Greenhouse Gas Removal (GGR) policy options – Final Report

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Executive Summary

Greenhouse gas removal (GGR) will become an increasingly important driver of UK decarbonisation. For the UK to reach net zero greenhouse gas (GHG) emissions around 2050, approximately 130 $MtCO_2$ of negative emissions could be required annually (Royal Society & Royal Academy of Engineering, 2018). The need for GGR at scale is driven by remaining emissions from three 'hard-to-treat' sectors: aviation, agriculture, and industry. Abatement of emissions from these sectors is expensive and requires significant technological breakthroughs. GGR is required to compensate.

BECCS and DACCS are expected to be the two key GGR options (in terms of tCO_2 removed), complemented by smaller, yet vital, deployment of land-based GGRs. Large-scale investment will be required for industrial GGRs such as bioenergy with carbon capture and storage (BECCS) and direct air carbon capture and storage (DACCS). The rate of roll-out will need to be rapid, particularly in the 2030s and 2040s and will require significant policy support. To achieve the expected level of negative emissions from land-based solutions, large areas of UK land will need to be afforested, and a large proportion of UK farmers may need to implement measures to sequester carbon, such as agroforestry, biochar, or enhanced weathering.

GGRs present policymakers with opportunities to meet a range of other sustainable development goals such as halting biodiversity loss and reversing land degradation. However, there are also policy challenges and policy needs to address:

1. *Costs:* GGR at scale will require multiple £ billions per annum. At this scale, the distribution of GGR costs will require careful consideration whether funded through general taxation, specific levies, or obligations on the private sector. Notably, costs are likely to be of a similar scale to current government spending on renewable energy support. Hence, there is precedent for government climate funding at the required scale.

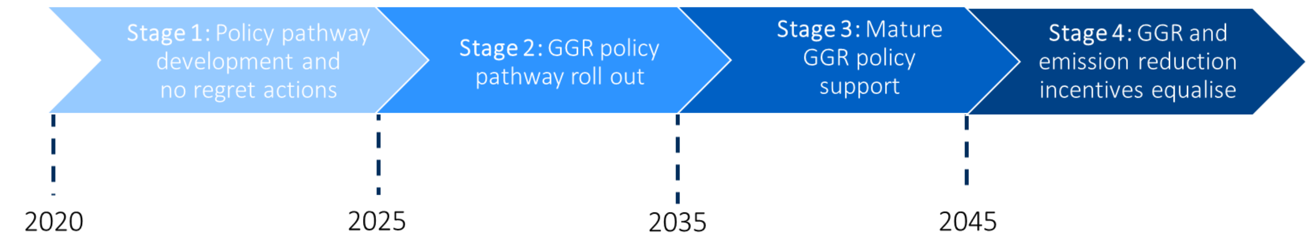
2. *Project accounting:* Quantifying negative emissions transparently and robustly is a key enabler for linking GGR incentives to performance. A key challenge for GGR reporting (not faced in emissions reporting) is the permanence of the removed CO_2. For some GGRs, such as afforestation, there are established methodologies. For BECCS and DACCS, significant work is still required to establish the appropriate (administrative) frameworks, although in principle this could be relatively simple. Land- and soil-based GGRs, such as biochar, present the greatest challenge as both the t/CO_2 that can be removed and the storage permanence are uncertain, and whereas national inventory reporting and accounting can cope with project failure the value of individual projects may be unacceptably uncertain.

3. *Uncertainty:* Given the technological immaturity of most GGRs, significant uncertainty remains around key GGR options. For example, enhanced weathering, which by some estimates could represent around 15% of UK GGR by 2050, has large uncertainties around cost (£39-£390 per tCO_2) and there are possible environmental impacts. As the need for GGR is clear, but the GGR methods offering greatest natural capital benefit are not yet known, policy flexibility will be required.

4. *Policy interactions:* GGR deployment will directly affect power, industry, and agriculture. This requires coordination across heterogenous sectors and government departments. Two key policy interactions stand out: firstly, GGR deployment will have significant implications for UK land use, requiring careful integration, possibly within a wider UK land management strategy; secondly, any GGR support policy will likely affect emitters and hence interact with, for example, existing carbon prices in the power sector. Managing these interactions to ensure consistency across policy frameworks will be a key challenge.

Policy support for GGR can be separated into four broad stages (Figure 1). There are several short-term actions that can be taken across various policy areas, such as enhancing the recognition for the established Woodland Carbon Code and increasing demand for associated credits, piloting land-based GGRs at scale in the UK to establish environmental viability and appropriate accounting practices, and supporting DACCS innovation. Furthermore, the next 5 years will be necessary to develop a substantive GGR support programme, considering the interactions across policy areas and Government departments. A GGR policy programme could then be rolled out in the late 2020s. For market based schemes, time is needed to establish credibility and a liquid market for trade, which can underpin deployment in the late 2030s and early 2040s. Finally, as GGR options in the UK reach commercial scale, market forces should begin to determine the optimal balance between GGR and non-GGR options.

Figure 1 Indicative phases for GGR policy



Source: Vivid Economics

This report describes four of the most promising policy pathways for future use of GGRs (Figure 2). Each pathway includes a portfolio of policies that develop over time as accounting and technical characteristics improve. The policies span different instrument types (e.g. price and quantity mechanisms), and different funding mechanisms (e.g. public or private).

Although each pathway has strengths and weaknesses, the obligations pathway appears to be a particularly strong candidate. This is due to high effectiveness and certainty over GGR quantity and low distributional impacts.

Figure 2 Archetypes for GGR policy support

1. Evolutionary pathway

- Builds on existing and planned policies in the forestry, buildings, power and agricultural sectors.
- Includes CfDs for BECCS, enhanced building regulations to encourage timber use, etc.

2. GGR obligations

- GGR obligations (% of carbon content) imposed on wholesale suppliers of fossil fuels and agricultural products.
- Obligations are met by securing negative emissions certificates. Certificates are tradeable.

