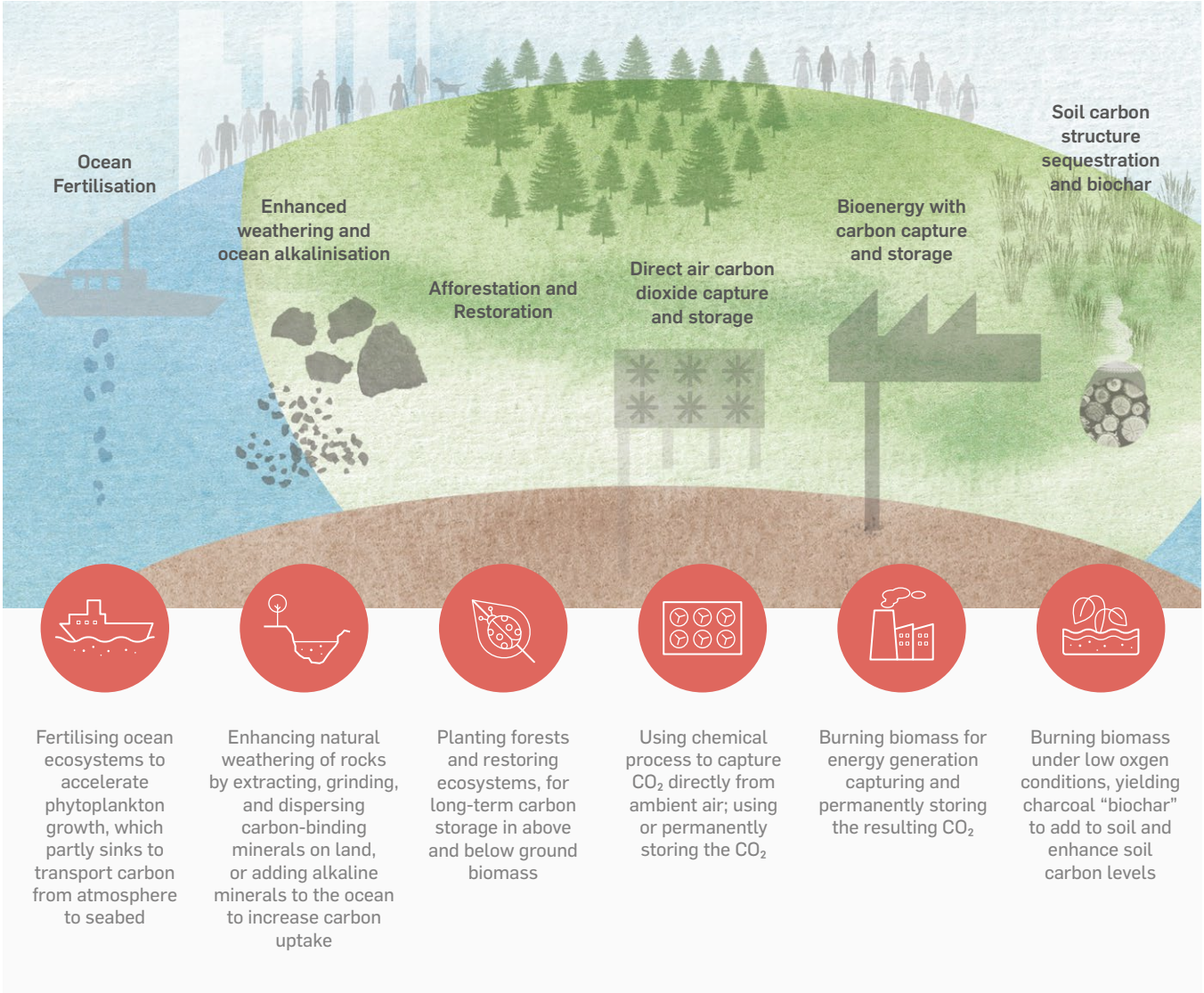


Figure 3. Overview of the range of GGR options. This report will consider only land-based options. (*Source C2G2 2019*)

A portfolio of GGR technologies will need to be supported (Figure 3) to achieve the 100MtCO_2 of removal in the UK, indicated by the CCC. Nature-based options such as peatland restoration and afforestation could create a net sink of over 22 MtCO_2 per year by 2050. The remainder of the removals will come from 'engineered removals'. Most analyses suggest that Bioenergy with CCS (BECCS) will play a major role, as it is currently considered the lowest cost and nearest to market, although this has yet to be proven. Other GGR options, such as Direct Air Capture (DAC), Biochar and Enhanced Weathering are in the pilot stage or have yet to be demonstrated at scale.

The GGR technologies and industries are immature and will take time to demonstrate and pilot them. Even the forestry sector is not ready to deliver at the annual planting rates that will be needed. Furthermore, each option has constraints and dependencies that will limit how quickly these new industries can scale up and how extensive they could become. Forestry will be limited by the amount of available land while the rate of deployment of engineered options will depend on build rates.

1.3.

Implications of deployment

Many of the land based GGR techniques, if they are to reach the scale suggested, will lead to extensive changes in land use and to landscapes. When deployed into existing communities and ecosystems it could open up a whole set of intricate, subtle and complex issues.

Afforestation, for example, will lead to wholesale changes to landscapes affecting the land use and agriculture within them, this in turn will have cultural, social and economic impacts on the local communities. A balance will also need to be struck between the need for this rapid land use change to deliver GGR for climate mitigation and other priorities such as the biodiversity crisis, soil degradation, regional flood risk and local economic and cultural interests.

If the GGR options are to gain social legitimacy in a local area, then they will need to negotiate these physical, social, cultural, ethical, environmental and political values, across a range of stakeholders and interested parties.

At present little is known about the impacts on local communities and how they will respond to large-scale deployment of GGR. Anticipating these issues will allow them to be considered in the design of the proposals.

In the UK, the main point where engagement is required is set in planning laws. But the definitions are vague, allowing the developer considerable leeway in how it is undertaken.

Social legitimacy and acceptance are not built just on understanding the facts. How parties are engaged in the process and their value recognised in the outcomes is just as important. This procedural justice emphasises participation and ensuring fair distribution of benefits.

Top down analyses struggle to capture these practicalities of deployment and therefore can present an unrealistic assessment of the rate and scale of deployment.

Experience in other sectors has shown that failure to invest time and effort into proactive, early engagement with local communities, stakeholders and interested parties around new technologies and large infrastructure proposals can lead to disruption, for example onshore renewables, fracking and genetically modified organisms.

Perspectives on GGR are already becoming polarised, at a national level, around the legitimacy of the different options, with assumptions being made about some of the largely unknown engineered options.

A more strategic, participatory approach is needed than has been used to date, which engages proactively with the local communities, and wider publics, so that it can anticipate these issues. By convening the various interests and explicitly addressing the issues face to face, it will help build trust, social legitimacy and new institutional capabilities. Working across sectors and interests a co-production approach will raise understanding, inform the development and design of the proposals and help realise any opportunities it can bring to the communities and overcome the barriers to GGR.

1.4.

The aim of the project

This short, proof-of-concept project set out to explore what deploying the various GGR options would look like on the ground and understand the implications from the bottom up. With a view to:

- Exploring issues of socio-legitimacy, social co-production and participatory consent for GGR options and their implications on the governance and scaling of the technology value chains.
- Developing a toolbox and lessons learnt from the bottom up study.
- Eliciting a data base of the non-financial benefits generated by GGR value chain deployment.
- Prospective map GGR value-chains at the Case Study location.

Using Yorkshire in the United Kingdom as a case study, it sought to identify the communities, stakeholders and interested parties to generate an evidence base of the likely attitudes and responses to local deployment of GGR options. Nearly 100 interviews were undertaken alongside two participatory workshops with over 30 participants with broad representation (see Annex A). Interviewees were identified through a stakeholder mapping exercise combined with engagement with local networks and community recommendations.

The project explored how enhancing participation in developing solutions and in the decision-making process could affect social legitimacy. Two workshops took a participatory and co-production approach, with over 30 local organisations and stakeholders, to explore the issues around afforestation explored the specific issues. Further details can be found in Section 3 and Annex B.

The report starts by exploring the value of the participatory approach taken by the project and then sets out the findings and the implications for the governance of GGR. Further insights and supporting evidence are provided in the Annexes.

Section 2 outlines the project area and the approach taken by the report. Section 3 explores why a participatory approach is important for technology deployment and how this can lead to social legitimacy and procedural justice. Section 4 considers the difficulties of delivering this for new technologies where there is little information. Section 5 presents the responses from the participants, highlighting the financial and non-financial aspects that will need to be addressed when the technologies are deployed at scale on local communities. Section 6 considers the broader strategic aspects for governing GGR that need to be in place. The annexes provide additional evidence gathered from the study that support the conclusions and recommendations in Section 6.4.

The project considered five main GGR options: Afforestation, Bioenergy with CCS (BECCS), Direct Air Capture, Biochar and Enhanced Weathering (Figure 3). It also noted the role of other nature-based solutions including peatland restoration and protection. National scenarios for each option were transposed for the region (see Annex A and D).

The project approach.

02.

The case study focused on the Yorkshire and Humber Region, to the north east of England (Figure 4). Chosen for its mix of land use types and large energy infrastructure, including the UK's largest power station, Drax, its diversity makes it applicable to other areas in the UK and globally. The main economic sectors of the region include agriculture, industry, mineral extraction and power generation, followed by tourism and technology services[7].

With a population of 5.3 million (10% of England, 8% of UK), in an area of 11,902 km^2 (1,190,280 hectares), about 10% of the area of England (5% of UK). Agriculture accounts for about 10% of land use, a third of which is pasture, and a third rented[8].

The region includes three National Parks, Yorkshire Dales, North York Moors and part of the Peak District. Characterised by their extensive heather moorland, they include European Special Protection Areas for key bird species. Tourism accounts for about 8% of its GDP, employing about 250,000 people.

The main city, Leeds, is the UK's third largest city. It has its own Climate Commission and leads on Inclusive Growth for the UK Core City group. In March 2019 it declared a climate emergency with the intention of becoming a net-zero carbon emission city by 2030.

Humberside, on the east coast of Yorkshire, is an industrial centre, built on refining and steelmaking. The UK government's Carbon Capture Utilisation and Storage (CCUS) Action Plan, identified it as a potential area for developing a CCUS cluster[9]. Close to one of the most viable geological CO_2 storage sites in the UK[10], in the Southern North Sea, the cluster would provide a low-cost access terminal for CO_2 emissions from the industrial facilities in the region.

As the biggest industrial area in the UK with about 100 hard to abate chemical and refining companies[11], the cluster could help retain and create new jobs for those exposed during the transition to decarbonisation[12].

If the UK intends to meet its net zero emissions target by 2050, the first cluster should be operational by 2026[13].

Yorkshire is well placed for developing GGR. It is part of the Northern Forest, which aims to plant 50 million trees (approx. 30,000 hectares) between Liverpool and Hull, an area with some of the lowest tree cover in the UK (7.6%). Yorkshire Water committed to supporting the Forest with 1 million trees.

The Yorkshire and Humber region is well placed for developing BECCS, as it has the highest density of biomass-fired power generation in the UK[14]. Combined with the CCUS cluster it could enable the deployment of BECCS at scale. In 2018, Drax power station (about 30 miles west of the Humber) launched Europe's first BECCS pilot project, capturing up to one tonne of CO_2 per day from its biomass generation[15]. If expanded to its full capacity it would deliver up to 12% of the BECCS capacity that the CCC suggests might be necessary, depending on the scenario. It is currently fuelled by imported feedstock sourced from certified, sustainably managed forests, the majority originating from the south eastern USA[16]. Estimates suggest that the UK might only be able to sustainably supply 36% of feedstock demand under a 50 $MtCO_2e$/year removal scenario[17].

A partnership between Drax, Equinor and National Grid Ventures, announced plans, in 2019, for the UK's first zero carbon cluster, to be based in the Humber region, during the mid-2020s[18]. Government support to Drax of £500,000 to investigate new carbon capture technology. The partnership will continue to generate power from bioenergy and will also explore the possibility of combining hydrogen production, with CCUS.

[7] NYCC 2017 | [8] Defra 2020 | [9] BEIS 2018 | [10] Senior 2010 | [11] BEIS 2018; ETC 2018, Equinor 2019 | [12] BEIS 2018; Robins 2019 | [13] CCC 2019 | [14] Biofuelwatch 2019 | [15] Drax 2019 | [16] ibid | [17] Albanito 2019 | [18] Hill 2019

Figure 4. Map of UK with Yorkshire highlighted in yellow

Given the current business proposals and the political legitimacy for Drax to pursue BECCS within the Yorkshire and Humber region, it is imperative to identify local community and key stakeholder attitudes towards BECCS, to understand the legitimacy which might be conferred upon it.

2.1.

The GGR options

The project considers five main GGR options: Afforestation, Bioenergy with CCS (BECCS), Direct Air Capture, Biochar and Enhanced Weathering. It also notes the role of other nature-based solutions including peatland restoration and protection, which came up in proceedings, but are not explored in depth.

The five options can be grouped into three broad categories – CCS dependent, forestry/nature dependent and mechanised/industrial. All these options were determined as viable for the region, to varying degrees, and could be deployed in different locations.

In order to provide a basis for discussion, regional scenarios were generated for the options, providing an indication of the scale of deployment and characteristics (see Annex D for details of the scenarios). The scenario for each option was based on a literature search, with each option determined independently, which meant they were not necessarily consistent.

For example, UK scenarios indicate that up to 2.5 billion trees will need to be planted by 2050 across the UK, which requires planting approximately 50,000 hectares per year, with Scotland expected to plant a larger proportion. A basic assumption was made that the remainder will be split evenly across the UK. As Yorkshire accounts for approximately 10% of the land area (and about 10% of the population), the figure was scaled to 5 million trees planted per year. It was pointed out that urban land use would mean that Yorkshire may be expected to take a higher proportion. However, even if the figure was out by 50%, this represents a 5-fold increase in planting effort compared to existing programmes in the region and would lead to a doubling of tree cover, which would be higher in specific locations (details of the other technologies can be found in the Annexes A & D).

2.2.

Engagement methods

The project aimed to pilot a participatory approach, identifying a broad range of stakeholders and bringing them together to identify and prioritise the issues that are of concern.

To inform the study an extensive literature review was undertaken which was combined with over 100 interviews and two participatory workshops with over 30 participants with broad representation (see Annex B).

The scale and breadth of each GGR option (see Annex A) means there are a wide range of parties that have interests and concerns. Interviewees were identified through a stakeholder mapping exercise with recommendations from local networks and communities. Representation was sought from the local communities and interest groups, local authorities, administrative and regulatory bodies, technical academics and social scientists, landowners, farmers, businesses and industry. In addition to local interest groups, national perspectives were sought from civil society organisations and NGOs to understand the contextual and wider concerns that will determine the social legitimacy of the technologies.

The project considered three dimensions – governance of GGR, procedural justice and social legitimacy concerns, and the business models and commercial delivery platforms.

The stakeholder responses and attitudes were assessed by presenting the local scenarios for how the options might be deployed in the region and the possible implications for specific locations. The scenarios were developed from literature reviews and interviews (see Annex D for details).

The interviews sought to identify the non-financial values, including the social, cultural and political aspects (see findings in Section 5). An important part of the evidence gathering was understanding the commercial and financial dimensions and how these might influence the perspectives of the local communities (see Annex A).

The intention of the discussions was to draw out the attitudes and issues that would need addressing rather than deciding whether an option would be deployed on a specific site. This allowed the assumptions behind each scenario to be questioned, which gave an indication of the distributional and equity aspects of deploying the options at a national level.

For the forestry option several projects and schemes are underway to support tree planting. Comparison was made between the scale of these projects and the proposals suggested for GGR. In the case of forestry net-zero could require a greater than 5-fold increase in activity.

The two participatory workshops focussed on afforestation and brought together over 30 local organisations and stakeholders, from industry, landowners and farming community, local government and regional authorities, civil society, local communities, NGOs and academics. They identified the wide range of challenges and opportunities that will arise from large-scale deployment. Using a co-production approach enabled the group to prioritise the extensive issues and identify national strategic requirements, regional reviews of land use and planning, and the need to build local capacity to coordinate activities and build understanding and engagement.

The participatory approach taken by the project was widely supported by the participants (see Workshop Reports in the Annex B). The short timeframes meant that not everyone was able to attend, but it generated widespread interest, which emphasises the value of an inclusive approach.

Benefits of engaging different publics.

03.

At present most of the analysis of GGR has been assessed through techno-economic analysis, based on top-down assumptions about the uncertainties. This has provided an indication of the overall scale of removals that will be needed and the extent to which each option is likely to be deployed. From this a range of governance needs have been identified to enable deployment.

However, success is unlikely to be determined on their technical and economic merits alone. Technology development rarely follows a linear path – modifications are required as uncertainties are identified and iterations as governance is developed. A variety of framings and viewpoints are therefore valuable during development.

Having visibility of the all the issues that might arise will reduce the risk of disruption at a later stage. A proactive approach to engagement means these potential impacts and issues can be anticipated, allowing governance and regulation to work with and adapt to deployment rather than responding. It will also enhance procedural justice (Text Box 2).

Identifying opportunities

Engaging widely across local communities and businesses also has potential to identify opportunities that may enable deployment. Co-benefits may be identified where the value may not accrue to the developer but could make the proposal more favourable to the local community. These commercial opportunities and innovation go beyond simple top-down analysis of income and changes in jobs and can move the discussion from social impact to social demand[19].

In Yorkshire this included planting trees for flood alleviation, which has led to the development of new engagement platforms. Innovative ideas are being developed for biochar working with local farmers. Forestry can bring financial and non-financial co-benefits, delivering well-being and recreation.

Text Box 2: Anticipatory Governance and Regulation

Anticipatory Governance (AG) is being applied to a wide range of issues where there are high levels of uncertainty and complexity and is particularly applicable to new and emerging technologies and areas where there are a wide range of interested parties. It is therefore highly applicable to the development of carbon removals and the development of GGR options. It has been defined as "a system of institutions, rules, and norms that provide a way to use forewight for the purpose of reducing risk and to increase capacity to respond to events at early rather than later stages of their development." (Fuerth 2009)

Within this sits Anticipatory Regulation, which takes a similar approach to AG but focuses on how regulation can be used to enable technology development and innovation.