3. Tax credits funded by a carbon levy

- Tax credits offered (i) on a £/tCO_2 basis, banded to each GGR type based on costs, and (ii) capital investments in GGR.
- Fully funded by a levy on carbon emissions.

4. GGR subsidies

- Targeted grants for individual landowners deploying small-scale GGRs (standard subsidy rates, e.g. £/hectare).
- Service contracts for companies that deploy large-scale GGR projects (competitive bidding).

Source: Vivid Economics

A suite of supporting policies is required to overcome the market barriers faced by GGRs. This suite of supporting policies is independent of the chosen policy pathway and includes:

- *Establishment of accounting frameworks.* This includes frameworks to robustly and transparently include GGR in the UK's carbon budgets and the development of monitoring and verification practices for all GGRs.
- *Innovation support*, particularly for immature GGRs. Pilots and demonstration projects will be crucial across all GGRs, both to push the technologies forward, but also to inform the development of appropriate accounting frameworks and environmental safeguards.
- *Support for capital investment* in infrastructure and supply chains. This is particularly relevant for BECCS and DACCS, where there is an opportunity to coordinate CO_2 transport and storage infrastructure with wider carbon capture utilisation and storage (CCUS) deployment in the UK.
- *Development of environmental safeguards* will be crucial, particularly for land-based GGRs, where there are risks to soil and water quality.
- *Integration within wider land use strategy* to ensure land demands from GGR are appropriately balanced against other uses for land and wider ecosystem services.
- *International policy linkages* to ensure UK imports of biomass do not adversely affect the Sustainable Development Goals (SDGs) and to grasp opportunities for collaboration to push, for example, DACCS innovation.

In the short term, several policy actions can be pursued to support GGRs regardless of the longer-term policy pathway.

- Strengthen existing afforestation schemes by increasing the upfront grants for landowners and complementing them with annual payments. The government can increase recognition for Woodland Carbon Units by directly purchasing some of them, or obligating businesses to do so.
- Include BECCS and DACCS under the emissions trading scheme (ETS), or its replacement version post-Brexit.
- Support pilots for immature land-based GGRs (soil carbon sequestration, biochar, and enhanced weathering) to establish their environmental impact and potential for negative emissions.
- Support demonstration projects of BECCS and DACCS, along with broader investments in CCUS infrastructure.
- Provide land managers with skills and information to transition into new land management practices.
- Relax the permanent land use change requirement in afforestation schemes to encourage the production of biomass.

This report provides an initial guide as to the most promising areas of policy development for rolling out GGRs. Although this report includes some indicative policy designs and costs, it is only a first step in policy development. More detailed analysis of the trade-offs and costs is required to design policies and estimate costs that could provide a basis for Government decision making.

Introduction

Under the Paris Agreement the UK is committed to working with other countries to achieve global net zero emissions in the second half of the century. The Intergovernmental Panel on Climate Change (IPCC) has indicated that global net zero (CO_2 emissions) will be necessary around 2070 to stay below 2°C global warming, with global net zero around 2050 necessary for 1.5°C. Indeed, with the latest IPCC work demonstrating that there is a significant difference in climate change impacts between 2°C and 1.5°C degrees warming, there is growing interest for countries to set net zero targets on tighter timescales. Reflecting this, the recent advice from the Committee on Climate Change (CCC) concludes that for the UK '*net-zero is necessary, feasible and cost-effective.*'

Greenhouse Gas Removal (GGR) is likely to be key to achieving net zero emissions. Even if emissions are reduced aggressively across the economy, the UK is expected to continue to emit a significant amount of greenhouse gases (GHGs) annually. This is primarily because some economic processes, which are key to our way of life, are very difficult to decarbonise with current technologies. For example, approximately 15 $MtCO_2e$ of nitrous oxide (N_2O) emissions from the agricultural sector are the result of fertiliser use and are very difficult to eliminate while maintaining current levels of food production. Similarly, aviation and certain heavy industries are likely to continue to emit, which will necessitate GGR deployment.

GGR will require significant policy support, but has received limited attention to date. Partly because of their technological immaturity, no GGR option has been significantly incentivised in the UK aside from afforestation. GGR required for the UK to reach net zero emissions by around 2050 is likely to be approximately 130 $MtCO_2$ of negative emissions (Royal Society & Royal Academy of Engineering, 2018). This implies significant deployment scale. As a point of comparison, GGR by 2050 would be of comparable scale to emissions of the UK's entire road vehicle fleet today.

Policy design to support GGR is, however, receiving increasing attention. The Chancellor's 2019 spring statement included a call for evidence on offsetting transport emissions. Furthermore, the recent CCC net zero advice explicitly includes extensive deployment of bioenergy with carbon capture and storage (BECCS) and relies on various more speculative GGRs to close the 'gap' between remaining emissions and achieving net zero.

This report presents policy pathways to support GGR at scale by 2050. It is intended as a basis for understanding the different policy options to encourage GGR deployment, and identifying practical considerations with respect to emissions accounting, environmental regulations, supporting infrastructure, and innovation policy.

The report is structured as follows:

- *Section 1* provides an estimate of the cost and deployment of GGRs in the UK. The presented deployment levels and costs are highly indicative and uncertain; however, they provide useful context when considering policy options.
- *Section 2* underlines the need for a policy portfolio to support GGR rather than a single mechanism. The section sets out the conceptual policy taxonomy used throughout this report and the rationale behind the selection of policy portfolios set out in detail in this report.
- *Section 3* reviews GGR policies in the UK and internationally.
- *Section 4* presents policy pathways to 2050. The discussion sets out 4 archetypical policy portfolios and includes an implementation roadmap and key strengths and weaknesses of each policy.