The primary principles are:

1. Future-facing to identify issues early, which includes engaging interested parties.
2. Proactive engagement which purposefully encourages a broad range of perspectives.
3. Inclusive and collaborative, with the intention of being able to develop solutions that can integrate different sectors, such as biodiversity and commercial agriculture.
4. Iterative approach to resolving issues, allowing response to adapt as issues emerge.
5. Outcomes based definitions of governance and regulatory, rather than on defining rules.
6. Experimental approach to regulation, allowing adaptation in order to achieve acceptable outcomes. (Armstrong et al 2019)

These approaches enhance Procedural Justice as they are dependent on early and collaborative participation.

[19] Buck 2016

3.1.

Participation builds trust

A key component of identifying and understanding the potential impacts is participation. Involving a broad range of interested parties in a well-informed process will allow them to understand and consider the proposals and raise any issues and concerns.

Participation can also build trust, alongside fairness between the parties involved, which are essential for enabling social legitimacy (Text Box 3). All parties should be able to hear each other's perspectives and they should be presented with equal prominence. This will recognise the breadth of issues whilst allowing local interests to be compared with national concerns. Allowing the parties to deliberate the issues and co-produce priorities and solutions can lead to more consensual outcomes. A range of tools can be used to enable participation (see Toolbox Annex C).

This contrasts with the requirements for engagement set out in UK planning law. The specifications are vague and do not define a participatory or deliberative process. This allows consultations to be one-way, with vague requirements on reporting how the views of interested parties have been incorporated into any revised proposals.

Planning regulations are also vague about who should be regarded as a concerned party, allowing developers to 'design-out' engagement, and therefore procedural justice, by applying the lowest level of publicity[20]. The physical scale and the length of the value chains for GGR options means that there will be a wide range of stakeholders and concerned and interested parties.

Text Box 3: Social legitamacy and procedural justice

Social legitimacy is often regarded as acceptance of a technology , or acceptability of an outcome, such as deployment of a project. Gaining this is dependent on building trust not only in the technology but the process and the developer (Figure 5). The procedures should allow an informed discussion of the impacts and risks, which requires providing open and honest information to allow the local community and interested parties to understand what is being proposed. For novel technologies, such as many of the GGR option, this is particularly important as there is limited information in the public domain. The perspectives and values of the local community need to be explicity incorporated into the outcomes, to give confidence in the governance. The interests of the developer (which may align with national benefits) will need to be distributed fairly with the local concerns and benefits. Affected parties should also have access to legal challenge, if they do not feel the process has been acceptable.

In the UK, the elements of procedural justice are enacted through the EU Environmental Impact Assessment and Strategic Environmental Assessment Directives. These are implemented in the UK through the Town & Country Planning and Environmental Assessment of Plans & Programmes Regulations (England & Wales).

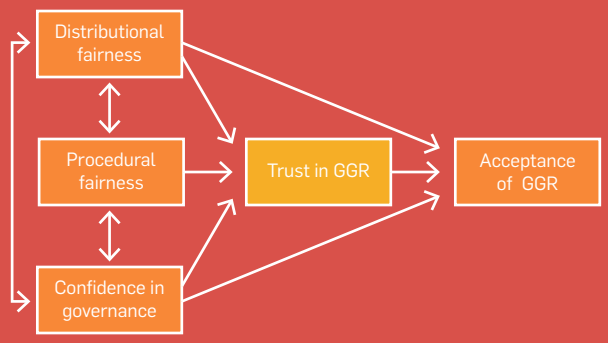


Figure 5. Acceptance and social legitimacy are dependent on attention to trust and fairness within the governance system (after Moffat 2015)

[20] Aczel 2019

GGR options cross between sectors and locations

A further concern is that the current legislation allows GGR developments to be split into separate components and not consider the whole value chain or the impact across multiple sites. This means an Environmental Impact Assessment (EIA) and consultation can consider, for example, just the CO_2 capture infrastructure, without the CO_2 pipelines or, in the case of BECCS, without the bioenergy feedstock supply.

Many of the GGR options have complex value chains across several locations and economic sectors: for BECCS this includes bioenergy crops, power generation with CO_2 capture, CO_2 pipeline leading to a transportation hub and industrial cluster and then to an offshore facility for injection into storage.

Small woodlands and agroforestry may be too small for an EIA, but multiple sites across a particular area may have a cumulative impact on the local environment. Similarly, planning permission for CO_2 pipelines for BECCS may focus on impacts on the specific location but may be looked on more favourably if details of the wider context are provided.

Considering these together, along with the different communities involved, will allow a more informed understanding of the technology and the needs and dependencies of each party.

This could be implemented using the Strategic Environmental Assessment, which has a more robust engagement process, enabling a wider debate that allows different aspects to be traded-off or balanced.

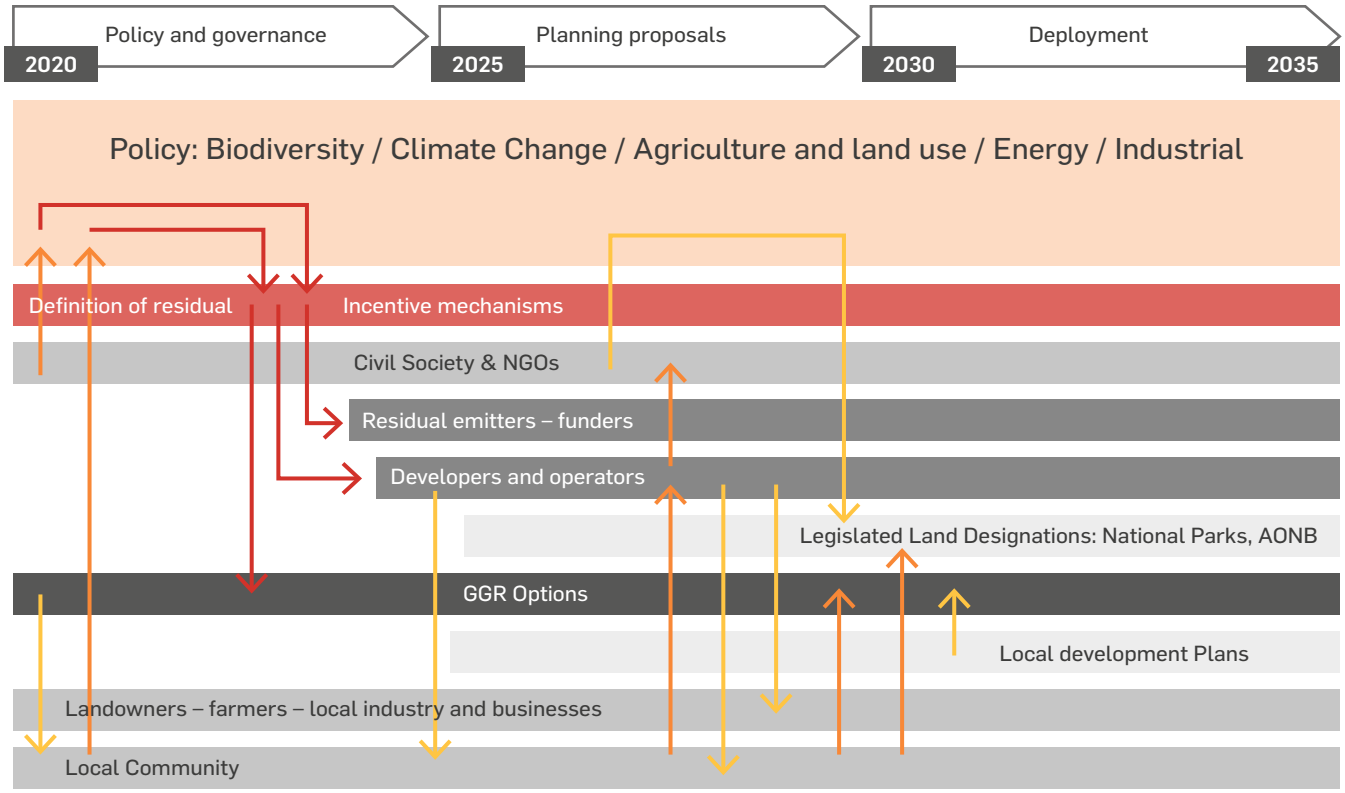


Figure 6. Indicative illustration of the complex interactions between stakeholders and policy that would be expected from an anticipatory and participatory approach. (Yellow arrows = information, Orange arrows = perspectives and vales, Red arrows = governance)

Public attitude surveys are also used to assess support and may help identify issues and perspectives. But the limited participation means they do not deliver procedural justice and can therefore not be used to demonstrate social legitimacy.

A more participatory approach to engagement will help anticipate the issues that are likely to arise when the technologies are deployed at scale. As Figure 5 illustrates, an iterative flow of information is needed between the various parties from the development of the GGR technology through to its deployment, to enhance the outcomes and build social legitimacy.

It is this approach to procedures that will determine the social legitimacy of the technology. Failure in the processes can undermine trust and the social legitimacy of a new development, leading to disruption and delays in deployment as values are contested.

Lack of awareness of GGR and the need for information.

04.

Anticipation and participation will require reliable information to enable participants to understand the breadth of benefits, challenges and uncertainties. Access to information is integral to procedural justice.

Developers clearly have an interest in the outcomes but can engender trust by taking an open approach to sharing information. Parties should be able to challenge the information and have an honest conversation about the trade-offs.

Suspicions that information is being withheld or obscured will raise distrust in the provider. Residents close to Drax raised concerns that the facts behind a new proposal were being deliberately obscured behind technical language and presentations, preventing them from being challenged[21].

Lack of awareness of GGR

However, it was clear from the interviews and discussions for this project, there is currently limited understanding of what carbon removal and GGR means. While most supported cutting greenhouse gas emissions, few appreciated the scale of effort required for mitigation. Several respondents supported setting targets for net-zero well before 2050 but were unaware of the implications for carbon removal.

Few people were aware of the range of GGR technologies, the scale required and the timeframes, even amongst those who support climate action. Knowledge was often limited to tree planting and CCS, with only a few relating the latter with bioenergy and BECCS. Two-thirds of participants close to Drax power station had never heard the term BECCS, despite the recent developments there[22].

Despite the widespread support and recognition of tree planting few appreciated the extent to which afforestation efforts will need to increase and what this would mean for the countryside and landscapes in Yorkshire and the UK.

Risk to GGR

Without this understanding of the scale it is difficult to identify what deploying these options will mean practically and the issues that might arise, which could present a barrier to acceptance of the technologies[23].

A mix of options will need to be deployed on a large scale and in a relatively short timeframe, with extensive impact on the landscape. It should not be assumed that the public will accept this wholesale transformation, nor the means for funding and incentivising it. This could lead to developments and impacts being contested.

There are already diverging views about the role of GGR and which options should be used. Furthermore, there are uncertainties in the science that have yet to be resolved and gaps in the methods to account to carbon storage and permanence.

4.1.

Framing of GGR

Care is needed in how GGR is presented and framed as this can bias responses. For example, a large industrial GGR facility could be presented as a better option than the dangers of future climate impacts, but this is subjective and risks polarising, and potentially politicising, the response and risks undermining the efforts to deliver sustainable decarbonisation[24] .

An open approach is needed where the framing and the perceived drivers emerge from the process. For example, the length of the GGR value chains means they will touch on numerous communities and a range of different policy objectives, beyond climate change. BECCS spans from feedstock production through to electricity generation and geological storage of CO_2. Afforestation will interact with biodiversity and soil management, along with and flood alleviation, construction and well-being and recreation.

[21] See O'Beirne 2020 for further details | [22] O'Beirne 2020 | [23] Gough 2018a | [24] Gardiner 2013

Recognising the commercial value is also important for social legitimacy. In order to deliver GGR businesses need to make money. However, the involvement of large companies, such as aviation and oil and gas, risk shifting the perceived framing of GGR from climate mitigation to protecting commercial interest.

Building trust through open and honest information sharing and participation – procedural justice – will be an important of part of developing a social licence to operate.

4.2.

Ensuring local voices are heard

Identifying the issues that will affect how a technology is deployed will depend on the perspective of the stakeholder or interested party. Proximity to deployment can alter the perceptions and values and the issues of concern, which may not be the ones envisaged by the developer[25]. A scheme that is based within a community or 'at the end of the road' will trigger very different attitudes and values to one that is the other side of the country, which may only be seen when on holiday.

One participant noted that some local residents were in favour of urban tree planting but opposed to one outside their house due to concerns about root damage and insurance.

The role the respondent plays in the deployment will also affect their perspectives about a scheme – farmers, landowners, energy users, homeowners, parents and national NGOs will all have different interests in local or national schemes[26].

Residents living close to Drax power station generally trust the operator and tended to support new infrastructure proposals, whereas national NGOs were not supportive due to concerns about the carbon accounting of bioenergy.

Another participant highlighted how local landowners support tree planting more generally but gave cultural and commercial reasons for not changing how their land was used, despite strong financial support.

Local opposition to developments may be regarded as NIMBYism[27], but the causes are not necessarily due to the technology or development but more to do with how the development was imposed on the community. This procedural failing highlights the importance of fairness in gaining legitimacy.

Consent should also not be assumed based on support for its components. For example, whilst there may be support on public attitudes tracker for bioenergy and CCS[28] deploying BECCS will raise issues that will need to be considered separately[29].

4.3.

Distributing the impacts fairly

It was noted by one of the workshop participants that Yorkshire may be expected to take plant more trees per capita or land area than urban regions, where competition for land use and commercial value will limit the land available. While the study did not reveal any evidence that the additional burden might be regarded as unfair, this may be due to a lack of appreciation of the scale of the transformation.

The study was also not able to test whether this might become an issue for other GGR options, where deployment in the region might be due to availability of land or access to infrastructure such as CCS transportation. It is possible that the co-benefits make it attractive, or equally the option reaches saturation point and objections prevent any further deployment.

[25] Cox 2020 | [26] Walker 2007 | [27] Devine-Wright 2011 | [28] BEIS 2019 | [29] Gough 2018b

4.4.

Implications for procedural justice and social legitimacy

As this chapter has highlighted the approach taken to deployment and how interested parties are engaged is as important as the issues that arise, and can itself exacerbate the concerns. Embedding Procedural Justice into the development and governance of the technologies will help enable it to gain social legitimacy and reduce the risk of delays as aspects are contested. However, the current governance frameworks provide inadequate support for procedural justice and, in places, allow it to be avoided. Embedding it will require national, regional and local authorities to recognise the complexity of GGR and promote better engagement.

The proactive engagement and participatory aspects of procedural justice align with an anticipatory approach to governance. As the next chapter illustrates deploying GGR will raise a wide range of financial and non-financial aspects that will need to be addressed in the emerging governance frameworks. Adopting an anticipatory approach will allow these issues to be identified early and decisions made about acceptable interventions.

Enabling this means procedural justice and anticipatory governance need to be embedded into existing and emerging frameworks across GGR and for each of the technologies[30].

There is also a need for capacity building, to increase the level of debate about GGR, which will require raising awareness and understanding of the technologies and creating the frameworks to discuss it.

Strategic level governance

In parallel to enhancing engagement around the deployment of the different technologies, a broader debate is required about how GGR integrates with climate mitigation and other policy priorities. Trade-offs will be required between environmental, social, cultural, economic, industrial and commercial objectives. A wide range of methods and tools have been developed that could help determine these trade-offs and open a national conversation about GGR (see Annex C).

Interviews for this project illustrate that threats posed by GGR (local to international, ethical to sustainable), particularly for technologies like BECCS and afforestation, can be recognised despite limited background information. The wider trade-offs and expectations concerning GGR will arguably require further clarification and deeper discussion. This will require better representation of the publics at all levels of governance.

[30] Bellamy 2018; Talberg 2018

What issues are local communities concerned about?

05.

This project set out to understand the impacts on local communities and the regions where the GGR will be deployed.

A wide range of issues were identified that will affect deployment of the various GGR technologies. Further work was undertaken for forestry where a participatory workshop characterised and prioritised the main issues.

The issues included social, cultural, environmental, legal, technical, economic and commercial aspects. Whilst there may have been agreement about the issues for many of the issues determining a solution will require negotiations between the values, some of which are subjective, or the science has yet to be established and agreed. These will include trade-offs between financial and non-financial values and between different sectors. Afforestation, for example, will require negotiating carbon benefits and commercial values with biodiversity benefits and cultural perceptions of landscapes.

Governance frameworks for agriculture, water management, biodiversity, energy and carbon emissions will need to be integrated. Conflicting incentives and gaps in regulations in each of these sectors risks missing opportunities or leading to degradation of environmental objectives.

Most of the issues, if unresolved, could undermine the legitimacy of any proposed developments, which would risk delaying or slowing deployment through low uptake rates or challenges to planning permission or legal review. However, participants also identified opportunities that would enable deployment and help build social legitimacy.

Resolving these issues will require a range of interventions that will form the emerging governance frameworks for each technology. Regional plans and national legislation may need to be re-evaluated, to assess how they affect land availability and the risks they pose to investments. Local development plans should factor in the carbon value of woodland to protect them from land developments and identify opportunities for planting.

Managing non-financial values

The discussions highlighted several cultural values that could hinder the uptake and deployment of GGR options. These associations to landscape and cultural identity are complex and cannot be addressed through governance or incentives. As land use is a key asset for afforestation, biochar and enhanced weathering, building trust is likely to be an important factor.

Furthermore, the assumptions and science supporting different viewpoints have yet to be agreed, particularly the biodiversity aspects and carbon accounting and permanence of storage. Agreements will be needed as to how to address these, including allowing an adaptable approach where adjustments can be made in the light of new evidence. Underlying this is the need for trust in the motives and compliance with the processes.

Some issues will require further scientific research or developing guidance and advisory documents. The need for well-informed discussions was also identified.

The study also identified diverging views about the role of GGR and which techniques should be used, as well as the costs and effectiveness.

The following section focuses mainly on afforestation, but details of the findings can be found in Annex A.

5.1.

The challenges facing afforestation

This project explored afforestation in greater depth, partly because it is currently the primary GGR option for the UK but also because it is currently more tangible than the other options. The issues raised in response to proposed afforestation (Table 1) are likely to be similar to those from other GGR options, particularly the change in land use and the substantive physical and aesthetic impacts.

Commercial and non-financial returns

One of the main concerns expressed by industry experts was the lack of recognition of the immaturity of the forestry sector. If tree planting is to reach the rate suggested by the CCC and supported by recent political commitments then it will require establishing new nurseries, skills and advisory capabilities, as well as long-term future markets for timber products. This will take to build, and investors will require confidence in the future demand.

This is similar for other GGR options where most have yet to be demonstrated at scale and the skills and capacity will need to be built.