- *Section 5* presents the key supporting policies required for GGR deployment. This section covers a broad array of existing policy and is informed by two rounds of engagement with BEIS and DEFRA policy teams, the Environment Agency, and the Forestry Commission.
- *Section 6* addresses frequently asked questions related to GGR policies. The section elaborates on policy considerations that were identified from expert workshops, alongside discussions with policy teams across BEIS, Defra, the Forestry Commission and the Environment Agency. These issues have practical implications for both the design and implementation of policies.

1 Scale and cost of future Greenhouse Gas Removal

Box 1 Key takeaways

- *Large-scale GGR is expected to be necessary:* Both the scale of GGR and the rate of ramp-up required are high and will require strong policy support.
- *Uncertainty around cost and viability:* Most GGR options are immature, with uncertain costs and outstanding questions around their viability. To achieve the required scale under this uncertainty, a portfolio of GGRs needs to be supported.
- *Approximate costs are of a similar order to renewable support:* Costs could be around £13 billion per annum by 2050, similar to current government support for renewables.

1.1 Deployment scale of Greenhouse Gas Removal (GGR)

The negative emissions potential of different GGR options remains uncertain. This study provides an indicative deployment scenario as context to the discussion of possible GGR policy. However, the feasible scale (in terms of $MtCO_2$ removed) of different GGR methods is the subject of ongoing debate. While uncertainty remains around the potential of individual GGR options (see Box 3), it is possible to get a sense of the approximate scale of GGR required, and the potential role of different GGR options to deliver this. The following briefly sets out an indicative scenario for GGR roll-out in the UK, as context for the policy options discussed in the remainder of the report.

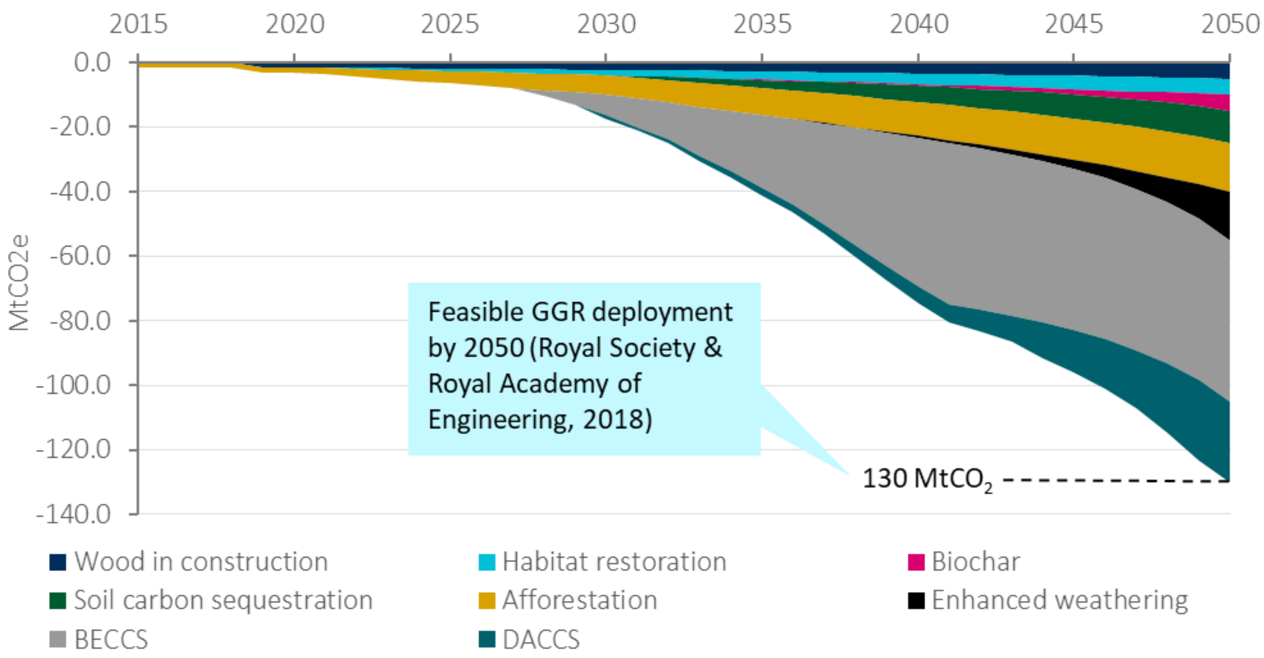
This report considers policy options to support a range of GGR methods at a scale compatible with a net zero goal by 2050. Even when emissions are reduced aggressively across different sources, a significant amount of annual emissions are likely to persist. GGR is therefore *necessary* for the UK to reach net zero greenhouse gas (GHG) emissions to offset remaining emissions from hard-to-treat sectors such as aviation, agriculture, and various industries. The precise scale of GGR required in the UK remains uncertain. The latest CCC advice suggests approximately 90 $MtCO_2$ of GGR will be required by 2050 (CCC, 2019). While options such as biochar, enhanced weathering, and soil carbon sequestration remain speculative, the Royal Society estimates suggest a total of 130 $MtCO_2$ of GGR is technically feasible in the UK (Royal Society & Royal Academy of Engineering, 2018).

The order of magnitude, rather than the exact level, of GGR provides important policy context. As GGR technology matures, the optimal balance between GGR and emission reduction, and the portfolio of GGR options, will crystallise further. However, recognition of the broad scale of GGR required has two key implications for policy design:

- *A broad suite of GGR options is required* to supply large-scale negative emissions. Constraints in supply chains and land availability limit the deployment potential of any single GGR option.
- *Short-term policy action is required* to ensure the required levels of deployment can be reached by 2050, including, for example, commercial demonstration of BECCS in the 2020s to prepare for roll-out in the 2030s.

As set out in Figure 3, a pathway to achieving (near) net-zero emissions is feasible, but highly ambitious. Not only are the 2050 deployment scales ambitious, but given current technological immaturity, so are the ramp-up rates required. For example, the roll-out of BECCS included in this scenario is comparable to the capacity installation rates (~1 GW/year) of the 'dash for gas' in the UK in the 1990s, and direct air carbon capture and storage (DACCS) roll-out rates in the 2040s are similar to recent exponential growth in solar deployment (Vivid Economics, 2018). Box 2 provides further detail on how the pathway was constructed.