Another major concern was that carbon removal targets and funding for afforestation focus largely on numbers and areas of trees. However, tree planting is more than just numbers of trees as there are financial and non-financial considerations that determine the type of species planted and the system and regime used – plantation, mixed woodland, field-edge agroforestry or regeneration and rewilding. The system used will depend on the objective of the tree planting, which may be commercial timber production, or for water catchment management for flood alleviation, or recreational and community use.

Growing purely for carbon benefit would favour fast growing mono-culture conifer plantations, which are felled for construction timber after 50 years, rather than broadleaf woodland. But this would conflict with biodiversity benefits and, for an area such as Yorkshire, potentially unacceptable changes to the landscape and the cultural perception of the Yorkshire Dales and North York Moors. In Ireland this has led to conifer plantations are being uprooted.

Broadleaf woodlands are much slower growing and are generally non-commercial, requiring ongoing maintenance, to ensure healthy tree growth. Many tree planting schemes focus solely on the cost of planting and ignore the need for ongoing income to cover costs.

Leaving the European Union (EU) and replacing the Common Agricultural Policy was highlighted as a potential benefit, as it has been an obstacle to land-based carbon sequestration.

However, the new support mechanisms indicated in the new Agriculture and Environment Bill suggest that subsidies would only be available if there was no other market mechanism. Woodland creation could become dependent on a carbon market. It is unclear how this will be balanced with non-financial concerns such as biodiversity.

Furthermore, it was noted that the new funding mechanism may not be in place until 2028. Uncertainty could affect investment, as the industry will need to use the intervening time to prepare for rapid scaling up.

For Yorkshire, leaving the EU may threaten the livelihoods of the sheep farming community. Alternative income streams will be needed, and landownership issues addressed for the farmers who are unable, or do not wish, to diversify their activities.

Permanence and liability

A key part of carbon removal is permanence. Any carbon sequestered by a tree will need to be secure, such as using timber in construction or as fuel for BECCS, or by preserving mature standing woodland.

Workshop participants pointed out that forestry is a high-risk industry, as it is exposed to threats from disease, fire and changes in the climate. It is also open to changes in policy, revenue streams and revisions of in local development plans.

Long-term liability was regarded as a significant barrier to making forestry an acceptable investment. For a farmer or landowner, who is considering making a cultural change and committing land to a new business and income model these changes can turn a woodland into a burden, which may be expensive and legally difficult to remove.

The carbon asset value of trees will need to be considered by local planning policy and in new developments. Without protection trees could be felled before maturity, adding cost and reducing the use in possible markets. At present tree planting schemes are having to do risk assessments of for sites to test the likelihood of there being changes to planning policy. Long-term strategic planning for land use would help protect these schemes.

Table 1

Values and their significance associated with afforestation in Yorkshire, identified by participants and interviewees.

Key

- Likely to have significant impact on rate and scale of deployment
- Could delay or slow deployment
- Likely to benefit deployment rates
- Less significant impact

	Concern	Implications	Considerations	Options toward resolution
Immature UK forestry sector. Limited culture of tree planting / forestry	» Expanding current capacity to meet five-fold increase in planting: Professional, advisory and nursery capacity will take time to develop.	Risk of reduced deployment rate.	Investment in skills and capacity needs policy framework.	Co-development of forestry capacity with local government, forestry sector, NGOs, farming sector, national policy representatives.
Fragmented and siloed thinking	» Complexity: More than just "planting trees" – different forms and systems of afforestation, species choice, location dependent. » Multi-functionality: Need to consider all benefits: biodiversity, soil health, flooding, amenity etc.	Risk of delays as developments are contested due to disagreement about best use of land.	Need an agreed land use strategy. Processes need to consider how to represent non-financial values.	Ongoing participatory governance and co-development. Working with investors, farming sector, scientists, forestry sector, local government, Environment Agency, water sector, NGOs and civil society and community representatives, GGR sector (biochar, BECCS, construction). Relates to activities to determine future of the new ELM subsidy scheme.
Biodiversity awareness	» Need for greater understanding of role of tree planting beyond Carbon » Opportunity in that rewilding has captured public imagination.	Public support to be balanced with commercial returns.	Recognition of financial and non-financial needs.	Stakeholder mapping to identify value sets, interest and engage them with processes to help balance commercial and non-financial interests.
Flood awareness	» Need for greater understanding of ecosystem services provision of tree planting beyond Carbon.	Public support aligns with functional benefits.	Need awareness of flood management as a driver.	Communication activities to raise awareness of the value of trees in flood prevision schemes. Interactive and immersive engagement activities to visualise futures and test ideas.
Finance and Funding	» Level and mix of incentives required to encourage tree planting is not understood.	Reduced deployment.	Need to factor in a range of issues.	Mapping of issues and stakeholder engagement to identify needs and concerns with a focus on landowners.

	Concern	Implications	Considerations	Options toward resolution
Available funding	» Funds are available now – enough to support some early projects.	Enable planting to prime sector.	Ensure covers long-term costs.	Stakeholder and project mapping to engage and develop schemes to ensure whole of life costs are understood.
Liability	» Funding contracts shorter than lifespan of tree. » High-risk industry: disease, fire, future climate, & changes in policy, & local development plans etc.	Delay/reduced deployment. Farmers reluctant to commit due to financial risk.	Determine liability for lifetime of tree. Integrate with local development plans.	Integrate commercial factors into funding mechanism and contracts. Develop legal and contractual aspects along with carbon accounting for risks.
Replace Common Agricultural Policy (CAP) after brexit	» Opportunity to revise land policies. Shift Environmental Management system to offsets.	Revise funding mechanisms.	Support for different planting systems.	Governance frameworks will need to be developed to address a range of complex local, regional and national issues. Process needs to be collaborative between commercial and non-financial interests and iterative between local, regional and national level, whilst frameworks are developed. Broad, proactive participatory engagement at local level that engages commercial interests, local authorities and community, NGO, scientific and civil society interests. Supported by strategic guidance developed through similar co-productive approach at a national / regional level. Interaction will also inform the requirement for environmental subsidy support. Needs to interact with issues considered in the siloed-thinking discussion.
CAP's Basic Payment Scheme (BPS) does not support woodland creation, agroforestry or silvo-pasture.	» Uncertainty about subsidy support proposed in Environmental Land Management Scheme (ELMS). » Full transition to ELMS may take to 2028. Delays would push future planting rate to an historic high.	Delays to sector development & deployment. Higher cost to GGR as ELMS income lowered.	Clarity on integration of future land management scheme, ELMS and other markets e.g. carbon, timber use.	
	» Determination of 'spatial prioritisation', between the public goods objectives of ELM, environmental, ecological, heritage and local amenity.	Local collaborative approach to decision making.	Clarify collaborative approach for 'spatial prioritisation', to integrate national 'top-down' and local 'bottom up' perspectives.	

	Concern	Implications	Considerations	Options toward resolution
Availability of land	» Multiple demands on land compete with area available for tree planting. » Legislated designations – Sites of Special Scientific Interest (SSSI), National Parks, Areas of Outstanding Natural Beauty (AONB). » Competes with farming and recreation.	Reduced deployment rate. Creates upfront investment costs and risk.	Need for clear policy guidance. Constraints include local, regional and national legislation and publicly agreed development plans.	In anticipation that new governance frameworks will need to be developed to address climate adaptation and mitigation legislated designations and land use decisions will need reviewing. National or regional level strategic reviews through proactive, participatory engagement processes to co-develop solutions that integrate the various needs.
	» Historical & cultural connections (see below).			Proactively engage in local and regional development plans.
	» Complex landownership and tenure: multiple tenants, private & publicly owned land.			
Do not have clear guidelines on sequestration	» Quantification of carbon sequestered is poorly characterised by tree species, planting regime, and uptake rates over lifetime and age to maturity. » Evaluation of soil carbon sink/source not fully understood and incorporated.	Risk for investment decisions and inappropriate planting.	Further research required and guidelines for decision making.	Scientific community to develop advice and inform guidance. Specific need and criteria may come out of participatory, co-development processes associated with new developments.
Limited understanding of upfront requirements	» High resource requirements and costs to undertake upfront assessments for grants etc. High data, info, knowledge of sites requirement.	Delays and lower planting rates.		Upfront investment to de-risk proposals. Map data sources and enable interactions between parties to reduce costs and effort.
Protection of existing trees	» Existing trees are vulnerable to felling for developments, such as housing, as have inadequate protection and value.	Permanence of carbon affected.	Integrate into planning policies.	Integrate carbon value and other non-financial values into local development plans and planning policies.

	Concern	Implications	Considerations	Options toward resolution
Cultural identity of farmers / landowners	» Farmer's identity associated with types of farming, such as hill-sheep. » Change in skills and business models.	Risk of delays and reduced uptake.	Participatory processes to identify and consider.	Proactive engagement to explore values and social context. Provide insights that will enable mapping of potential deployment.
Cultural identity defined by landscape	» Cultural resonance with traditional land use. » Change is intergenerational and irreversible.	No social acceptance. Risk delays and reduced uptake.	Participatory processes to identify and consider.	Local and regional level engagement to explore values and social context, along with immersive activities to test ideas and raise awareness of futures.
Change in diets – reduced meat uptake	» National changes in food consumption will lead to changes in demand on land use potentially freeing up land for afforestation and bioenergy.	Potential opportunity to rethink some land use.	Need to balance with other land uses e.g. bioenergy, other food crops.	Map farmers and landowners who may be affected and provide proactive support and advice to enable transition to new land use.
Distributional burden	» Disproportionate amount of tree planting compared to fall in rural areas relative to other areas of UK, especially northern jurisdictions.	No social acceptance. Risk delays, reduced uptake.	Participatory processes to identify and consider.	Proactive local and regional level engagement to explore values and social context and develop trust in underlying objectives and purpose.
Public supportive of tree planting	» Growing environmental awareness. » Community led projects » Resource effort to support existing schemes.	Enable and accelerate projects and reduce costs.	Need to balance with commercial interests.	Supportive engagement to empower and coordinate distributive activity.
Accounting	» Determine how GGR credit is split between carbon schemes and trees planted for other objectives?	Risk of double counting tree planting.		Incentive mechanisms and regulatory guidance on how carbon credit is accounted. Does GGR have to demonstrate additionality?

Cultural dimensions

Several cultural dimensions were identified that are restricting the amount of land available for tree planting. The workshop noted a woodland creation scheme in one of the National Parks where large landowners were offered fully funded proposals, but it was not taken up due to cultural affiliations to traditional land uses and a lack of confidence in the long-term policies and financial support.

Availability of land is already a major barrier to tree planting. Multiple constraints mean current regional tree planting schemes are struggling to meet their targets. These included legislated land designations, such as SSSI, AONB and National Parks that permitted only specific types of activities. These definitions have been developed through democratic processes at a national, regional and local level.

In Yorkshire, local connections to landscape define aesthetics and create a presumption of land use. Sheep farming defines the cultural identity of farmers. On the moors, forestation may affect grouse shooting, which is valued both culturally and economically.

These cultural affiliations and designated land uses will not be resolved by simple incentive mechanisms but will require a diversity of solutions, some of which have regional and national implications.

5.2.

Issues affecting other GGR options

Commercial and non-financial returns

For most GGR options the value stacks are complex and cross several sectors (Table 2). Interviewees noted that the business models to capture these diffuse values can be a deterrent and investors are likely to be wary about making investments that involve sectors where they are not familiar with the markets and regulations.

For example, a developer interested in biochar may have an understanding of the engineering process and the energy and carbon markets, but may not have the expertise to assess the risks in the biomass feedstock supply and farming policy and regulation, which is likely to be a potential market for the products. Enhanced weathering carries similar cross sector uncertainties.

In addition, the non-financial values, such as landscape amenity, flood protection, biodiversity and economic development, provide both incentives and risks to deployment. However, the co-benefits do not necessarily accrue to the developer, but they can be important for acceptability. For the negative non-financial values, governance structures may not yet be in place to determine how they will be managed or regulated, which adds risk to the investment.

Local businesses opportunities and innovation

Deploying new technologies presents the opportunity for businesses to innovate and develop new solutions.

A range of uses are emerging for Biochar. It is already being sold to residential users as a soil improver, and a small business in Yorkshire is exploring it use as a soil stabiliser in wet conditions as a better alternative to using aggregates. A farmer in the midlands is producing biochar from hedge trimmings and is working with the University of Coventry to explore its use as a feed supplement for cattle and its potential to reduce methane emissions. Further research is needed to prove the stability of the carbon and understand any other impacts, such as on soils.

The Environment Agency in Yorkshire, as part of their Aire Valley Flood Alleviation scheme has developed a software package that allows them to go to local farms and have a dialogue about where trees can be planted on their land, with an instant feedback as to the benefits for flood management.

The Green Economy Panel of the West Yorkshire Combined Authority has been visiting local companies, such as Drax, to understand more about the technologies, in response to a substantial increase in the number of manufacturing groups and businesses looking for advice about what net-zero means for their activities.

Future markets

Biochar and Enhanced Weathering both require markets to develop for their products. Both produce stable forms of carbon that could be supported by a carbon removals market but require solutions to manage the resulting products.

A biochar company in South Yorkshire, Solid Carbon Storage, focuses mainly on burying biochar in a disused quarry, but could reduce costs if a usable and viable market were found. Research is underway to explore its value as soil improver, along with other sustainable uses, and verify their ability to sequester carbon in the long term.

Enhanced weathering is dependent on access to large areas of land to spread the minerals. Research is underway to test its impact on the soils and its potential to act as a soil improver. Demonstrating value could turn the land use from a cost to an income source, subject to other potential environmental factors being addressed.

Finding applications and developing new markets would provide revenue streams that would bring down the costs. Market interventions could be introduced to ensure uptake and build investor confidence.

Permanence and liability

Permanence and liability of carbon sequestration will depend on the option. For CCS the CO_2 will be sequestered in geological formations. It is expected that government will take on the long-term liability for storage. Agreements will be needed as to when that happens and the role of the private sector in funding the monitoring and any remedial action. Gaining a social licence to operate will benefit from a well-managed public engagement programme, which provides access to the science and the addresses the concerns of the public.

For Enhanced Weathering and biochar, the science is still being developed to determine the long-term impacts and permanence of the products. In the meantime, voluntary frameworks could be developed, which could provide a foundation for future legislation.

Whilst the stability of the mineral products of Enhanced Weathering were demonstrable, there is still a need to understand how they are used. As one study illustrated, the public raised concern about where the mineral products of enhanced weathering might end up if there was run-off from the fields, particularly if they ended up in the oceans. Identifying these concerns early means they can be addressed in the verification tools, which will help build the legitimacy of the procedures.

Table 2

Values and their significance for CCS and associated GGR technologies – BECCS, DACS and CO2 utilisation – Biochar and Enhanced Weathering in Yorkshire, identified by participants and interviewees.

Key

- Likely to have significant impact on rate and scale of deployment
- Could delay or slow deployment
- Likely to benefit deployment rates
- Less significant impact

Concern	Implications	Possible solutions
Geological CO_2 storage and transportation - Common component of BECCS and DACS		
Objection to new build infrastructure and compulsory purchase of land » Planning permission for industrial facility and pipelines.	Legal challenges to developments. Case and process dependent.	Early engagement and participation required.
Concern about CO_2 leakage from storage » From geological storage. » Who has liability for costs and remediation?	Weaken support from projects or risks growing into opposition to CCS.	Access to impartial information and participation required. Regulations and transparency in monitoring.
Complex commercial model for CO_2 storage and transportation » High risk investment as dependent on multiple commercial actors.	Significant delays to deployment.	Government support to de-risk transport and storage investments and liabilities. Align and integrate commercial operations.
Low risk carbon credit » Permanence is geological in duration and verifiable.	Attractive credits. Support investment.	Supportive carbon market.
Other local CO_2 emitters able to decarbonise » Potential for local CO_2 transport network. Will reduce costs for other emitters.	Supports other local industries and spreads costs of infrastructure and operation.	Participatory, co-development process to design and enable efficient network.
Association of geological CO_2 storage with fracking » Underground CO_2 storage perceived to be related to hydraulic injections. » Suspicion that deploying CCS will decarbonise gas, encouraging fracking.	Undermine legitimacy of CCS leading to delays and decreased uptake.	Emphasis on procedures to develop trust and legitimacy - access to impartial information and participation.

Concern	Implications	Possible solutions
BECCS		
Scale of UK feedstock provision – see afforestation for constraints on UK supply. » Confidence in future market / liability and land available.	Depends on feedstock supply chain.	Incentive mechanism to support investment.
Feedstock investment – uncertainty about future markets » Farmers reluctant to invest due to long timeframes for crop maturity. » Guidelines on what to plant – forestry for residues, for timber or biomass/bioenergy crops.	Delay to UK feedstock investment. Risks concerns about increasing imports.	Policy support and market signals.
Concerns about sustainability of feedstock » Verification of sustainability. » Competition for land use. » Concerns about imported feedstocks.	Possible restriction on availability.	Agreed standards in place, but uncertainty about scale of land use change.
CCS Retrofit – trust/distrust in operator » Divergence between local and national perspectives over need. » On retrofit – distrust of motives of operator (national perspective). » Suspicion that CCS will not be implemented on bioenergy.	Risk that retrofit not regarded as legitimate. Attempt to undermine use of biomass.	Need for open debate. Participatory process to engender trust. Supported by robust bioenergy standards and legislation.
New build – scepticism about need (national perspective) » Not regarded as sustainable as renewables (e.g. wind and solar).	Restricts deployment. New build BECCS not regarded as legitimate.	Participatory process to assess need and legitimacy.
BECCU – (same as BECCS but with additional concerns associated with CO_2 utilisation)		
Potential cost reduction due to sale of CO_2 » Need to verify displacement of fossil fuel.	Enable deployment of BECCUS technology.	Cost benefits from utilisation of CO_2 but need robust accounting to prove carbon benefits.
Distrust of developers' and investors' motivations » Suspicion of mitigation avoidance.	Likely to be sector specific depending on funder and product e.g. aviation, transport, oil and gas.	Definition of acceptable residual emissions. Participatory and co-creation of regulation.
DACS		
Investor uncertainty » Concern about efficiency of process as requires heat and electricity input. » Costs - very dependent on utilisation (see below).	Weak investment leads to delay in deployment.	Requires demonstration and commercial development. Incentive support to reduce investment risk.