Figure 3 Indicative roll-out of GGR in the UK



Note: Roll-out rates for GGRs are indicative and based on analogous agricultural change and infrastructure roll-outs

Source: Royal Society & Royal Academy of Engineering (2018)

Box 2 GGR roll-out scenario

- *GGR deployment levels:* The feasible 2050 GGR level is taken from the Royal Society & Royal Academy of Engineering (2018) report on GGR. This provides a plausible split of GGR options (in terms of $MtCO_2$ removed) to offset the remaining UK emissions by 2050, considering constraints such as land and biomass availability.

- *Cost optimality:* The presented scenario is *not* necessarily cost-optimal. GGRs are too uncertain to construct a robust cost-optimised scenario.

- *Roll-out rates:* The roll-outs of individual GGRs are based on current technology readiness levels (TRLs), observed past scale-ups or behaviour changes in analogous industries and, where available, existing targets and roll-out plans (Vivid Economics, 2018).

Large-scale roll-out of GGR methods will primarily occur in the 2030s and 2040s, as most options are not yet mature. Established GGR methods, particularly afforestation, will be responsible for most negative emissions before 2030. By 2030, annual negative emissions reach around 17 $MtCO_2$, driven primarily by first-of-a-kind (FOAK) BECCS and afforestation. The deployment of BECCS ramps up significantly after 2030 and contributes up to 62% of UK annual negative emissions by 2040. Given its immaturity, the deployment of DACCS would accelerate only after 2040. By 2050, BECCS and DACCS could contribute 50 $MtCO_2$ and 25 $MtCO_2$ of annual negative emissions respectively (Royal Society & Royal Academy of Engineering, 2018).

A portfolio approach to GGR is required. There is still significant uncertainty around the viability of various GGR options. Both the exact amount of negative emissions and the broader environmental sustainability of techniques such as enhanced weathering are yet to be fully established, see Box 3. This uncertainty, combined with an increasing recognition of the need for GGR, suggests the prudent strategy is to take a portfolio approach. That is, a broad array of GGRs should be piloted, demonstrated, and deployed to minimise the reliance on a single GGR and maximise the chances of achieving GGR at scale.

The portfolio of viable GGR options available to the UK may expand. When providing examples, or suggesting sector-specific policy, this report focusses on a basket of the most mature, i.e. technology readiness level (TRL) 3 or above, GGR options (see Table 1). There are, however, various further GGR options under development which may emerge as viable candidates for scale deployment in the UK, such as ocean fertilisation, ocean alkalinity, and mineral carbonation. While not considered explicitly in this report, the policy pathways have been purposefully designed to be flexible around the GGR options they support.

Box 3 The negative emissions potential of individual GGR options remains uncertain

Given the immaturity of GGR options, there is ongoing debate around the viability of various GGR options to remove CO_2 from the atmosphere, particularly for soil-based options. The CCC report on land use (2018) provides a comparison of multiple studies. Notably, the negative emissions potential reported by the Royal Society & Royal Academy of Engineering (2018), presented in Table 1, is seen as relatively optimistic for a number of GGR options, particularly soil carbon sequestration. The below provides an indicative list of areas with limited scientific consensus.

- *Soil carbon sequestration:* The Centre for Ecology & Hydrology (CEH) found that improved land management practices have limited effectiveness in raising the soil carbon of agricultural land (CEH, 2013). Research by Rothamsted Research using long-term field experiments in England, dating back as far as 1843, also reveals severe limitations to soil carbon sequestration (Pulton et al., 2018).
- *Biochar:* The technology is not yet demonstrated at scale and there is some scepticism over whether its deployment in the UK can reach 5 $MtCO_2$/pa by 2050 (CCC, 2018).
- *Peatland (habitat) restoration:* Improvements in scientific understanding suggest changes in peatland emissions are likely to mean peatland restoration represents emission reduction, rather than GGR, methods (CCC, 2018).
- *Wetland (habitat) restoration*: There is a risk of increasing emissions of methane and nitrous oxides from restored wetlands in the short term, with net GHG emissions rather than GGR (CCC, 2018).

Table 1 Overview of GGR options considered

GGR option	Description	Maturity (TRL)	Indicative scale 2050 ($MtCO_2/yr$)	Notable risks to the environment or GGR ($MtCO_2$) potential
Wood in construction	Increased use of domestically produced wood in buildings (in nearly all new build homes) to permanently store carbon	TRL* ~ 9. Approximately 50,000 homes a year already constructed with wood frames in the UK	5	- Ability to source enough domestic timber of appropriate quality - Processing and transportation may reduce GGR potential - Requires adjustments to building requirements and safety and quality assurance to enable sufficient scale
Afforestation/ forest management	Increasing forest area to increase CO_2 absorption from the atmosphere	TRL ~ 9. Already widely practised throughout the world	15	- Biodiversity risks - Competition for land may limit deployment
Magnesium silicate/oxide in cement	Replacement of carbonate in cement allows for potential absorption of CO_2 over concrete lifecycle	TRL ~ 6. There are several start-ups attempting to implement this	1	- Net GGR over lifetime of concrete not fully understood - Full life cycle impacts (including emissions from inputs) may be significant - Regulatory standards for concrete strength etc. may prohibit implementation
Habitat restoration	Rewetting and restoration of peatlands, wetlands, and other coastal habitats to enhance natural carbon absorption	TRL ~ 5. Significant knowledge and readiness around habitat restoration, but not focussed on GGR	5	- Expected that the evidence will imply this will not be a GGR but rather an emission reduction measure - Short-term emissions of non-CO_2 GHGs as a result of restoration - Competition for land may limit restoration or lead to indirect land use change emissions elsewhere
Biochar	Storing carbon through partially combusted organic matter (char) by burying it in topsoil	TRL ~ 5. Method has been piloted, but not yet widely applied in UK	5**	- Negative impacts on soil quality from both heavy metals and organic contaminants - Reversibility and irreversibility risks - Competition for feedstock with BECCS and, to a lesser degree, wood in construction
Soil carbon sequestration	Implementing land management options thought to increase soil carbon sequestration	TRL ~ 8. Ready for implementation and many of the practices are already used in some places	10**	- Reversibility risk: After approx. 20 years soil becomes saturated, requiring maintenance to avoid CO_2 being re-emitted - Limited evidence of efficacy in the UK context and risk of possible increased emissions of N_2O