Concern	Implications	Possible solutions
Visual impact of capture plant and noise of operation » Includes processing plant and CCS infrastructure.	Delay / reduce deployment due to local opposition.	Benefit from participatory co-development and demonstration.
Availability of land for capture plant and additional energy supply » Similar to afforestation (but not as extensive).	Restrict preferred site availability.	Participatory process to locate and design facilities.
DACU (same as DACS but with additional concerns associated with CO_2 utilisation)		
Concerns about carbon emissions » Need to verify new products will displace carbon / fossil fuels.	Risk that utilisation process, and potentially DAC, is not regarded as legitimate.	Acceptable verification and certification process.
Potential cost reduction due to sale of CO_2 » Need to verify displacement of fossil fuel.	Enable deployment of Direct Air Capture technology.	Cost benefits from utilisation of CO_2 but need robust accounting to prove carbon benefits.
Distrust of developers' and investors' motivation » Suspicion of mitigation avoidance.	Likely to be sector specific e.g. aviation, transport, oil and gas.	Definition of acceptable residual emissions. Participatory and co-creation of regulation.
Concern that CO_2 will be sold for Enhanced Oil Recovery (EOR) to reduce costs » A pilot project in the USA is producing CO_2 for EOR to reduce the costs of DACU. A majority of the CO_2 is expected to remain underground. » Concern about carbon emissions and the motives of the oil industry.	Undermine legitimacy of CCS leading to delays and decreased uptake.	Engagement with stakeholders to develop conditions for social licence to operate. Could include long-term development strategy for DAC. Robust legislation to manage EOR processes.
Additional infrastructure to support utilisation » New-build plant or supply existing facilities. » Development of hydrogen production infrastructure (depends on CO_2 use).	Case dependent.	Participation required at project development stage.
Biochar		
Complex value chains – crossing several sectors » Hard to evaluate due to need to assess multiple markets and revenue streams. Creates investment risk in technology and feedstock supply.	Delay to investment.	Requires demonstration. Incentive support to reduce investment risk.
Concerns about sustainability of feedstock » Diverse sources including imports (of feedstock or biochar).	Could delay investment.	Varied feedstock requires verifying sustainability standards.

Concern	Implications	Possible solutions
Possible dust from spreading (depends on process used).	Risks restricting deployment on land.	Research and regulations to manage impacts.
Innovation in process » Develop alternative uses and markets. » Identify new feedstocks.	New demand stimulates production.	Work with regulations to explore potential.
Enhanced weathering / mineralisation		
Confidence in future markets for products » Application to land of minerals or mineralised product.	Delays investment in manufacturing processes.	Demonstration will provide learning. Research soil impacts.
Monitoring of application » It is unclear if the minerals will provide benefits to the soil. Any carbon credit payments must therefore be subject to verification of application to the land.	Additional monitoring and risk of inadequate deployment.	Development of monitoring tools and verification processes to support deployment.
Uncertainties in value chains » Evaluation uncertainty.	Delays to investment.	Requires demonstration.
Concerns about run off from land » Concern about risk of contamination of waterways and oceans.	Risks restricting deployment on land.	Research and regulations to manage impacts.
Impacts of application (Depends on process) » Dust from spreading on land. » Concern about risks of detrimental impact on soils or contaminants.	Risks restricting deployment on land.	Research and regulations to manage impacts.
Innovation in utilisation of products » Develop alternative uses and markets.	Demand stimulates production.	Work with regulations to explore potential.

The implications for governance.

06.

This project has found that the current governance frameworks for GGR are fragmented, with some clear gaps that need to be addressed. A range of governance interventions will be needed (see Text Box). These will need to stimulate the development and deployment of GGR whilst avoiding undermining efforts to mitigate emissions.

While there are some incentives and regulations in place for forestry, bioenergy and CCS, it is clear from the local evidence that there are significant gaps that is hindering investment.

Governance will also need to address the impacts of deployment. The evidence from this project highlights the urgent need to develop guidance at a strategic level to integrate GGR with several policy objectives, including biodiversity, agriculture and energy.

Declaring a target of net-zero has transformed carbon accounting, affecting businesses and the public, which requires a clarification of offsetting. However, there is a poor understanding of how removals and GGR options should be incentivised and supported and who should be able to access them. Strategies and action plans are being drawn up that incorporate GGR or assume access to removals to achieve net-zero objectives. Without governance there is a risk that demand for GGR will outstrip supply, putting at risk the objective of achieving net-zero.

An anticipatory approach to developing the governance frameworks will ensure they capture the breadth of issues. Embedding procedural justice into the development will deliver robust outcomes that will be widely supported.

This project identified a range of cross-cutting issues that will require governance interventions at a strategic level (Table 3).

6.1.

Strategic governance of GGR

A major concern about removing CO_2 from the atmosphere is that it could undermine efforts to mitigate emissions, as emitters find it easier to buy offsets to achieve net-zero than to implement mitigation measures.

At present the analyses indicate there will be a few sectors where emissions will be economically and socially difficult to mitigate by the 2050 net-zero target. Interviewees indicated that government might seek to protect certain industries such as agriculture, industry and aviation allowing them access to offset these residual emissions.

However, there is no clear agreement on the definition of “hard to treat” emissions. Without a clear definition, emitters will have open access to buy offsets. Whilst this may provide an important early stimulus for the GGR sector there is a risk that early movers, such as aviation, buy the bulk of the cheap and readily available GGR options, as part of a commercial strategy. This would leave other sectors, like industry and agriculture, to pick up the bill, and the risks, for developing more expensive BECCS and DACS based carbon removal technologies. Alternatively, if the rules are not put in place quickly enough, it may require government to intervene and provide the support.

Text Box 4: Definition of governance

"Governance is the formal and informal systems that guide the way in which GGR technologies are developed, implemented, operated and monitored, and that shape how decision-making around GGR takes place. These systems may be voluntary or mandatory and can be administered by national governments or by other actors, such as scientific bodies, industry associations, local authorities, community groups or international organisations. Instruments of governance may take the form of legislation, regulation, policy, financial mechanisms, codes of practice, standards, certification schemes, accounting procedures, or other systems. Governance is not limited to the operational phase of generating negative emissions, but spans the whole lifecycle of the technology." (IPCC 2018)

How the public view and access offsets will also need to change. One member of the public asked, during the study, whether it was possible to offset all emissions. Whilst this highlights a lack of awareness of the scale of the challenge, it highlights the desire of the public to be able to 'manage' their personal emissions, which may go beyond hard-to-treat activities such as aviation. The desire to support and undertake tree planting exercises raises concern about who should have access to 'emission offsets', and whether they should be reserved for the potentially large volumes of hard-to-treat emissions. This will require a wider narrative about climate action, combined with policy support to enable mitigation activities.

The classification of emissions as hard-to-treat will have strong socio-economic implications for the products and services that are provided. It could also affect the sector's international competitive position.

This raises a strong argument for using deliberative public engagement tools, which could consider the trade-offs between the sectors and their classification, including personal transport, heating and food supply and also raise a greater understanding of the local and environmental impact of the removal options (see toolkits in Annex C).

Key

- Likely to have significant impact on rate and scale of deployment
- Could delay or slow deployment
- Likely to benefit deployment rates

Table 3

Table 3 Strategic governance challenges of developing and deploying GGR and risks.

Theme	Challenges	Risk/Opportunity
Strategic governance of negative emissions	Early definition of 'residual' or 'hard-to-decarbonise', and therefore need for offsets. Determine distribution of removals in relation to residual emissions, and which actors will oversee this.	Emphasis must be on mitigation first. With constraints on the scale of removals, a lack of definition allows sectors to buy removals to avoid action, thereby making offsets harder for legitimate technologies.
	Current governance frameworks not designed with negative emissions in mind.	Lack of support delays technology development. Undermine sustainability objectives and miss opportunity to align policies.
	Need to avoid harm to UK business competitiveness.	Weaken emphasis on mitigation, shifting burden onto removals – increasing competition and cost.
	Existing UK climate and environment governance regime provides a foundation for regulating removals.	Aspects can be adapted to support removals.
GGR business models, incentives and obligations	Incompatibility of the current EU ETS with negative emissions.	Rules could be adapted or they may require a deeper revision, which will lead to a long delay.
	Difficulty of accounting for permanence in rewards for removals. Liability aspects – for removals.	Shifts focus to a narrow set of GGR options as some struggle for support and investment.
	Current incentives for forestry and renewables could be applied to GGR. Leverage existing energy policy and carbon taxation to support negative emissions.	Governance frameworks already in place for forestry. Existing frameworks could provide models for GGR support.
	Integrating policy objectives including agriculture, land use, climate change, biodiversity and energy. Incentives could lead conflicting options.	Strategic guidance will be needed to guide priorities, supported by engagement that prioritises procedural justice.
Governing GGR in the context of Brexit	Uncertain how UK will replicate EU regulations and legal provisions.	Risk of weakening sustainability support and protection.
	Uncertainty around future funding for CCS and peatland restoration.	Risk of delaying or undermining GGR options.
	UK carbon pricing mechanisms may be at risk.	Reduced incentives for removals.
	Replace CAP with new Agriculture and Environment Bill could support GGR and integrate with wider policy objectives.	Opportunity to develop policy that will provide cross-sector integration and legitimise GGR.

6.2.

GGR business models, incentives and obligations

The lack of strategic guidance and governance structures for the options means the market structures to support funding of GGR are weak. GGR is also incompatible with the current EU ETS with negative emissions.

While existing incentives schemes could be directly applicable to GGR, evidence from this study indicates that funding streams may not be the key constraint, as other aspects will need to be addressed to give confidence to the investors, landowners and farmers. Permanence of sequestration and liability aspects, particularly for the non-CCS options were identified as key concerns.

Governance decisions to support GGR will need to integrate across land use and soil management, biodiversity, biomass supply and planning law. Incentives for GGR and carbon benefits will need to balance against support mechanisms delivering the non-financial benefits, alongside other commercial drivers (see Annex A).

This highlights the need for a strategic framework for land management that can align economics, policy and regulation to allow business models to capture value from land use change / tree planting. Policies and subsidies for farming, agriculture, land use and energy will need to be coordinated and aligned with landscape amenity, flood protection, biodiversity and economic development.

A common theme from the interviews was the uncertainty about the impact of Brexit on GGR, in terms of the governance and incentivisation mechanisms as well as on those that will be involved in its deployment. It is unclear how certain EU regulatory frameworks and legal provisions will be replicated at UK level.

For forestry and land use, post-Brexit legislation and incentive schemes are emerging, but interviewees suggested that it may take 8 years before the schemes are functional and there will need to be clarity about how they apply to carbon and the various new markets that will emerge from GGR.

6.3.

Participatory process and governance

The current processes are not set up to promote participation and the provision of information – the requirements of procedural justice. Most of the deployment decisions are managed through planning law, which effectively allows developers to shape the form of public participation. Meanwhile, access to information is largely upheld in laws relating to GGR developments.

With the current polarisation around components of GGR options, particularly around the impacts of bioenergy and an emphasis on nature-based rather than engineered options, greater effort should be put into building a broader understanding about GGR and the technologies that are being developed. This needs to proactively engage a diverse range of interests from the local communities and the wider publics. Participatory processes should be a priority, with provision of open and honest information (see toolkits in Annex C).

These anticipatory activities should be used to inform the development of the governance instruments as well as provide valuable social learning. However, this is from a low starting point as there is little awareness or comprehension of the scale and implications. A shared learning exercise is needed that is not ad hoc and requires a trusted set of sources and a co-ordinated programme of impact and co-production. These could be online platforms that allow groups of individuals to deliberate new information and evidence and develop informed responses.

Streamlining procedures to accelerate deployment risks undermining the whole process and the procedural justice required to enable public acceptability[31].

6.4

Need for a GGR Strategy, Coordination and Implementation Agency (GGR-SCI Agency)

Successfully developing critical new GGR industries will require a coordinated effort between several government departments.

This could be achieved by establishing a dedicated Agency whose mission would be to build the trust of the public and the confidence of the investors and businesses in GGR while addressing the tough economic, industrial, social, political and environmental challenges. It should adopt a proactive, participatory approach to engaging the public in the development of this new sector, and embed this into project developments and planning decisions, and monitor implementation.

The Agency would stimulate deployment, overseeing the development of a GGR strategy and manage its implementation and operation. It would report to the Business Energy and Industrial Strategy (BEIS), Department for Transport (DfT), Department for Environment and Rural Affairs (DEFRA) and Ministry of Housing, Communities and Local Government (MHCLG). It would include stakeholders from public-private enterprises, local communities, developers, industry and policy makers.

The Agency would interact internationally to harmonise standards, policies and incentive frameworks. It should also engage with the European Commission to establish the regulatory frameworks post-Brexit.

Roles of the Agency would include, but not limited to, the following:

Strategic governance

Tasked with stimulating the development and deployment of GGR capacity in the UK, the Agency will need to set the rules and definitions necessary to avoid undermining efforts to mitigate emissions. It will need to balance the economic, industrial, political, social and environmental interests of the various government departments and set rules to enable fair and equitable access to GGR.

Balancing policy priorities

The Agency will need to develop strategic guidance and mechanisms to address the areas where GGR objectives intersect with other policy priorities, particularly agriculture, land use, biodiversity, and energy.

Awareness raising

A priority for the Agency will be to raise awareness and understanding of GGR amongst the various publics and stakeholders. It should work at a local and national level and impress the value of this approach on developers and local authorities to maximise the information available.

Development of carbon accounting

New rules and standards will need to be developed to distribute the carbon removal funding and to verify the permanence of removal. They will also need to establish liability for sequestration, and how the levels of insurance and remediation require to address the risks.

The opportunity for these roles to be undertaken, based on best available knowledge, will be supported by the UK's Strategic Priorities Research Fund Greenhouse Gas Removal Directorate Hub and associated Demonstrators which are scheduled to be running by Q2, 2021.

[31] Sheate 2017

Conclusions and recommendations.

07.

In 2019 the UK enshrined the target of net zero emissions into UK legislation. Analysis by the Committee on Climate Change indicates that this will be difficult to achieve without GGR, which means that it is likely to become part of the government's strategy to mitigate climate change.

But analysis for this project found that the frameworks needed for governing GGR, and the portfolio of technologies that will be needed, are fragmented. This could put at risk the ability to deploy GGR at scale. Given the uncertainties about the potential scale of carbon removals that GGR could deliver, the governance of GGR needs to be closely integrated with mitigation. With companies and industries developing plans to meet net-zero, which assume GGR will be available, there is a risk that demand for GGR will outstrip supply, putting at risk the objective of achieving net-zero.

Most analyses of GGR has been from a top-down technical and least cost perspective. But, as this project has shown, a wide variety of framings and perspectives are needed to provide insights into the likely scale of deployment. Each of these financial and non-financial aspects will need to be negotiated in order for deployment projects to go ahead.

These perspectives come from within the local communities and a range of interested and concerned parties. How these values are negotiated and finding fair and socially acceptable outcomes is as important as the issues themselves. This procedural justice, and the need for participatory engagement, needs to be embedded into the development processes, and planning legislation.

An anticipatory governance approach to developing the necessary frameworks will ensure the breadth of issues are captured early. Participatory engagement will promote recognition of the different needs, allowing responses to be co-produced, and fairness in the solutions.

Rather than being a hurdle to deployment such an approach can add value to the proposals, enabling social legitimacy and opening up opportunities for innovation and commercial developments.

Negotiating deployment

The scale of change presented by many of the options onto the local communities, where the GGR options will be deployed, will raise questions about whether they are socially legitimate. Yet, there is little understanding of their impacts on these local communities and how they will respond to the deployment. A situation made harder as most are unaware of the technologies and have little understanding of GGR.

Furthermore, the technologies will interact with other key policy areas that are important to society, such as biodiversity, flood management and soil protection, and are likely to have wider economic impacts on industry and aviation.

At present, the decisions about the trade-offs between these objectives are being made at a local level. With limited guidance to understand their wider regional and national implications, these decisions are open to being contested. The proposals for agricultural policy, post-Brexit, indicate the need for local collaborative approaches, but it may be years before this is enabled.

The rate and scale of deployment of GGR will be strongly determined by the social legitimacy of each option. If public concerns are not identified and addressed early, then each of the options – including large-scale tree planting – risk delays as aspects of their deployment are contested.

This project identified a broad range of stakeholders and multiple issues that will arise when GGR is deployed. These include cultural, social, environmental, legal and economic aspects. It also identified the potential for commercial opportunities and innovation to emerge as local business and industry are engaged in the deployment.

Many of these financial and non-financial aspects will be contested by developers and commercial interests. Achieving legitimacy will depend on how the concerned parties are engaged and the processes used to balance these issues with the national and commercial objectives of GGR.

However, the current governance frameworks make little provision for engaging stakeholders in the planning and development of GGR. Embedding procedural justice will require modifications to planning law and Environmental Impact Assessments, expanding engagement and the need for well-informed participation. The current specifications allow developers to adopt a narrow interpretation of engagement, with consultations becoming mere 'tick box' exercises, with little indication of how and if stakeholder concerns have been addressed.

Procedural justice is based on interested parties having access to information that allows them to make an informed response. This needs to be based on wider awareness of GGR in order to allow a more informed response to the impacts.

Given the scale and complexity of the GGR supply chains, it will affect large number of different communities and span across interested parties in several economic sectors. Whilst there may be local issues that need to be considered for specific projects, this study has shown there are common issues that will be contested for all developments, such as land use, where there is a pressing need to develop strategic guidance. These concerns that are common to all projects are also likely to arise for GGR options such as DACS, where there will be aspects affecting infrastructure design and deployment and resource use.

This needs a strategic co-productive approach that convenes the various interests and explicitly address these issues face to face, to build trust, social legitimacy and new institutional capabilities. Working across sectors and interests a co-production approach will raise understanding, inform the development and design of the proposals and help realise any opportunities it can bring to the communities and overcome the barriers to GGR.

Recommendations

The use of GGR to help address climate change will have a transformative impact on mitigation strategies. It will also require the creation and rapid expansion of new industries.

However, there are fundamental gaps in the governance frameworks for GGR at a strategic level and at a local level.

The government departments for Business, Energy and Industrial Strategy (BEIS), Transport (DfT) and Department for Environment, Food and Rural Affairs (DEFRA) should adopt an Anticipatory Governance approach to the development and deployment of Greenhouse Gas Removal and achieving the net-zero target. This will help identify and inform the development of the governance frameworks that will need to be put in place.