GGR option	Description	Maturity (TRL)	Indicative scale 2050 ($MtCO_2$/yr)	Notable risks to the environment or GGR ($MtCO_2$) potential
BECCS	CO_2 is captured and stored from combustion (or gasification) of biomass	TRL ~ 6. Bioenergy from biomass-based power plants is a mature technology, as is CO_2 capture in other applications, but the combination is largely at the demonstration stage	50	-Use of unsustainable feedstock -Competition for land may limit feedstock availability
DACCS	Absorption of CO_2 directly from the atmosphere using amines, suspended on a branched framework	TRL ~ 4. Only small-scale DACCS currently piloted	25	-Wastes produced from DACC process (absorbents etc.)
Enhanced weathering	Spreading silicate minerals across soils to increase soil alkalinity, which increases absorption of acidic CO_2	TRL ~3. Needs to be piloted in the field	15	-Immaturity of technique means GGR potential in various local UK environments not yet fully understood -Impact on soil and water quality -Environmental impacts due to large-scale mining of required minerals - Reversibility and irreversibility risks

Note: *TRL: Technological readiness level, method of estimating technology maturity. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. **Negative emission potential in the UK is contested (see Box 3) despite relatively high TRL

Source: Vivid Economics. Indicative UK deployment scales and notable risks are based on Royal Society & Royal Academy of Engineering (2018). TRL levels were triangulated between Royal Society & Royal Academy of Engineering (2018), Mclaren (2011), (CCC, 2016), and expert interviews.

1.2 GGR costs

The costs of GGR deployment are uncertain, with estimates varying from £4-£20/tCO_2 for soil carbon sequestration and up to £160-£470/tCO_2 for DACCS. Table 2 below provides indicative costs for respective GGR options. The large ranges in the cost estimates reflect:

- *The technological immaturity of GGR technologies,* which implies significant uncertainty around the quantity of tCO_2 each GGR can sequester (and hence the £/tCO_2 cost) and the general cost of the GGRs.

- *The dependence of cost on local environmental conditions*. For example, the amount of CO_2 sequestered by enhanced weathering will depend on rainfall, soil types, and other environmental conditions. Costs will hence significantly depend on where enhanced weathering is applied. Costs are difficult to assess without detailed local planning knowledge; as a result, Table 2 provides a wide range.

- *Uncertain cost reductions over time.* As GGR options are deployed, costs are likely to come down as a result of learning by doing, learning by research, and economies of scale. The size of the cost reductions over time are difficult to predict and are a key driver for the wide cost ranges. Indeed, a recent announcement by Carbon Engineering suggests a further lowering of costs for DACCS, to £75/tCO_2 (Keith, Holmes, St. Angelo, & Heidel, 2018).

Table 2 Indicative costs of GGR

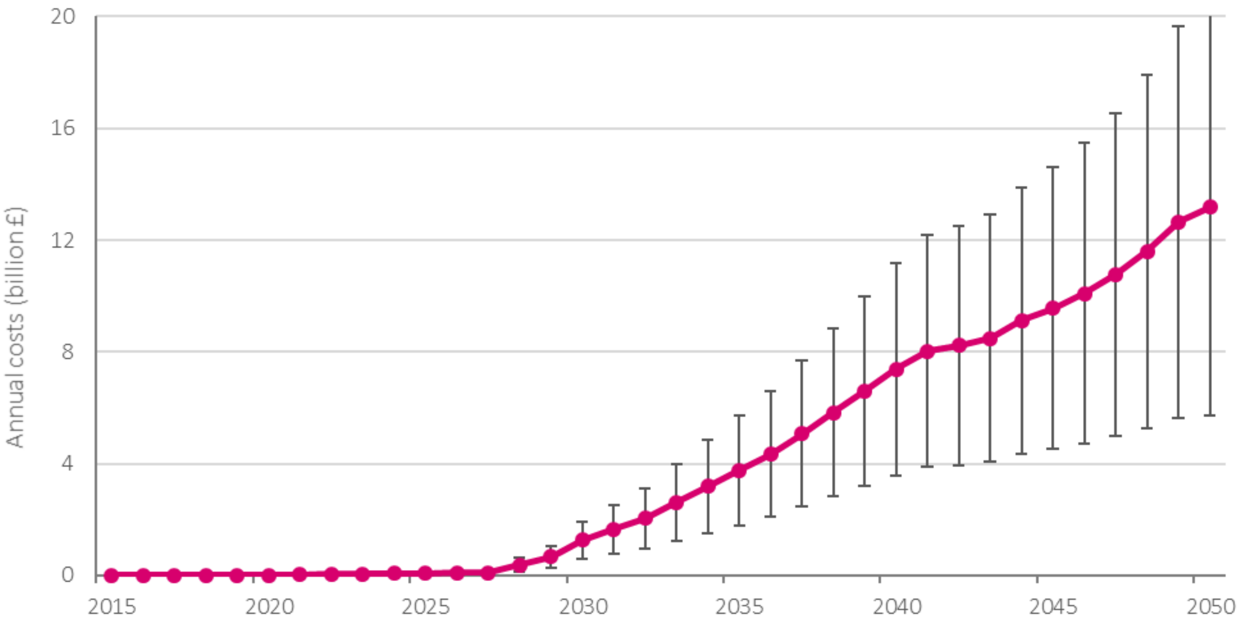
GGR option	Approximate cost (£/tCO_2)	Indicative scale of UK deployment by 2050 (MtCO_2/yr)
Wood in construction	Negligible	5
Habitat restoration	8-78	5
Biochar	14-130	5
Soil carbon sequestration	4-20	10
BECCS	80-230	50
Afforestation	2-23	15
Enhanced weathering	39-390	15
DACCS	160-470	25