- **Greenhouse Gas Removal is integral to achieving the net-zero target, but a clear understanding is needed of the role it will play in abating climate change and how it integrates with reducing emissions.** Perspectives are already becoming polarised. Proactive and participatory engagement will allow issues to be identified in advance and a balanced consideration of any concerns and opportunities.
- **Strategic guidance and governance are needed on how GGR integrates with other policy priorities particularly agriculture, biodiversity, and energy.** This will need to integrate learning from local developments with top down strategic guidance and scientific input. The issues identified at a local level highlight where GGR deployment will be contested by other policy objectives and incentives.

- **A proactive participatory approach should be integrated into planning law, with clear guidance for developers and local authorities on how public engagement should be undertaken. This will integrate procedural justice into the development of GGR proposals which is fundamental to social legitimacy.** Planning law is currently the primary point of engagement for GGR, but its current vague specifications do not promote procedural justice and social legitimacy, which risks projects being disputed and delayed.

Multiple issues will arise when GGR technologies are deployed into local communities and regions. These will define the scale and rate at which the technologies will be deployed. How these perspectives are addressed is as important as the issues.

- **Local and regional authorities will need to value carbon removal and sequestration and integrate it into local and regional development plans, to avoid conflicting objectives.**
- **Technology developers along with central and local governments should focus on raising awareness and understanding of GGR and the technologies. This capacity building is essential to enable more informed decision making.** Few people are aware of GGR technologies, which will reduce the value of the insights that can be gained by developers when presenting project proposals. Proactive engagement will help raise awareness and build the understanding and capacity.
- **A national level discussion led by BEIS, DfT and DEFRA, is needed to explore the assumptions about GGR and to understand the role of the different options in mitigating climate change.** This should explore the multiple dimensions that will need to be considered and be informed by local perspectives. National discussions should be used to inform the development of the strategic governance frameworks. A range of tools and media have been developed to enable this.

Demonstration projects for emerging GGR technologies should incorporate local engagement e.g. BBSRC GGR Demonstrator project. While the focus is often on technical and commercial learning, local engagement would identify wider issues that could affect commercial deployment, which could be incorporated into the design. It could also identify new opportunities. The technologies would benefit from wider awareness and understanding, which would raise their legitimacy.

Current governance frameworks for GGR are fragmented, with some clear gaps that need to be addressed. Stimulation of the development and deployment of GGR, whilst avoiding undermining efforts to mitigate emissions, will be essential, together with managing the wider impacts of deployment.

- Developing these frameworks is urgent and the **establishment of an independent body with responsibility for GGR should be a high priority.**
- **A GGR Agency is proposed that would oversee the recommendations outlined above with responsibility for the development of GGR strategy, manage its implementation and monitor its impact.** It would oversee the engagement and participatory activities required to deliver successful outcomes. Agency stakeholders would include public-private enterprises, local communities, developers, industry, civil society and NGOs and policy makers.
- **The Agency would report to Government through the three departments of BEIS, DfT and DEFRA.**
- **The Agency would interact internationally to harmonise policies and standards,** including with the European Commission and EU regulatory frameworks post-Brexit.

References.

08.

Aczel MR & Makuch KE 2019. ***Shale, Quakes, and High Stakes: Regulating Fracking-Induced Seismicity in Oklahoma, USA and Lancashire, UK.*** Case Studies in the Environment. DOI: https://doi.org/10.1525/cse.2018.001719

Albanito F, Hasting A, Fritton N, Richards M, Martin M, Mac Dowell N, . . . Smith P 2019. ***Mitigation potential and environmental impact of centralized versus distributed BECCS with domestic biomass production in Great Britain.*** Global Change Biology. Bioenergy.

Armstrong H, Gorst C, Rae J 2019. ***Renewing Regulation 'Anticipatory regulation' in an age of disruption*** NESTA.

BEIS 2019. ***BEIS Public Attitudes Tracker.*** United Kingdom: Department for Business, Energy and Industrial Strategy.

Bellamy R 2018. ***Incentivize negative emissions responsibly***, Nature Energy 3(7), 532–534.

Biofuelwatch 2019. ***Open letter to the secretary of state for business, energy and industrial strategy: Please say no to Drax's climate-wrecking gas power plans.***

Buck HJ 2016. ***Rapid scale-up of negative emissions technologies: social barriers and social implications***, Climatic Change 139(2) p155–167.

C2G2 2019. ***Infographic: Governing Large-scale Carbon Dioxide Removal*** Carnegie Climate Geoengineering Governance Initiative November 2019.

CCC 2019. ***Net zero the UK's contribution to stopping global warming. United Kingdom: Committee on Climate Change.***

DEFRA 2020. ***Defra Statistics Agricultural Facts.***

Devine-Wright 2011. ***Renewable Energy and the Public,*** Earthscan.

Drax 2019. ***Enabling a zero cost, lower carbon energy future - Drax plc annual report and accounts 2018.*** United Kingdom: Drax Group plc.

EASAC 2018. ***Negative emission technologies: What role in meeting Paris Agreement targets?*** European Academies Science Advisory Council.

Equinor 2019 https://www.equinor.com/no/where-we-are/united-kingdom/zero-carbon-humber-campaign-launch.html

Cox E, Spence E & Pidgeon N 2020. ***Incumbency, trust and the Monsanto effect: Stakeholder discourses on greenhouse gas removal.*** Environmental Values, 29(2), 197-220.

ETC 2018. ***Mission possible - reaching net-zero carbon emissions from harder- to- abate sectors by mid-century.*** Energy Transitions Commission.

Fuerth LS 2009. ***Foresight and anticipatory governance*** Foresight 4(11) pp14-32 Emerald Publishing Group Ltd.

Gardiner SM 2013. ***The desperation argument for geoengineering***. PS: Political Science & Politics, 46(1), 28-33.

Gough C, Cunningham R & Mander S 2018a. ***Understanding key elements in establishing a social license for CCS: An empirical approach.*** International Journal of Greenhouse Gas Control, 68, 16-25.

Gough C, Mabon L & Mander S 2018b. ***Social and ethical dimensions of BECCS.*** Biomass energy with carbon capture and storage (BECCS) pp 251-276 Chichester, UK: John Wiley & Sons Ltd.

Hill E 2016. ***Examining Authority's Report of Findings and Conclusions and Recommendation to the Secretary of State for Energy and Climate Change.*** The Planning Inspectorate.

IPCC 2018. Summary for Policymakers. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M & Waterfield T (eds.). ***Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty***. Sweden, World Meteorological Organization.

ITM
https://www.itm-power.com/item/58-project-to-demonstrate-delivery-of-bulk-low-cost-and-zero-carbon-hydrogen-through-gigawatt-scale-pem-electrolysis-manufactured-in-the-uk

McLaren D, Parkhill KA, Corner A, Vaughan NE & Pidgeon NF 2016. ***Public conceptions of justice in climate engineering: Evidence from secondary analysis of public deliberation.*** Global Environmental Change 41 pp64-73.

Moffat K, Lacey J, Zhang A & Leipold S 2015. ***The social licence to operate: A critical review.*** Forestry - an International Journal of Forest Research. 89

Nesta 2019a. ***Collective Intelligence Design Playbook***

Nesta 2019b. ***Our Futures: By The People, For The People.***

NYCC 2017. ***North Yorkshire population information North Yorkshire Combined Council.***

O'Beirne P, Battersby F, Mallett A, Aczel M, Makuch K, Workman M, Heap R 2020. ***The UK Net-Zero Target: Insights into Procedural Justice for Greenhouse Gas Removal.*** Environmental Science & Policy Volume 112, October 2020, Pages 264-274

Robins N, Gouldson A, Irwin W & Sudmant A 2019. ***Investing in a just transition in the UK how investors can integrate social impact and place-based financing into climate strategies.*** London: Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science.

Royal Society & Royal Academy of Engineering 2018 ***Greenhouse Gas Removal.***

Senior B 2010. ***CO_2 storage in the UK - industry potential.*** United Kingdom: Department of Energy and Climate Change.

Shackley S, Hammond J, Gaunt J, & Ibarrola R, 2011. ***The feasibility and costs of biochar deployment in the UK.*** Carbon Management, 2 (3), 335-356.

Sheate W 2017. ***'Streamlining' the SEA Process. In: Jones G & Jones S (eds.). The Strategic Environmental Assessment Directive: A Plan for Success.*** Oxford, Hart Publishing pp 185-212.

Talberg A, Christoff P, Thomas S & Karoly D 2018. ***Geoengineering governance-by-default: an earth system governance perspective.*** International Environmental Agreements: Politics, Law and Economics. 18(2), 229-253.

UNEP 2017. ***Emissions Gap Report 2017***. United Nations Environment Programme.

Walker G & Cass N 2007. ***Carbon reduction, 'the public' and renewable energy: Engaging with socio-technical configurations.*** Area, 39(4), pp458-469.

GGR value-chains mapping.

Annex A.

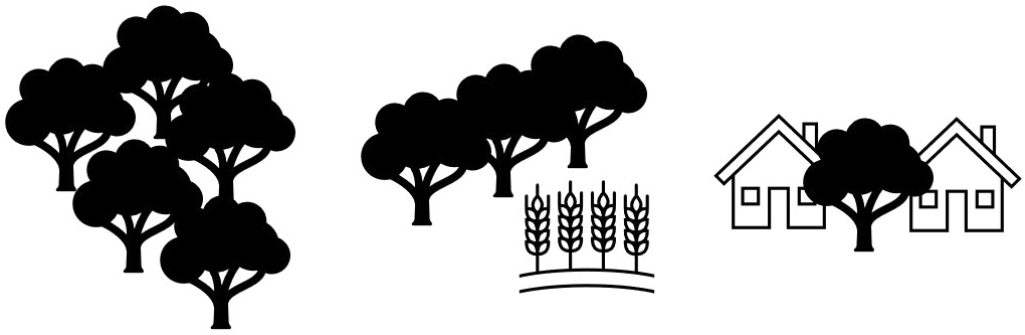
A. GGR value-chains mapping

The following Illustrative value maps set out the carbon chain for a set of Greenhouse Gas Removal (GGR) techniques. The tables indicate the financial and non-financial values that are likely to accrue at each stage with the Primary value accruing to the developer and the secondary and possible values accruing to other parties. These are indicative as it will be dependent on the commercial models that emerge and how the values will be apportioned, particularly for the sequestered carbon credit. Other financial interventions may also be required at each stage to stimulate investment.

Gaps in the table are where no information was available during the study, from the literature or interviews, or a value has yet to be identified. The same applies to other parts of the tables, where further research is required, or the values will emerge as projects and proposals move through to deployment.

A.1. Afforestation – Broadleaf woodland, agroforestry and urban trees

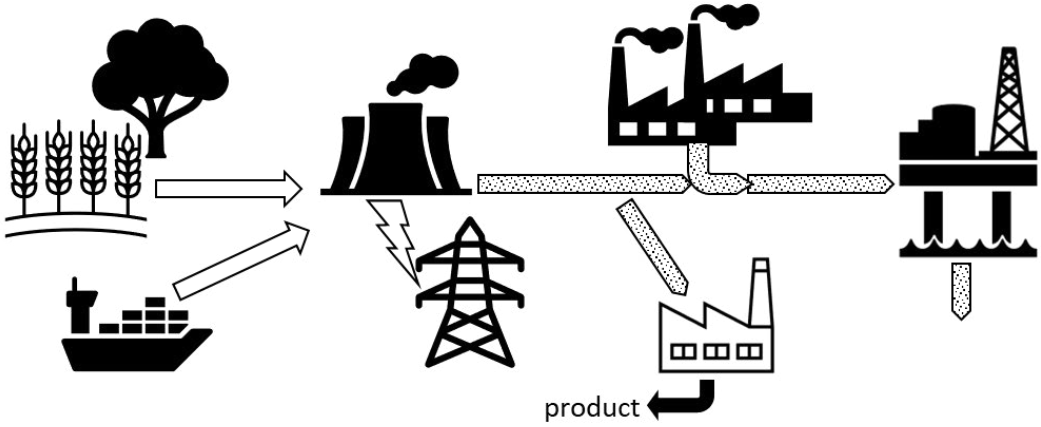
Illustrative values for different afforestation options. Woodland planting or rewilding is likely to provide the bulk of the planting because of the potential scale and area that can be covered. However, field edge agroforestry and urban areas offer potential for some tree planting, although the costs are higher, particularly for urban trees.



Type of GGR	Broadleaf woodland	Agroforestry	Urban / amenity trees
Primary value	Carbon sequestration value Ecosystem payment. Thinnings to bioenergy or BECCS.	Carbon sequestration value Ecosystem payment	Carbon sequestration value.
Secondary and possible value	Water catchment management and flood alleviation. Recreational.	Water catchment management and flood alleviation. Possible benefits to crop production.	Possible water management, depending on location.
Non-financial value	Biodiversity benefits Health and well-being. Air quality benefits.	Biodiversity and soil degradation benefits. Health and well-being.	Health and well-being. Climate adaptation benefits. Air quality benefits. Biodiversity benefits.
Negative values	Ongoing maintenance cost. Conflict with other land use. Cultural identity – landscapes and employment change. Liability risks.	Higher planting costs. Ongoing maintenance.	High planting costs. Ongoing maintenance. Insurance risk.

A.2. Bioenergy with Carbon Capture and Storage or Utilisation (BECCS and BECCU).

BECCS offers several value opportunities and the potential for very long-term geological CO_2 storage. The volumes of CO_2 produced by a BECCS power station means it can play an important role in leveraging a CCS cluster, reducing investment risk and sharing costs between several industrial emitters.

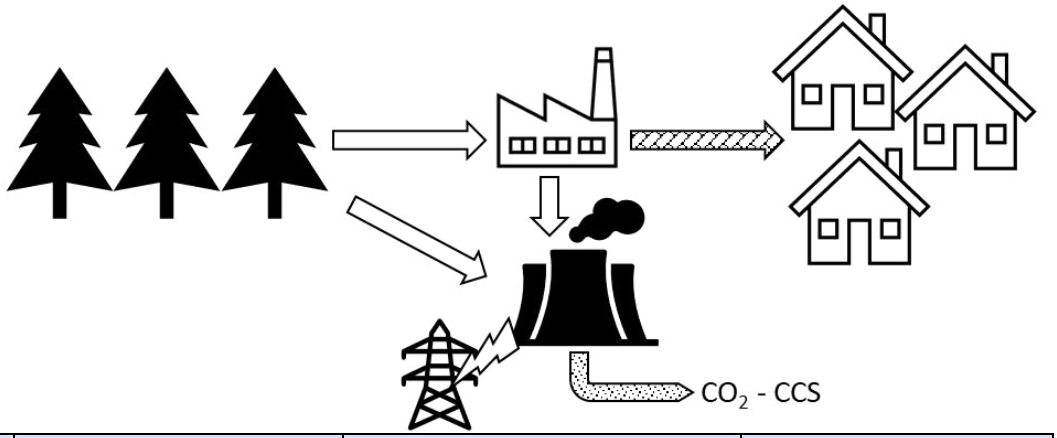


Stage of value chain	**Feedstock: Bioenergy crops, Timber and residues, Imports***	**Power generation and CO_2 capture**	**CO_2 transmission and cluster. Or, CO_2 Utilisation.**	**Geological storage**
Primary value	Feedstock sales. Use of residues - lower disposal costs. Possible ecosystem payment.	Value from energy. Value of CO_2 capture. Electricity Grid services.	Revenue from use of infrastructure. Optional CO_2 utilisation.	Income from CO_2 disposal charges. Value of negative CO_2 emission credit.
Secondary value	Timber for construction. Possible water catchment value. Employment in supply chain e.g. pellet making.	Possible source of heat. Local employment.	Access to CO_2 network, reduces transport costs. Support local businesses.	Possible use for Enhanced Oil Recovery
Non-financial values	Possible biodiversity value depending on feedstock.			
Negative values	Conflict with other land use. Sustainability and carbon accounting of feedstocks. Cultural identity – landscapes and employment change. Ethics of importing feedstock.	Reduced efficiency of power generation. Aesthetics of facilities.	Aesthetics of facilities and pipelines. Uncertainty about fate of carbon / permanence of storage in utilisation products.	

* It is unclear what volumes of feedstock could be produced locally. Analysis of the UK potential suggests that UK production would account for about a third or less of total demand from BECCS. The remainder would be imported, which could raise ethical concerns.

A.3. Commercial afforestation

Fast growing coniferous plantations with timber used for construction or whole or partly used for BECCS.



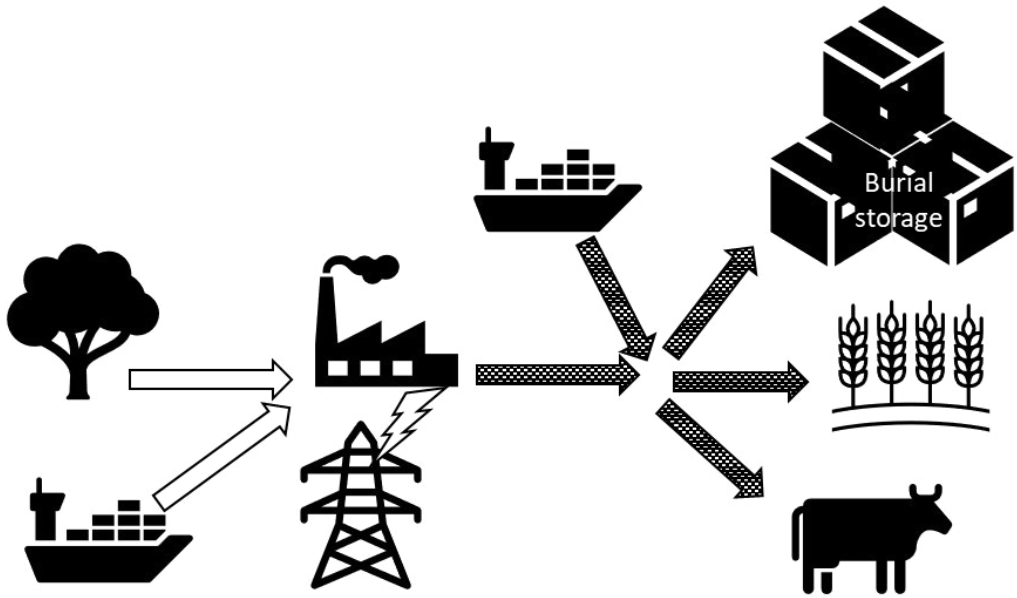
Stage of value chain	Timber production and thinnings*	Sawmill Forest and sawmill residue to BECCS	Construction industry
Primary value	Timber sales. Sale of thinnings Use of thinnings - lower disposal costs. *Ecosystem payment – unclear**.	Sale of finished products (construction ensures longevity of carbon storage). Possible proportion of carbon storage. Possible sale of offcuts for BECCS or bioenergy.	Sale of buildings and construction materials. Carbon storage value.
Secondary value	Possible water catchment value, depending on felling regime. Employment in supply chain.	Employment in supply chain. Carbon removal credit from BECCS.	Employment in supply chain. Possible lower embedded carbon than other construction materials.
Non-financial values	Possible biodiversity value – depends on planting regime.		
Negative values	Conflict with other land use. Cultural identity – landscapes and employment change. Liability risks.	Aesthetics of facilities and timber transportation.	Permanence of storage, liability issues.