Note: Costs are intended to indicate the order of magnitude. Analysis considering detailed deployment schedules, location-specific costs, likely cost reductions over time, etc. is required to provide more accurate cost estimates. As explained in Box 3, deployment estimates are uncertain and purely indicative.
Source: Royal Society & Royal Academy of Engineering (2018)

Under the GGR deployment scenario defined above, annual costs of total GGR deployment are £1-£2 billion in 2030 and £6-£20 billion in 2050.[1] Figure 4 below displays the pathway for annual costs of total GGR deployment based on the indicative pathway in Figure 3. As discussed above, this pathway and these costs are highly uncertain. Particularly for 2050, the costs and levels of deployment are likely an overestimate, as they do not account for likely cost reductions over time. However, the estimates provide an indication of the potential cost to deploy GGR at scale, and hence the type of policy required to support the scale of roll-out. As a point of comparison, annual costs of the levy control framework (supporting renewable energy deployment) are expected to be £9.1 billion by 2020-2021. This excludes the broad suite of additional innovation and supply chain support that is provided in addition to price support (HM Government, 2014). The 2050 GGR costs are hence comparable in scale to current support for renewables.

[1] The annual costs of GGR deployment over time are estimated by multiplying the unit costs of each GGR (£/tCO_2), shown in Table 2, by the scale of their deployment under the Royal Society & Royal Academy of Engineering (2018) scenario presented in Figure 3. The unit costs of each GGR are assumed to fall at constant rates between 2015 and 2050. For land-based GGRs, the cost reduction rates are proxied by the historical trajectory of UK agricultural productivity. For BECCS and DACCS, the cost reduction rates are assumed to be similar to those used in relevant Energy Innovation Needs Assessments (ongoing work for BEIS).

Figure 4 Annual costs of total GGR deployment

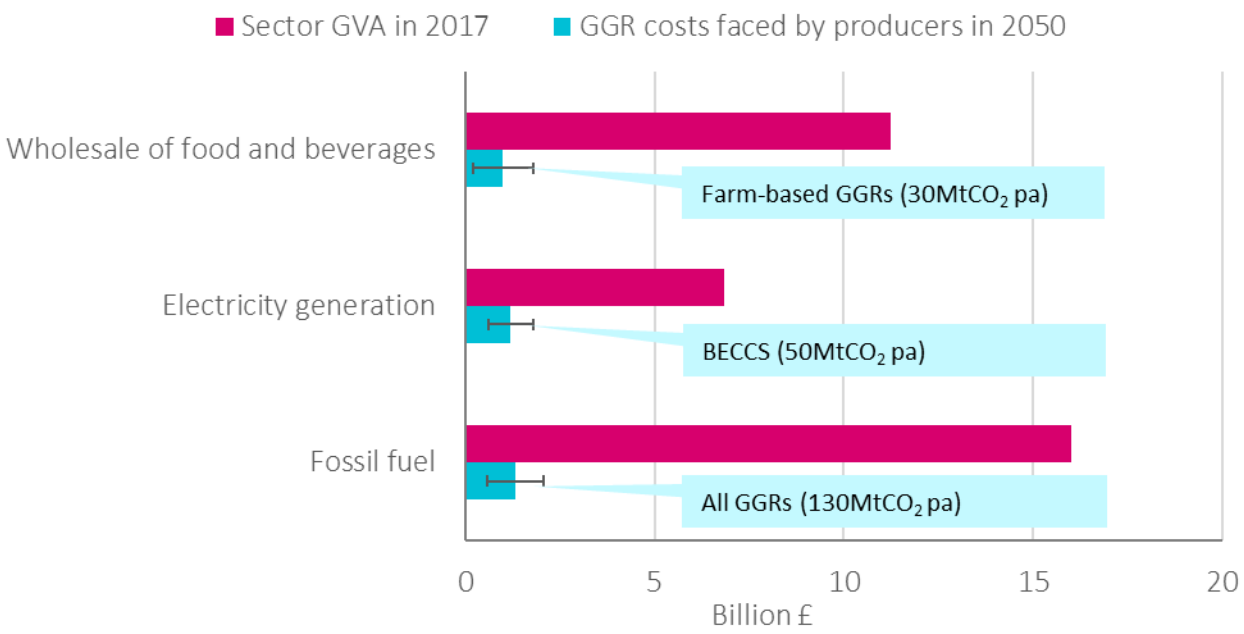


Note: Estimates based on the indicative costs of each GGR option and their corresponding deployment pathway
Source: Vivid Economics

Regardless of the exact cost of GGR deployment, the annual costs are significant, and care will need to be taken to appropriately distribute this cost to avoid undue burden on any single group. The burden of any policy mechanism can be shifted by government through targeted levies, tax breaks, or compensating subsidies. To give a sense of likely costs of deploying GGRs in 2050, the below gives a sense of the impact of this cost when funded through various avenues:

- *General tax receipts:* If the costs of deploying GGRs are spread across the tax base, it amounts to 1%-2% of total tax receipts by 2050. This is a relatively small percentage, but a sizeable expense, nonetheless. It is comparable to the expenditure in the Levy Control Framework to support renewables, and roughly a fifth of the defence budget.
- *Consumer prices:* Much of any tax or other burden on producers is typically passed onto consumers, see Box 4. Indicative price impacts are provided below. This assumes 2050 annual costs as per Figure 4 and expenditure on food, electricity, and fossil fuels in 2050 is comparable to current level in constant prices (note, much more detailed analysis is required to accurately assess price impacts):
  - ◊ *Food prices:* +0% to3% (if food retailers are obligated to fund farm-based GGRs)
  - ◊ *Electricity prices:* +7% to 20% (if electricity generators are obligated to fund BECCS)
  - ◊ *Fossil fuel prices:* +5% to 17% (if fossil fuel suppliers are obligated to fund all GGRs).
- *Costs for producers:* Producers bear only a fraction of the costs of deploying GGRs because a majority of costs are passed through to end consumers (Element Energy and Vivid Economics, 2018). Indicative sizes of the burden are shown in Figure 5.

Figure 5 2017 sectoral gross value added (GVA) versus annual costs of related GGRs in 2050



Note: Farm-based GGRs are soil carbon sequestration, biochar, and enhanced weathering. Costs shown are based on figures from Table 2, and accounting for the approximate cost pass-through rate of each sector: 60% for food and beverages (Besanko et al, 2005); 80% for electricity (Fabra & Reguant, 2014); 90% for fossil fuel (Marion & Muehlegger, 2010). Error bars indicate lower and upper cost estimates.

Source: Vivid Economics based on data from Royal Society (2018) and ONS Annual Business Survey (2018).

Box 4 Percentage of costs passed through to consumers

- Cost increases are passed through to consumers when producers in the market adjust prices upwards. This adjustment is, however, often less than 1-to-1 (i.e. a £1 increase in unit costs leading to £1 increase in unit price, or a 100% *cost pass-through* rate). In general, costs are shared between consumers through higher prices and producers through reduced profits. A higher cost pass-through rate means that consumers bear more of the cost increase and producers bear less of it.

- The *cost pass-through rate* of different goods and services generally depend on two factors: price elasticity of demand, and the competitive structure of the market.[2]

  - Demand elasticity: cost pass-through rate higher when consumer demand is inelastic (i.e. less sensitive to price changes). Examples include petrol and food.

  - Competitive structure: cost pass-through rate is higher when there is intense competition in the market, such as in groceries. At the extreme of perfect competition, price changes 1-to-1 with marginal costs.

[2] This is a simplified description of the microeconomic theory. In practice, one should consider the upstream and downstream nature of markets. A more technical synthesis of the literature is published by RBB Economics (2014).

2 The need for a policy portfolio to support GGRs

Box 5 Key takeaways

- *A suite of policies is required to support GGR.* Given the many different market barriers faced and the variety of GGRs the UK will likely require, a single policy mechanism is unlikely to suffice. Instead a coherent policy portfolio is necessary, which includes direct policy incentives, enabling policy (e.g. innovation support) and wider integrating policies.
- *GGR policy will need to be flexible.* Given the uncertainty surrounding the cost and potential of different GGRs, policy must be able to adapt as new information becomes available.

2.1 Market barriers to GGR

As discussed in Section 1, a full suite of GGR options will need to be deployed for the UK to reach net zero. The various GGRs differ along key dimensions including stages of technological readiness (TRL), capital requirements, environmental considerations, and sectors/actors that are likely to deploy them. A flexible policy framework is crucial to accommodate the variety of GGRs that is expected to be required.

GGR options face numerous market barriers and hence a single policy providing financial incentives (or penalties) to deploy GGR is unlikely to suffice. In addition to the carbon externality, there are several other market barriers limiting private investment in GGR. Minimal private investment, combined with an increasingly strong evidence base for the need of GGR, provides a clear rationale for government intervention. However, one policy is unlikely to effectively or efficiently overcome all market barriers. Instead, a suite of policies is required to address key barriers beyond the current lack of incentive for deployment. Key barriers faced by GGRs, and indicative roles for government, include:

- *Innovation and demonstration barriers:* Within the set of GGR options, TRLs vary from 3-4 (demonstration phase) for biochar and DACCS to 9 for afforestation (ready for commercial deployment). The technologically immature GGR options will require innovation and demonstration support before the private sector will deploy these in response to £/tCO_2 (or similar) incentives.
- *Non-financial deployment barriers:* These go beyond the current lack of profit incentive and include, for example, the CO_2 transport and storage infrastructure required for BECCS and DACCS. The upfront cost of this infrastructure is too large to be borne by a handful of GGR projects. However, there are opportunities for coordination between GGR and wider CCUS deployment, where government could play a strong role.
- *Financial barriers:* Potentially large upfront investment, long payback periods, and uncertain long-term incentives (e.g. price of carbon) can all reduce or completely deter private investment. Government can play a role in providing financial certainty, potentially providing guarantees or long-term contracts.
- *Accounting barriers:* Uncertainties in the amount of CO_2 removed, the permanence of storage, and difficulties around monitoring and verification can create barriers to deployment of GGRs. Crucially, any support policy must be flexible enough to accommodate varying degrees of accounting accuracy.
- *Broader (environmental) externalities and risks:* Large-scale deployment of GGRs will have implications for national land use patterns, create local environmental risks, and raise concerns around the sustainability of large-scale biomass imports. Any policy supporting GGR deployment

should include careful consideration of these risks, and may require strengthening existing safeguards, or creating new ones, to mitigate undesired outcomes.

This report presents four broad policy pathways, based on a portfolio of policies, which could support large-scale GGR deployment in the UK. Before describing the policy pathways in detail, the following sets out:

- *A policy taxonomy*, to enable a concise discussion of the collection of policies required in an effective policy pathway.
- *A brief rationale* behind the design of the policy portfolios. This includes a discussion of how to interpret the portfolios. They are intended as archetypes which broadly span the space of possible policy frameworks for supporting GGR. They are explicitly not intended as policy recommendations. Indeed, elements of the presented policy pathways may be combined.
- *A discussion of the need for a flexible policy approach,* including a brief discussion of the link between GGR and emission reduction policy.