* The Environmental Land Management Scheme is in development. It is unclear if it will provide payments for commercial operations.

A.4. Biochar

Biochar offers a range of pathways with several options for deployment, including bulk storage or utilisation as soil improver or cattle feed, although the latter is still in development. Biochar can be produced at varying scales which may alter which values are accessible. Imports of biomass and biochar are included as feedstock growth is likely to be higher in tropical regions.

As with other value maps, it is unclear how and where the carbon removal and sequestration value is paid out



across the supply chain.

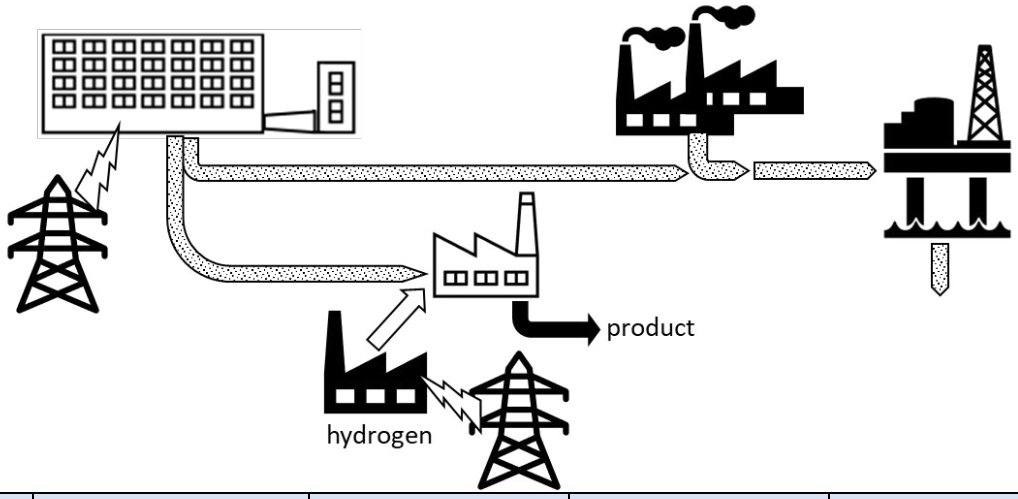
Stage of value chain	Forestry – feedstock production. Imports	Pyrolysis of feedstock into biochar with electricity generation.	Imported biochar	Utilisation of Biochar: Burial storage, soil improver, cattle feed additive
Primary value	Carbon removal value. Ecosystem payment*.	Carbon removal value. Sale of energy, mainly electricity.	Carbon removal value	Carbon sequestration value – on land storage and burial. Product sales - variety of uses.
Secondary and possible value	Reduced disposal costs of woodland thinnings and residues. Afforestation benefits.	Local employment. Scalable technology can be used for local applications (although may lose energy benefits).		Soil improver / fertilizer - displace manufactured options. Cattle feed supplement for methane management (under testing).
Non-financial value				Innovation in application.
Negative values	Possible competition with other land uses.		Need to ensure environmental standards.	Depending on application to soil, risk of dust.

* Ecosystem payment depends on new agricultural support policy (Environmental Land Management Scheme).

A.5. Direct Air Capture - with CO_2 sent to Storage (DACS) or Utilisation (DACU)

Direct Air Capture offers a range of pathways. The simplest is the captured CO_2 is sent for geological storage. CO_2 could be used for Enhanced Oil Recovery, which adds complexity to the carbon accounting[32].

DAC to Utilisation: The CO_2 can be used in range of applications, although most markets are limited in size. In this illustration the CO_2 is converted into synthetic fuels, also known as Electro-fuels. This needs a supply of hydrogen, which will mean additional infrastructure and possibly energy supply. Here the hydrogen is produced from electrolysis, which would require additional electricity infrastructure, which may, or may not, be co-located. Hydrogen could come from Steam Methane Reforming of natural gas and would require CCS to remove the fossil CO_2.



Stage of value chain	Direct Air Capture facility	CO_2 utilisation and hydrogen production	CO_2 transmission and cluster	Geological storage
Primary value	Carbon capture value. AND/OR Sale of CO_2 for utilisation – *carbon capture value to be determined*.	Value from utilisation product. Possible carbon offset value.	Revenue from use of infrastructure.	Income from CO_2 disposal charges. Value of negative CO_2 emission credit.
Secondary value	Local employment. Possible electricity grid services if demand is flexed. Utilise local waste heat.	Local employment. Hydrogen could supply other markets. Possible grid services.	CO_2 network spreads costs. Benefits local businesses.	Possible use of CO_2 for Enhanced Oil Recovery.
Non-financial values				
Negative values	Land use conflict. Aesthetics: noise and visual impact on landscape. Substantial energy demand.	Need for hydrogen* production facilities and energy source**. Aesthetics of facilities.	Aesthetics of facilities.	

* Need for hydrogen depends on utilisation option. Synthetic, or Electro-, fuels will require hydrogen source.

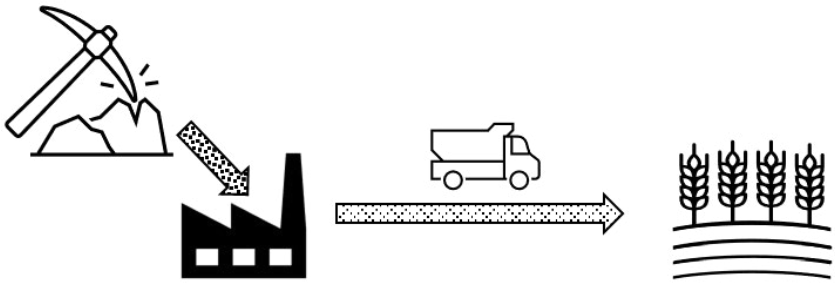
** Proximity of hydrogen production facilities and energy source to CO_2 utilisation facility has yet to be determined.

[32] The viability of this for offshore oil fields is questionable and the scale may be limited.

A.6. Enhanced Weathering

Enhanced weathering is in relatively early stages of development and further research is required to determine the likely pathways and feedstocks. This presents a simplified pathway of how it might develop. A range of different feedstocks including industrial residues and wastes might be available, subject to further assessment.

An alternative pathway is to heat the minerals on an industrial scale, which would accelerate the CO_2 uptake. The resulting products could be utilised as construction materials. This would avoid the need to spread the finely ground minerals on land. This option was noted during discussions but not considered in detail.



Stage of value chain	Mineral extraction, crushing and milling	Dispersion on land
Primary value	Carbon credit value	Carbon credit value.
Secondary value		Possible benefits to land as a soil improver (yet to be proven).
Non-financial values	Physical impacts of operations and impact on	Increased transportation.
Negative values	Costs of mining and milling. Physical impacts of mining and milling operations.	Physical impacts of transportation and spreading on large expanse of land. Uncertainty about possible environmental impacts on soil, crops and mineral run-off on water bodies and seas. Depending on application method to soil, risk of dust.

Workshop reports.

Annex B.

B. Workshop reports

GGR-CaSE Roundtable – 24th October 2019

How can Yorkshire plant 5 million trees per year?

Meeting Note

The Roundtable considered the question, how can Yorkshire plant 5 million trees per year for the next 30 years, as a key part of our response to both the climate and biodiversity crises?

The level of planting proposed in this scenario will surpass any previous efforts. The task is to consider what this would look like from a wide variety of perspectives to understand the opportunities and issues this presents and identify what is needed, who's role it is and who should be involved.

Objectives of the Roundtable

- Consider the scenario from a wide range of perspectives - What opportunities could this deliver?
- Create an understanding of what will be needed to deliver the scenario?
- Who needs to do what to take this forward - what are the next steps?

Opening presentations

Richard Heap set out the background to the Greenhouse Gas Removal (GGR) Commercial and Socio-legal Evidence (CaSE) project, which is led by Foresight Transitions and funded by ClimateWorks, a US philanthropic organisation. The project seeks to provide insights into the socio-legitimacy and participatory consent of deploying GGR options on a large scale, which analysis suggests will be needed to meet the Paris Agreement objectives. To achieve this scale in an appropriate timeframe requires a deeper understanding of their potential impacts and the societal response, to enable appropriate actions and measures to be put in place. Leeds/Yorkshire has been chosen as the focus for the study because of its mix of land use and large energy infrastructure. The findings will be made public and expected to be of value to others developing GGR options.

Richard Heap presented the scenario – How can Yorkshire plant 5 million trees every year for 30 years. This will have to be achieved whilst addressing other environmental demands. The figure is based on analysis, by the Committee on Climate Change, of pathways for the UK to achieve net-zero emissions by 2050. This would require a five-fold increase on the proposed regional ambitions – including the Northern Forest and Yorkshire Water.

Overview of Roundtable discussion

- The scenario will require land-use change on a large scale and for the very long-term.
- It will require an incentive mechanism that addresses the lock-in and long-term business models.
- It will need to address the current attitudes and presumptions of land use and landscape, across society. This should be combined with building a social understanding of the need for Greenhouse Gas Removal and wholesale tree planting.
- Barriers will need to be addressed at several spatial scales. It highlights the need for a strategic framework for land management that can align economics, policy and regulation to allow business models to capture value from land use change / tree planting.
- Considerable amount of work is already available to draw upon for the next steps.

Conclusions and next steps

It was widely felt that this was a valuable grouping of perspectives and expertise that could work to identify solutions.

- A follow-on workshop was proposed, which would have a specific place-based focus. Engaging the same participants – with slight expansion – it would seek to generate insights into the specific socio-legitimacy, socio-participatory and social co-production around long-term, large-scale, land-use change for tree plantation.
- Foresight Transitions will organise the follow-on meeting, support by Leeds Climate Commission.
- Richard Heap will follow up with participants on points raised and options for the next workshop.

Roundtable discussion

- Need to be clear on defining objective of tree planting
    - If the objective is carbon, then focus should be on bulk trees in the rural environment.
        - Urban trees important, but scale means they offer limited carbon sequestration.
        - Cost of planting in urban areas is substantial and would wipe out the budget – far more effective to spend on carbon sequestration in rural areas.
    - Amenity trees in towns are important as create a micro-climate and the canopy provides multi-functional benefits - resilience, public welfare, air pollution and heat-island effects.
        - Opportunities to plant in the urban environment – Bradford, Leeds and Sheffield. Noted that canopy cover in Greater London, at 25%, is greater than in Leeds.
        - Need to understand existing asset. Each local authority has assets they control, which they can give over to planting. Leeds City Region knows where trees are from LIDAR – Blue Sky Survey. It was noted, authorities are struggling to manage the existing woodland, as it is.
        - Multi-disciplinary and multi-agency approach and then engage with landowners.
    - Need to address biodiversity crisis and deliver environmental restoration.
        - Forestry for biodiversity: hard to measure, it is about how it is done, and area used.
        - Rewilding is an important aspect of this. Evidence that natural regeneration, over time, will allow more carbon to be stored than from broadleaf plantations.
    - Ecosystem services: trees have value, but it is small compared to growing for use.
    - Silvopasture and agro-forestry – can provide value now, medium-term carbon and providing shade for plants to avoid heat stress, which stops plants functioning over 23°C.
- Metrics
    - Best to measure as tonnes of CO_2 sequestered, rather than area or number of trees. Stocking density depends on purpose – big difference between 1.5m and 3m spacing.
    - Double counting – risk that multiple stakeholders claim credit for same planting.
    - Need to account for soil carbon storage as it is a significant part of woodland, which will continue to increase once the trees develop to maturity.
    - Carbon uptake rates of managed and unmanaged woodland are not linear, as is often assumed. Rate of carbon sequestered flips at a specific point – and is different for broadleaved or coniferous woodland.
    - Trees planted on improved (inputs) grassland had better carbon capture than unimproved lands.

Issues and Barriers

- Scale and availability of land
    - Five million trees per year is ambitious, but for Yorkshire it will probably be higher. Allocating by proportional area does not consider the land opportunities. London and South East have fewer opportunities for planting – could they buy planting in other areas?
    - White Rose Forest, DEFRA and Environment Agency mapped areas that could be planted.
    - There are multiple demands and constraints on land that restrict potential to change use.

- Liability - Need for long-term certainty
    - Liability of planting trees is substantial. Trees will need to be on land in perpetuity. Therefore, once planted they deliver long-term land-use change.
    - Really important to determine who is responsible for maintaining the trees, as it is the deal that has to be struck with the landowners. How long is the contract – to 2070?
        - Costs of managing a woodland means planting trees creates a liability. Coniferous just about break-even if wood is sold. For broadleaved it is only costs, as growth is slower and less likely to be felled/utilised.
        - This liability, and costs, are not recognised by many planting schemes.
        - Finances need to exist in perpetuity. Example: 20-30 years after planting the goal posts change and funder walks away. How address contractually?
        - Need to ensure the tree species planted are resilient to the climate in 2070.
    - Society will need to accept inter-generational dimension of planting, to enable policy stability.
- Policy uncertainty
    - Need for pace in defining incentives. And, build trust in the process to enable revenue streams, otherwise it will take 5 years to get trees into the ground.
        - ELMS (Environmental Land Management Scheme) to replace CAP – completed by 2028. If a market mechanism exists for service provision, then no direct support.
        - Post 2028 – no direct support for tree planting, so need to generate own return.
        - Unclear if market mechanism in place by 2025.
    - May take 8-10 years to establish new incentive system to replace the CAP legislation. Once in place will need rapid scale-up to catch up with the required planting rates.
    - National and regional guidance is lacking on how the landscape and its use will change.
    - Landowner is one issue, but the occupier is an important stakeholder.
    - Farmers already deal with multiple challenges: logistics, environment and regulation. Average UK landholding of 94ha, average salary £36,000 – suggests £400/ha/pa.
    - With Brexit 25% of farming expected to go bust in next few years – farmed woodland is just as critical. Who will buy the land and what will happen to it?
    - Tree planting lost momentum at the end of the Countryside Stewardship Scheme in 2014 – its replacement was too bureaucratic and lost co-ordination. It led to many landowners and farmers walking away from plans to plant trees.
- Regulatory barriers are substantial and immediate. Addressing them is expensive and may not lead to a project going ahead.
    - Flooding costs £50M = value of intervention, but many regulations and interests to address.
    - Yorkshire Water – 2nd largest landowner in Yorkshire, but land available for planting is constrained: Water-catchment 28,000 ha – take away SSSI, ecological and archaeological areas, 142 tenant farmers, protected lands, and then where does the food growing go?
    - Aire Valley aiming to plant 2-3 million trees by 2025 for flood risk management. Multiple barriers make it challenging.
- Cultural issues around the willingness to change landscapes
    - The various regulatory authorities are not aligned. In Northumberland, Natural England and Forestry Commission opposed each other over a tree planting scheme.
    - Landowners are not always convinced that the change is necessary. There will be trade-offs and conflict with existing land uses – e.g. shooting.
    - Tree planting will challenge Landscape Character Assessments
    - North York Moors National Park
        - Millions of pounds available to spend: 73ha/pa for 100 years (87 million trees)
        - Non-commercial, as regional decision that all trees must be mixed deciduous.

        - Independent grant fund set up – government scheme was too bureaucratic.
            - Good value for money – all costs covered, maintenance and planning are all done for landowner, including EIA, to meet policy requirements.
        - Present case to landowners – but not enough to encourage take up – too much uncertainty and not enough money.
    - South Pennines: At the moment the Area Plan defines it as being a tree-free zone.
    - Decision-making process is weighted against change – it only takes one Commoner to object to a proposal for it to be rejected.
    - Woodland Trust designing woods that are expensive, due to bureaucracy.

Markets for timber

- Clear need for offset market, so what is the mechanism to enable that.
    - Noted there is an ethical question about offsetting and risk to mitigation
    - Big buyers mainly looking for carbon credits – based on accrued carbon e.g. 10-15 years.
    - Smaller companies driven by CSR perspective are happy to support newly minted carbon credits from SMEs, Defra providing quality assurance method, by ISO certified credits.
    - Woodland Carbon Code can be applied to generate markets, but transaction costs of achieving verified code status.
    - Woodland Carbon Guarantee is being developed to provide guaranteed income for 30 years from carbon credits. The scheme will use a reverse auction.
- Role of Bio-Energy with CCS (BECCS)
    - Any timber used for energy production, without CCS, will lose its carbon credit.
    - Drax business model is to use pelleted off-cuts from US sawmills, providing timber for construction. Replicating this sourcing model in the UK would create enormous demand for timber, beyond local provision.
    - Scenario suggests building seven Drax. Better to go for more efficient CHP – although this would mean that the BECCS would have to be smaller.
- Timber in construction
    - Construction demand is going to grow exponentially and increase demand for timber.
    - Unclear how big the market will be compared to potential future supply.

Solutions for Barrier Removal

- Are we being brave enough? Cultural change
    - Need to engage people with the consequences of not planting trees and to agree to land being converted to tree cover.
    - Tendency for mono-cultures of productive conifers to be the end state. So, have to be careful as to whether that is what we want.
    - Community engagement and Climate Emergency can be used to address regulatory barriers. Engage local organisations who are sympathetic to tree planting.
- Northern Forest area should be designated as a woodland priority area
    - Similar to designation for National Forest and in Scotland. In the National Forest awarded 25 yr contracts (although not clear what happens at end of this period.
    - Currently planning constraints prevent land conversion to trees.
    - In Slovenia - 56% tree cover – it is engrained in the culture and in the way that they do things – wood construction.
- What is the scale we can start implementing solutions at? Is it local authorities, LEPs etc
    - Nested scale of landscape design.
        - What is the scale of Landscape Character Assessments?
        - What can be done locally without national policy?
        - Who should be driving the agenda?
        - Can we start trailing new concepts – e.g. Sheffield City Region?
    - Possible to have a development model that is independent of central government policy?
    - The Northern Forestry Board: purpose of group is to remove barriers for tree planting
    - Can the market economy provide solution, or can local authorities regulate/dictate?

- Down-scaling to different land parcels. Need for buy-in by government on that advice. Problem with lack of government buy-in.

- Business models
  - Does there need to be different funded business models for leisure and use in construction, to allow incentive.
  - Could split a carbon price between grower and end user, e.g. carbon price of £150tCO_2: half to the farmer, on an annual basis as the tree is growing to provide a regular income, and remainder to the user when they have used it, such as construction (e.g. Citu).
  - Impact on economy for widespread tree planting: Change in inward investment
- Farming industry is adapting, and they might be ready for a shift to tree development.
  - Need for multiple markets.
  - Need for regulatory frameworks to encourage the landowners to grow trees. There is an interest, but it will be slow unless frameworks change.

Attendees

Chris Thompson	Managing Director & Founder	Citu Group Ltd
Anne Robinson	Campaigner	CPRE The Countryside Charity - South Yorkshire
Rosa Foster	Strategic Partnerships & Project Manager	Environment Agency - Yorkshire Flood Risk Management
Stephen Prior	Co-founder and Director	Forest Carbon
Simon Bowens	Regional Campaign Organiser	Friends of the Earth North East & Yorkshire
Sam Wyman	Education Lead	LEAF - Linking Environment And Farming
Glen Gorner	Natural Environment Manager, Parks & Countryside	Leeds City Council
Andy Gouldson	Chair	Leeds Climate Commission
James Copeland	Environment & Land Use Adviser	NFU - North East
Guy Thompson	Partnership Manager	White Rose Forest
Alasdair Fagan	Woodland Creation Officer	North York Moors National Park Authority
Andy Goldring	Coordinator/CEO	Permaculture Association
Helen Thomson	Co-Chair	Roundhay Environmental Action Programme
Matthew Tulley	Director	Solid Carbon Storage
Anna Gugan	Natural Capital Valuation Officer	United Bank of Carbon
Hazel Mooney	Science & Communications Officer	United Bank of Carbon
Dominic Spracklen	Professor Biosphere-Atmosphere Interactions	University of Leeds
Cat Scott	Research Fellow / LEAF Director	University of Leeds
Geoff Lomas	Recreation & Resource manager	Yorkshire Water
Mark Workman	Managing Director	Foresight Transitions
Richard Heap	CaSE Project Lead & Analyst	Foresight Transitions
Apologies on day		
Tom Knowland	Head of Sustainable Energy & Climate Change	Leeds City Council
Joost van Schijndel	Woodland Officer	Forestry Commission - Yorkshire & N.E. Area
Tom Bliss	Business Development Coordinator	United Bank of Carbon
Mike Willison	Chairman	West Riding Area Countryside Committee, Ramblers Association
Noel Collings	Senior Project Officer (Infrastructure & Investment)	West Yorkshire Combined Authority

GGR-CaSE Workshop – 2nd March 2020

What are the next steps to enable a scale up in tree planting?

Meeting Note

This half-day workshop brought together a broad range of stakeholders to co-develop the next steps for tree planting, to enable it to achieve the rates of planting that are likely to be required to address climate change. A location-based approach was used to create an 'on the ground' understanding of the opportunities and challenges of deployment. Participants co-developed a prioritised list of the challenges that need to be addressed to enable tree planting to scale up. This provides a strong base on which to focus resources and co-create solutions that will have the most impact.

Objectives

- Co-create an understanding of what will be needed to enable and accelerate tree planting to the rate and scale that is likely to be needed in the region.
- Identify and prioritise the issues and values that affect tree planting for two specific locations.
- Co-develop how to address each issue, what needs to be in place and who involved.
- Create a set of next steps – that apply to the two locations.
- Assess the method and tools as a means for progressing the deployment of greenhouse gas removal options.

The outputs are expected to identify the market, regulatory and institutional interventions that will be needed to enable this sector to develop and scale up to the levels that analysis indicates will be required. Taking a location-based approach highlights the wide range of stakeholders – local, regional and national – that will need to be engaged to enhance the effectiveness and legitimacy of the solutions.

Using a participatory, co-creation approach will provide insights into the role it could play in developing social legitimacy around decision making, particularly for the complex issues that will arise from addressing climate change. It will also help build capacity in the sector, by encouraging knowledge sharing.

Overview of the project

This is the second workshop focused on forestry-based greenhouse gas removal (GGR). It is part of the Commercial and Socio-Legal Evidence (CaSE) project, which is led by Foresight Transitions, drawing on expertise from University of Leeds and Imperial College London, and funded by ClimateWorks, a US philanthropic organisation.

The project seeks to understand how commercial, social, cultural, and environmental aspects, at a local level, may enable or hinder the deployment of the various Greenhouse Gas Removal (GGR) techniques. This includes providing insights into how participatory processes to developing solutions can contribute to socially legitimate outcomes.

If Greenhouse Gas Removal techniques, including forestation, are to achieve the scale that is being suggested to meet the objectives of the Paris Climate Agreement, and in an appropriate timeframe, then a deeper understanding of their potential impacts and the societal response will be needed, to enable appropriate actions and measures to be put in place.

The Leeds/Yorkshire region has been chosen because of its mix of land use and large energy infrastructure, including the UK's largest power station, Drax, which is developing Carbon Capture and Storage with biomass co-firing and a regional hydrogen scheme. This makes the city uniquely suitable for a pioneering study, which will be applicable to other metropolitan areas in the UK and globally.

Methodology

The workshop was presented with a possible scenario in which Yorkshire would double its tree cover in the next 30 years, planting 5 million trees a year (see Annex D, based on Committee on Climate Change analysis). This would be delivered at the same time as responding to the biodiversity crisis.

The workshop set out to explore what this scenario would mean for two areas of Yorkshire:

1) Calderdale administrative area: Includes areas of moorland, river valleys prone to flooding, and livestock farming.
2) The peri-urban area to the north of Leeds, including the Wharfe Valley: Edge of urban community, some industry, with mixed farming.

To prime the discussion, participants were shown images of the landscape and land use in these two areas. They were also presented with the findings and issues identified by the first forest based GGR meeting, held in October 2019.

Splitting into two groups, one for each location, participants were asked to identify the barriers and opportunities/enablers affecting each area. From these, participants co-developed and prioritised problem statements to define the key issues. Participants also identified opportunities and aspects that would help enable the development of the sector.

Findings

Both groups developed problem statements relating to each location and ranked them in terms of their priority. The group considering Calderdale grouped several issues around four main themes, highlighting the need to integrate woodland with the other objectives of land use. North Leeds set out seven main issues, with an emphasis towards the practicalities of enabling tree planting. The two groups shared common themes, around finance, resource and capacity building in the sector, and the need to consider a range of planting regimes.

Both groups identified potential opportunities in the policy changes currently being considered for farming and land use support. Growing awareness of climate change and environmental issues amongst the population could lead to cultural and behavioural changes, for example in diets which could make land available for other uses. Communities were also willing to engage in tree planting schemes, although this needs to be supported by additional resources.

Calderdale

Problem Statements

1. **We do not have a culture of woodland use** and it will take time to create.
    a. The current woodland sector has limitations in providing advice, grants, professionals, graduates, nurseries. It will take time for it to grow to meet demand.
    b. Forestry is a high-risk industry, with multiple threats, e.g. 50% of Scottish cover comes from one species, Sitka Spruce, which makes it vulnerable to disease. Need to ensure future planting is resilient in face of multiple risks.
2. **Need to avoid silo thinking**. Woodland creation needs to be part of wider landscape design and management process. Need to include biodiversity, flooding and community use etc.
    a. We do not have a strategic land use map to guide decision making over the long term.
    b. It is more complicated than just “planting trees”. Need to understand the options for creation (e.g. planting and regeneration) and the forms of tree-based systems available.
3. **Current Basic Payment Scheme (BPS) does not support woodland creation**, agroforestry or silvo-pasture. Need to ensure that ELMS supports this.
    a. UK has one of the lowest percentages of government (publicly) owned land in the world, which affects how desired outcomes can be achieved.
4. **Are we subsidising business as usual?** Notion that off-setting means that companies and citizens do not need to make significant change.

Potential opportunities

- Shift EMS (Environmental Management Scheme) to offsetting
- Flood Awareness – greater understanding that tree planting, alongside other natural flood management approaches and better soil management, can help to reduce flood risk.
- Greater shift to vegan/vegetarian diets could create opportunity to rethink *some* upland areas.
- More people want to help plant trees, providing a volunteer capacity concerned about climate and environment.
- Examples of other planting forms and increasing e.g. agroforestry / silvo-pasture. ELMS may have explicit support for them.
- Re-wilding has caught public imagination.

Peri-Urban – North Leeds

Problem Statements

1. **Policy** – Legislation is needed to incentivise and simplify woodland planting at a national level.
2. **Availability of land** – Land is limited by competition and competing priorities of landowners.
3. **Finance** – Level of incentives required to encourage tree planting is not understood.
4. **Carbon capture strategy** – We do not have clear guidelines on sequestration on different types of trees / woodland.

4= **Information / knowledge of sites / grants** – So much data and information is required for grant application, makes very difficult.

5. **Resource and capacity** – Resources need for current land managers for grant applications and land manager skills. Grant applications are time intensive: do landowners need more assistance?
6. **Existing trees are being lost** – Existing trees are vulnerable and require additional support

Potential opportunities

- Clarity on future land management scheme and the role that tree planting plays: landowners are second guessing incentives at the moment. Including shift from Common Agricultural Policy (CAP) to Environmental Land Management Scheme (ELMS). Opportunity to make public money = public goods – over the 10yr transition period make tree planting economically viable.
- Funding is available for tree planting
- Shift away from extensive land use for livestock, as climate change is top priority.
- Build social and political buy-in:
    - Local population is engaged in thinking about climate change - community awareness and demographics
    - Understanding what we are aiming to achieve and why
    - Encourage communities to plant – they will own their trees then
    - Landscape character assessment for change can allow a visual of what the new landscape will look like.
- Variety of different ways to plant trees:
    - Cities: Garden planting – canopy + plant crop underneath; replant grass verges; stop tarmacking pavements to allow water ingress for trees; part of planning requirements; take derelict land into public ownership
    - Permaculture / forest garden in personal gardens or as productive farmland.
- Role of town/parish councils, e.g. Horsforth/Otley, as catalyst for community led initiatives.
    - Coming together of communities in Wharfe Valley and across Leeds
    - Cooperation with local authorities / partners in catchment
- Additional resources including staff to work up planning surveys, legislation checks etc.
    - Identify and map land which is available for tree planting.

- Clear guidance required about:
  - Planting – types of trees / intensity
  - Land management
  - Funding and volunteer management
- Legal requirement on developments to include a certain amount of planting / restoration of land – or invest elsewhere. Beyond replacing what is lost.
- Legislation to require 'X' amount to be trees to be planted.

Conclusions and recommendations

The participants were widely supportive of the process and were keen to explore how this can be sustained beyond the CaSE project. The University of Leeds proposed taking the outputs to develop a programme of further engagement that can develop and help implement the solutions.

It was recognised that the objectives of the workshop were ambitious in the time that was available. More time would be needed to develop in depth solutions to the problem statements that had been developed. The time available for the workshop had been restricted by the challenge of fitting the wide range of people's availability into the tight timetable of the CaSE project. It also coincided with extreme flooding events and the main season for tree planting.

Participants

Calderdale Group		
Miles Drury	Woodland Officer	Forestry Commission - Yorkshire & North East England
Rob Meetham	Landscape Architect	Peak District National Park
Carol Douglas	Woodland Creation	Yorkshire Dales Millennium Trust
Andy Goldring	Coordinator/CEO	Permaculture Association
Dominick Spracklen	Professor of Biosphere-Atmosphere Interactions	University of Leeds
Peri-urban, North Leeds Group		
Daniel Smith	Senior Project Officer, Energy	Leeds City Council
Glen Gorner	Natural Environment Manager, Parks & Countryside	Leeds City Council
Simon Bowens	Regional Campaign Organiser	North East & Yorkshire Friends of the Earth
Ailsa Henderson	Forest Officer	Harewood Estate
Andy Boyle		Otley 2030
Alexis Percival	Environmental & Sustainability Manager	Yorkshire Ambulance Service NHS Trust & Roundhay Envt'l Action Programme
Anna Gugan	Natural Capital Valuation and Woodland Creation Officer	United Bank of Carbon
Cat Scott	Research Fellow / LEAF Director	University of Leeds
Apologies on the day		
Rosa Foster	Strategic Partnerships & Project Manager	Environment Agency - Yorkshire Flood Risk Management
Andy Gouldson	Chair	Leeds Climate Commission
Ben Lascelles	Managing Director	Harewood Estate
Mike Willison	Chairman	West Riding Area Countryside Committee, Ramblers' Association
Joost van Schijndel	Woodland Officer	Forestry Commission - Yorkshire & North East England
Matthew Tulley	Director	Solid Carbon Storage

Workshop leads

Richard Heap	CaSE Project Lead & Analyst	Foresight Transitions
Stephen Hall	University Academic Fellow	University of Leeds

Unable to attend – deputised and keen to follow up

Andy Tickle	Head of Campaigns	CPRE The Countryside Charity
George Hepburn Scott	Business Development Manager	Forest Carbon
Mark Broadmeadow	Principal Adviser Climate Change	Forestry Commission
Crispin Thorn	Area Director, Yorks & North East	Forestry Commission
Carl Edwards	Director, Education & Public Eng't	LEAF Linking Environment And Farming
Polly Cook	Chief Officer	Leeds City Council
Martin Farrington	Director of City Development	Leeds City Council
Prof Simon Pringle	Chair, Green Economy Panel	Leeds City Region Enterprise Partnership
Jonathan Moxon	Flood Risk Manager	Leeds City Council
Clare Robinson	Team Leader Yorkshire Pennines	Natural England
Rhodri Thomas	Team Manager - Natural Environment & Rural Economy	Peak District National Park
Alexis Percival	Chair	Roundhay Environmental Action Prog.
Prof Piers Forster	Professor of Climate Physics	University of Leeds
Simon Mageean	Programme Director Northern Forest	Woodland Trust
Gareth Redmond-King	Head of Climate and Energy	WWF
Jacqui Warren	Policy Manager	WYCA (Leeds) Energy
Gordon Rogers	Head of Sustainability	Yorkshire Water
Geoff Garrett	Senior Trees & Woodland Officer	Yorkshire Dales National Park Authority
Carol Douglas	Woodland Creation	Yorkshire Dales Millennium Trust
Madge Moore	Chair	Yorkshire Food, Farming & Rural Support Network

Meeting Annex – Detailed notes of the issues for each area.

Barriers – Calderdale

- Under the current Basic Payment Scheme (BPS) establishing woodland means farmers lose any agricultural subsidy. Woodland tends to be less financially beneficial to landowner.
- Existence of BPS and 'agricultural condition' requirements
    - Current ELMS / Grant / land management systems → perception
- The current funding mechanisms for woodland are too complex.
- Carbon credits. Business wants to support tree planting but want certified woodland carbon credits rather than paying to plant trees.
- Better engagement and awareness of forestry economics etc – growth modelling.
- Misconceptions about woodland management and timber use
- Not just about trees – moorland can be valuable too – low scrub – in UK remove low scrub, but everywhere else it is allowed. RSPB notes that this may be more valuable for biodiversity.
    - Political interest in woodland drivers – agroforestry, flooding, carbon, but can be a risk as it is single issue and politically driven and lacking the depth of understanding, leading to arbitrary target setting.
- Not just about planting – needs to include regeneration and management
- Public land ownership – currently very low, which limits what can be done on land. Private land ownership allows owner to do what they like with little consideration or responsibility towards those 'downstream'.
- Access to land to do planting on e.g. Treesponsibility experience.
- Limited capacity in the sector: nursery stock, forest planting, contracting workforce.
    - People on the ground to support delivery i.e. mechanisms in place for people with land who want to plant.
    - Access to support for actually planting the trees – person power.
    - Access to advice about anything other than woodland or hedges. Minimal knowledge or support for agroforestry or silvo-pasture etc.
- Funding reaching those who can support delivery.
- Landscape Designations and Landscape character
- Other priorities e.g. breeding birds, archaeology

Barriers – Peri-Urban North Leeds

- Number of trees
    - Number of trees available in the correct season
    - Planting seasons
    - Knowledge of trees that will be climate resilient
- Availability of land
    - Underground cables / water etc
    - Water supply
    - Land classification e.g. arable, dairy etc
    - Suitability of land
    - Ownership
        - Council land availability: Assess what is currently available; identify what can be released going forward.
        - Private land availability: Agricultural landowner engagement / incentives; available to buy.
- Finance / access to grants

    - Limited financial reward for planting trees – for landowners or tenants
    - Long-term costs of maintenance
- Permanent land-use change – traditional use has cultural resonance
- Managing the balance of farm/estate land at the farm scale – how does it fit?
- Lack of knowledge – people with land may not be sure what to plant / where and how to maintain i.e. skills and information gap – practical and ongoing.
    - People to plant trees
- Private development land – more power required by LPA to force developer contributions,
    - green street principles
    - biodiversity net gain
    - percentage of tree cover
- Carbon Capture Strategy
    - Not enough resources of money for tree planting
    - No carbon capture strategy for people to buy-in to. Has not captured attention yet.
    - Data on carbon sequestration or skills to calculate - resources are out there but they are complex.
- Intensity of farming on land needs to change i.e. cows per hectare, sheep per hectare.
- Existing trees lost – Ash die-back, biosecurity
    - The role of big trees in climate mitigation.
    - Existing canopy is not static – but is assumed to be. Subject to pest and diseases
- Grant policy
    - Complexity of the schemes and subsidies and maintenance grants, post planning.

Toolkits.

Annex C.

C. Toolkits

Anticipatory and participatory approaches

An anticipatory approach aims to proactively engage with a broad and diverse range of interested parties, including local and national level, to identify the issues that will affect the delivery and operation of a new technology or policy. This aims to avoid blind spots and groupthink assumptions in the development of technologies and the governance frameworks that are needed. By identifying the issues and information early they can be integrated into the design and influence the outcomes.

The integral participatory aspects help build procedural justice, through awareness and recognition of the breadth of issues and perspectives, which in turn leads to trust and social legitimacy.

The processes and tools set out below have been utilised to inform this project and have been used across the world and for many purposes. They are designed to encourage engagement and to provide easier and lower cost means of gathering insights. While surveys and town hall meetings provide insights, they can often be hard work offer only a snapshot of views. Whereas a richer dialogue may be needed to respond to the information and develop ideas. Citizen's assemblies can enable this, but they can be time consuming and hard to scale. New tools are needed to widen engagement and deliberation of the issues.

There are several stages to anticipatory approaches and good participation, each has a range of tools to facilitate the process. These are broadly defined[33] as:

1) **Define the issue**, including what the issues are and who are the interested parties.
2) **Identify the data and information**, with a range of tools to enable an inclusive and proactive engagement with interested parties, with tools to effectively gather their views.
3) **Mobilise people** – gather data and insights from the stakeholders.
4) **Connect and interpret the data**, which encourages an iterative and collaborative deliberation of the information with the aim of identifying solutions that are agreeable to all parties.
5) **Create change**, where the ideas and solutions can be tested and trialled. This stage includes feedback loops within itself, but it could go back to earlier stages.

1. Define the issue

The following process and tools help define the issue under consideration and identify the parties that will provide value and insights.

Issue mapping

- Using a workshop, participants can capture and visualise the different and interconnected issues.
- Identify the drivers or causes of the issue, which are likely to include political, social, technical, environmental and legal. These can also be regarded as problem statements.
- The team then prioritise the drivers and then identify points for intervention of leverage.

Stakeholder mapping

- A small project team can map the stakeholders who are directly, indirectly or remotely influencing or affected by the issue.
- Stakeholders can be connected by flow of data, resources or value.

[33] See also Nesta 2019a & 2019b

Outcome based

- Develop a vision of the best-case scenario and outcomes and what was involved in the delivery.

2. Identify types of data, information and ideas needed to inform decisions

Identify existing data sources and link to the issues and stakeholders. The ethics of data gathering and how it is used also needs to be considered.

The following can be undertaken by a small group or project team, but are essential to developing the data gathering and

Data mapping

- A range of tools to link data needs with available data and alternative sources.

Map types of data

- Data may come from a wide range of sources depending on need including citizen generated and social media, official data, technical and academic.

3. Mobilise people

Having identified the data sources and types of data that are needed to inform the overall task there are an extensive range of tools and techniques to gather the data. These go beyond simple surveys as they are use a range of methods to illicit responses.

Tools for data gathering

- **Crowd sourcing –** through digital platforms, websites, small surveys either in person or digitally.
- **Digital visualisation** to gather responses and reactions using:
    - **gaming**
    - **immersive experiences**
- **Town Hall meetings** allow these have limitations and can be time consuming they can help raise awareness amongst the stakeholders of the breadth of issues. Participants and stakeholders are allowed to present to a panel of experts their views. The experts listen to the full range of views that are presented and do not ask comment or ask questions. Each stakeholder is each allocated a specific amount of time. All participants are expected to listen to all the other stakeholders' views. No feedback or judgement is made during the meeting. This allows all the views to be presented equally.

4. Connect and interpret the data to co-develop solutions

Stakeholders can engage with the data and with each other to understand and debate the trade-offs between the different options.

- **Deliberation** can be **enabled through workshops or online platforms**, using either verbal or written exchanges. It is vital that each participant is allowed to present their views in an equal manner.
- **Collaborative platforms** allow groups to work together to develop and create an outcome. Openness and transparency are essential to improve participation and trust.
- **The ORID framework** (Objective, Reflective, Interpretive, Decisional) can be used either online or in a workshop to use strategic questioning to deliver a structured conversation.

Using the information that the participants have gathered or has been presented to them, they can provide valuable insights and work towards a collaborative decision.

- **Generative Decision Making** is similar to the ORID tool where participants work debate proposals for a decision and modify it through response and debate until an acceptable proposal is made.

5. Create change

Having developed solutions this stage is used to make them usable and actionable. This involves testing and trialling the proposals with feedback to stakeholders about progress and outcomes. This may include feedback loops to earlier stages where further consideration is needed, or additional issues arise that need resolving.

The solutions can be tested using a range processes:

- **thought processes** where a small group can work through the practical implications and test the approach on real or perceived audiences.
- **sandboxes** that allow real time testing with data and any operatives using a safe or contained environment.

Scenarios

Annex D.

D. Scenarios

To inform the discussions and deliberative processes a scenario was developed for each GGR technology and what the future deployment might look like in the Yorkshire region. The scenarios sought to provide an indicative scale to the deployment and to set out the known characteristics of each option. This would create an understanding of the deployment and help identify the issues that are likely to arise and understand the underlying values and drivers.

The intention was not to be overly prescriptive about deployment and locations, so as to allow options to be proposed and considered. With few or no operational examples for many of the options, the scenarios sought to highlight the likely physical parameters and aspects rather than specific details. This provided participants and interviewees a basis on which to consider the potential implications of deployment.

For many of the technologies, analyses of the potential deployment at a national scale indicates wide variation. There is virtually no analysis at a regional scale. The regional scenarios were therefore largely extrapolated from the national assessments, taking into account any existing projects, proposals or local characteristics that would affect the scale. It was recognised that even if the scale proposed in the scenarios were out by 50%, they would still represent a substantive change to land use, landscapes or operational practices.

D.1. Afforestation

Context

- Afforestation is considered in all the CCC scenarios.
- UK is one of the least wooded countries in Europe at 13% of land area. Scenarios consider increasing national tree cover to as high as 19% in the stretch ambition. The latter would require planting about 2.5 billion trees between 2020 and 2050. Achieving this level of land use change would require planting 50,000 hectares of afforestation per year for 30 years, across the UK. It would sequester ~27 $MtCO_2$/yr by 2050.
- Afforestation is often expressed as area covered or numbers of trees planted, but there are any factors to consider. These include planting density, survival rates (with estimates varying between 50% and 80%), species planted and growth rates, previous land use and soil disturbance.
- The numbers presented in the scenario were intended to indicate the scale of effort and land use change required, rather than a precise estimate of value.
- Yorkshire has some of the lowest amounts of tree cover in the UK at about 7.5% of land area. Yorkshire has three areas that are designated as national parks, with other areas that are protected habitats and moorland.

Scenario

The scenario proposed planting 5 million trees per year for the next 30 years, which is equivalent to 3,000 hectares per year. Yorkshire is about 10% of the land area of England (and 10% of population), so the figure is based on an equivalent distribution of forestry. This would lead to a doubling of tree cover in Yorkshire and capture ~1.6 $MtCO_2$/yr in 2050.

The tree planting would see and expansion of existing schemes that have been set up in the last few years including the Northern Forest, Water Companies and Govt announcements. These schemes aimed to plant 15,000 hectares by 2040, so the GGR scenario would see a five-fold increase in planting effort, and a ten-fold increase on current planting rates.

A mixture of broadleaf woodland and coniferous plantations would be required. The proportion of each is unclear but the economics and carbon benefits favour coniferous plantations, which may account for more than 50% of proposed projects.

The new woodland is likely to be on land currently used for livestock and in the moorland and valley areas. For scale, the proposed 90,000 hectares of new woodland is about one quarter of the area currently used for livestock farming in Yorkshire. The new woodland is less likely to compete with current arable land.

It would require increasing tree nurseries and forestry skills. Up to 2050 most of the activity will be tree planting with some woodland management. Felling and timber processing is likely to develop in the decades after 2050.

A small proportion of the trees could also be planted in cities, with others planted as agroforestry in hedgerows or on the borders of fields.

D.2. BECCS

Context

- In the Committee on Climate Change's Net Zero report BECCS was included in all their scenarios for 2050.
- BECCS is dependent on access to CO_2 storage. There may be markets to utilise the CO_2, but most are relatively small, apart from its use for synthetic or electro-fuels. The market for these is as yet unclear and is not considered in this scenario.
- The current requirement for engagement with the public is under the planning permission and the environmental impact assessment, which is a requirement of any large project in the UK. It is possible this will be split across the components of BECCS rather than across its whole value chain (see Annex A).
- BECCS is expected to produce electricity, although some have suggested it could be used to produce hydrogen, although this is likely to take a while to develop.
- Analysis by the CCC suggests that there will be significant land use change – bioenergy increasing from 0.2% of land to 5%, although not all will be for BECCS.

Scenario

Following approval in 2022, the proposed retrofit development to the existing bioenergy power station at Drax aims to be operational by the end of 2026. This means the Yorkshire will host the world's first negative emission power station. It would also enable an industrial decarbonisation cluster in the Humber area to develop in one of the most carbon intensive industrial areas in the UK. Drax power station will generate electricity from burning dedicated bioenergy feedstocks. Overall Drax will contribute 15% of the UK's renewable energy supply (up from 12% in 2018). Once captured and processed, some of the carbon dioxide could be utilised in the beverage industry or to manufacture carbon fibre products. Once fully operational, Drax and partners' BECCS operation will remove up to 2 million tonnes of carbon dioxide from the atmosphere every year (equivalent to emissions from 224,000 people in the UK).

The Humber is the UK's biggest industrial economy, employing 55,000 people and contributing £18bn to UK GDP each year. With about 100 chemical and refining companies, it accounts for around 12% of total employment in the UK chemicals sector. Estimates suggest that industrial businesses across the Humber could face carbon taxes of between £1.4bn and £4.2bn if they fail to decarbonise by 2040, putting jobs and supply chains at risk.

Analysis suggests that up to a third of the bioenergy feedstocks used in BECCS in 2050 could be sourced in the UK. It is unclear how much could be produced in Yorkshire. It is also unclear how

much bioenergy Drax will source from the UK as the current commercial model is based on biomass residues which are cheaper than dedicated bioenergy crops. It is unclear how long it would take for UK forestry to develop a substantial supply. Extensive bioenergy crops would also compete with other land uses, particularly food.

D.3. DACS and DACU

Context

- DACS and DACU are considered in all the CCC scenarios. The CCC suggest that by 2050 DACS could remove 1MtCO_2/yr under the further ambition scenario or up to 25MtCO_2/yr under the speculative scenario. For this study the higher figure was adopted.
- DACS is dependent on access to CO_2 transport and storage. There may be markets to utilise the CO_2 (DACU). DACS requires a substantial energy supply, mainly electricity, but it can also utilise waste heat to reduce the electricity demand. This makes the CO_2 removal process, from capture to geological sequestration very expensive, about twice that of BECCS. Utilisation reduces the costs, but unless the CO_2 is immobilised permanently then it is no longer a CO_2 removal process and raises questions about carbon accounting.
- The main component is the CO_2 from direct air capture unit. There is uncertainty about how these will be configured.
- Estimates suggest that capturing 1MtCO^2/your will require an area of about 2km^2. The upper estimate of 25MtCO_2/yr will therefore require 50km^2 of land, equivalent to about a third of the area of the City of Leeds.
- DACU: Most CO_2 markets are relatively small, apart from its use for synthetic or electro-fuels. The market for this could be substantial particularly for aviation fuel, especially if the limited biomass supply is prioritised for BECCS. Rather than extracting new fossil fuels, electro-fuels means they could be replaced by zero-carbon fuels (subject to strict accounting to avoid adding to fuel supplies (it also does not resolve issues about contrails and high-altitude impacts)). The CO_2 would be circulated between the atmosphere and fuels. However, it is expensive and requires considerable energy input and a supply of zero-carbon hydrogen, which requires further energy input and infrastructure.
- The current requirement for engagement with the public is under the planning permission and the environmental impact assessment, which is a requirement of any large project in the UK. It is possible this will be split across the components of BECCS rather than across its whole value chain (see Annex A).

Scenario

The Humber is one of the sites identified as a likely CCS cluster and one of three on the east coast with access to the extensive geological CO_2 storage sites in the North Sea. It is also close to refinery infrastructure which could be used for electro-fuels (synthetic fuel) manufacturing.

With the successful development of the CCS cluster in the Humber region it was assumed that by 2050 that up to a third of the UK's DACS capacity could be deployed in the region, capturing about 8 MtCO_2/yr.

It was assumed that the CCS cluster in the region develops before DACCS, as it may be a few years before it can be deployed commercially. The focus of this scenario and development proposal is therefore on the DACS infrastructure and the potential for DACU providing CO_2 for electro-fuel production.

There is considerable uncertainty about what form and configuration the CO_2 capture (DAC) facilities will take. The units will require an area of about 16 km^2 (10 square miles), an area approximately twice the size of Immingham dock and Killingholme refinery complex – although it is not clear if they will be spread out in a line or confined to a single site. The units will be connected by CO_2 pipelines.

They will also require a substantial electricity input. For the proposed scenario the additional energy demand would require about 3.5GW of dedicated offshore wind. Where this came from was not included in the scenario, as it may come from the national electricity grid, or from a dedicated new offshore wind farm.

A DACU scenario was not considered in detail. The capture plant would remain the same, while the utilisation may be integrated with existing refinery facilities in the Humber region. The main additional facilities would be to produce hydrogen. This may could come from the proposed plant at Drax in the first instance. Although the future input would need to come from an electrolysis plant to reduce the dependence on CCS. Such a facility is the proposed ITM Power's Gigastack[34] plant, being developed with Orsted and Philips 66 refinery in Killingholme, Humberside.

D.4. Biochar

Context

Biochar is similar to charcoal and is produced from heating organic feedstocks in a low oxygen environment (pyrolysis). It is a stable form of carbon, which does not decompose on its own. The pyrolysis process burns off most of the non-carbon content of feedstock producing heat which, if combusted on a large scale, can be used to generate electricity.

- The CCC does not include biochar in its scenarios due to its early stage of development and the need for more research to understand its permanence and possible impact on the environment and soils.
- Estimates vary widely for the potential scale of biochar production in the UK. The produced biochar could be buried in bulk stores or distributed in small pieces across land.
- Evidence indicates that it can influence soil fertility and could be utilised in a wide range of agricultural soils. It is currently sold as a domestic soil improver. Up to 30-60 tonnes of biochar could be applied to arable soils without changing the primary purpose of the land.
- Alternative uses are being developed, which could open up a range of markets.
- It can utilise a range of feedstocks, from biomass residues to dedicated crops. Its potential scale in the UK depends on feedstock availability.
- The estimated range of removals it could achieve are 2-10 $MtCO_2$/yr. This could increase to 3.5 - 21$MtCO_2$/yr if improved crop productivity and displacement of carbon intensive energy production is included[35]. Another study suggests removals of 5 $MtCO_2$/yr, using dedicated biomass crops (requiring 0.1 Mha of land) and biomass residues, with biochar spread on 25% of arable land in UK (1.5 Mha) [36].
- The production technology can be easily scaled allowing it to be sited in a wide range of locations. This could make it attractive to the local economy.
- CCC analysis indicates that BECCS is likely to offer a more efficient use of finite biomass resources than biochar. It also notes that application of biochar to soils is effectively irreversible and recommends further research to establish its permanence and impact on soils.

Scenario

In this scenario, biochar becomes readily available following demonstration projects that confirm its carbon removal and environmental benefits. Previously small projects were being developed that

[34] ITM 2019
[35] Shackley et al 2011
[36] RS & RAE 2018

buried biochar in large bulk stores. This was more expensive but avoided uncertainties about permanence and any unknown environmental impacts.

Biochar is sold to farmers, landowners, plant nurseries and forest managers as a soil improver. It is spread on the land with existing agricultural equipment. A mix of sources are used, with some local production - some of which utilises the local CCS network – and the rest transported into the region. Small local facilities also operate as a low cost means of managing local waste streams, rather than to compete with the bulk market. It is difficult to estimate the likely scale of use as there are many uncertainties that will affect the price and availability, but it could become readily available with the carbon removal credit making it an attractive and low cost soil improver.

D.5. Enhanced Weathering

Context

Silicate rocks naturally react with CO_2 as they weather, trapping it in a mineral form. To accelerate this process the surface area of the rocks is increased by crushing and fine milling. It is then spread on land to react naturally. The process can be accelerated by industrial heating with a CO_2 rich air flow, producing a material that could be used in construction.

- The CCC does not include enhanced weathering in its scenarios due to the need for more research to understand the risk of any environmental impacts and early stage of its development.
- There is wide uncertainty about the scale of EW deployment. Analysis suggests it could remove up to 15 $MtCO_2$/yr by 2050, which would require spreading 20 tonnes of rock per hectare over 5.4 million hectares of agricultural land[37]. This would be similar to limestone spreading that farmers already do on an annual basis. As with biochar this would depend on developing appropriate incentives and markets.
- Enhanced weathering is estimated to remove around 0.3 - 1.2 tonnes of CO_2 per tonne of mineral. The CO_2 is captured in stable carbonated minerals. Mineralisation is accelerated with temperature; deployment in tropical regions can have reaction rates five times faster than temperate regions.
- Geological surveys indicate that there are no suitable rocks in Yorkshire. It is therefore likely to be a recipient of rock for spreading on land, mostly on arable areas. Some of the sources of suitable in the UK rock are found in environmentally sensitive areas and national parks, the acceptability of exploiting this requires further research.
- A proportion of the minerals may come from industrial waste, such as steel slag and construction wastes. The volumes are limited and will need investigating to avoid any hazardous contamination.
- Further assessment is needed of potential environmental impacts in the soil. The carbonate minerals can leach out of the soil into water courses and into the ocean, where it is deposited on the seabed. The rocks can also contain hazardous trace metals that could contaminate soils, water and crops.
- The minerals are spread on land as a fine dust. This may be a cause for concern and requires further research.
- The technologies are all available so it could scale rapidly, subject to support and regulatory frameworks and confidence in the lack of any negative environmental side-effects. Appropriate verification, monitoring and carbon accounting methods will need to be developed.

[37] Royal Society & Royal Academy of Engineering 2018

Scenario

It was assumed that Yorkshire would be a recipient of mineral rock for application on arable land. There are uncertainties about how the minerals would be applied to land, but the CCC analysis indicates that 5.4 million hectares would be required, which is over 85% of the UK's 6.2Mha of arable land[38]. It was assumed that Yorkshire would follow this level of deployment. Yorkshire has about 9.5% of the UK's arable land.

New markets and supply chains would develop to distribute the material. Guidance would be developed as to the application levels. It is unclear if spreading the material would provide any benefits to the soil, so monitoring and verification procedures would be required to ensure the material was applied in line with the guidance.

The scenario focussed on the application of mineral rock to agricultural land and did not explore the potential to use any of the industrial wastes or legacy waste stocks that might be available in the region as the availability and potential is uncertain. The scenario also did not explore the potential for heating the minerals to produce construction materials, as it is not clear if this might occur in the region.

[38] Defra 2020 & 2018 Agriculture and Farming Statistics

FORESIGHT
TRANSITIONS