2.2 Policy taxonomy

The purpose of the taxonomy is to enable a clear mapping of market barriers faced by GGR options to policies which address these barriers. For example, deployment barriers are addressed by deployment policies, accounting barriers by accounting policies. Policy categories are not completely mutually exclusive. For example, Contracts for Difference (CfDs) act both as a financial instrument, as they socialise the financial risk faced by an electricity producer,[3] and as a deployment policy if the strike price is set significantly above average prices.

The taxonomy is designed according to the primary market barrier that a policy addresses. The taxonomy for GGR support policies is as follows:

- *Direct policies:* These policies provide incentives to deploy GGRs. In other words, they provide a 'carrot' or 'stick' to deploy GGR. We distinguish between broad types of direct policy:
  - ◊ *Deployment policies:* Direct deployment policies are further subdivided into subsidies, taxes, cap and trade, and obligations.[4] These are the main policies to incentivise deployment.
  - ◊ *Financial policies*: These are primarily intended to reduce the cost of capital, either through the provision of government loans or by reducing risk for private investors and lenders. Financial policies involve a range of ways of socialising risk (i.e. the state taking on the risk) to de-risk investments for the market.
- *Enabling policies:* These are subdivided into innovation support, infrastructure support, and accounting policies. Innovation and infrastructure support can include a wide variety of potentially highly targeted policies. Accounting policies and frameworks are a key enabler to deliver GGR support and are also considered within this category.
- *Integrating policies:* Integrating policies maximise synergies between GGR policies and a broader policy landscape. These policies include environmental policies (e.g. water quality standards) and aim to maximise the co-benefits under the Sustainable Development Goals (SDGs), while reducing risks such as impacts on water quality.

[3] Specifically, CfDs remove the downside risk to electricity producers of the electricity price they are paid dropping below the strike price.
[4] Obligations are a regulatory intervention; other policy types are market-based interventions or market/regulatory hybrids (e.g. cap and trade is a hybrid of a regulation – the cap – and a market for permits).

Table 3 Policy taxonomy

Direct policies deliver GGR projects							Enabling policies support delivery		
Policies that primarily address *deployment barriers*					Policies that primarily address *financial barriers*				
Taxes	Subsidies	Cap & Trade	Obligations	Standards	Finance provision	De-risking	Innovation	Supply chain and infrastructure	Accounting
Integrating policies: • Maximising benefits (e.g. water regulation, amenity value with positive impact on SDGs 6, 11 and 15) • Integration with broader policy frameworks (e.g. land use) • Integration with international mechanisms (e.g. clean development mechanisms (CDMs)) • Minimising risk and unintended consequences of GGR									

Source: Vivid Economics

2.3 Designing and interpreting policy pathways

The proposed pathways are constructed around the most promising direct policies. To determine which direct policies are most appropriate to support GGR deployment, a series of direct policy options have been assessed. These options span the seven major direct policy categories outlined in Table 3, and several variations within the broad options. The policies are assessed by assuming a specific set of plausible design details (as set out in the Appendix) in order to operationalise the assessment (as policy performance typically hinges on detail). A summary of the assessment is presented in Section 8.1 in the Appendix, along with further detail on the assessment methodology and individual assessments.

We propose four policy pathways – an evolutionary pathway that presents a realistic development, and three new approaches that feature the best performing direct policies:

- *Evolutionary pathway:* This pathway adapts existing regulatory frameworks in respective sectors to encourage GGR deployment where possible. This involves providing grants for land-based GGRs through forestry and agri-environment schemes, embedding timber requirements into building regulations, and introducing separate CfDs for BECCS (both electricity generation and industrial) and DACCS.

- *GGR obligation scheme:* This pathway is selected based on the strong performance of obligation schemes in the assessment. It starts with a relatively narrowly defined obligation but broadens out over time into a cross-sectoral obligation with tradeable certificates.

- *GGR tax credit funded by a carbon levy:* This pathway relies heavily on tax credits, which have helped support CCUS deployment in the US. It is combined with a carbon levy (a form of tax) to reduce the financial burden on government.

- *GGR subsidy:* This pathway includes a variety of government payments to incentivise GGR. We consider this policy pathway for completeness, but as shown in the assessment, this is unlikely to be a very efficient policy and imposes high costs on government.

While the evolutionary pathway consists of a mix of policy instruments, the three other policy pathways are designed to span price and quantity instruments and whether the incidence is on the public or the private sector:

1. *Public vs. private funding*. Given the likely costs of large-scale GGR deployment, the distribution of these costs is a key policy design element. As shown in Table 4, two policy pathways place the costs on the private sector, whereas subsidies would be publicly funded. The pathways are intended to illustrate different funding mechanisms, but government can decide to mix funding sources. For example, some of the funding for tax credits can come from a levy, while the rest is funded through general taxation.

2. *Price vs. quantity instruments.* There are various costs and benefits to price and quantity policy mechanisms. We include a quantity mechanism, which sets a defined GGR obligation. This has the benefit that the amount of negative emissions is certain, allowing targets to be achieved. Furthermore, the market is left to 'find' the marginal GGR price. The tax credit and subsidy schemes are price mechanisms, offering an incentive at a defined price. This ensures that, as a society, the UK caps the £/tCO_2 price it pays for GGR, but it is uncertain how much GGR will be deployed.[5]

Table 4 Summary of selected policy pathways

	Public	Private
Price	GGR subsidy scheme	Tax credit for GGR, funded by a carbon levy
Quantity		GGR obligation scheme

Source: Vivid Economics

The proposed policy pathways can be 'mixed and matched' to a degree. We have set out the four policy pathways as distinct. However, there are options to 'mix' the pathways. For clarity, the remainder of the report chiefly discusses the policy pathways as distinct, but two key 'mixing' opportunities are highlighted below:

- *The funding of a mechanism need not be as suggested.* How a policy is funded is often separable from the policy itself. For example, the proposed tax credit pathway need not be funded by a carbon levy but could be funded through general taxation (publicly funded). Conversely, a GGR subsidy scheme could be funded through a carbon levy.

- *A GGR subsidy scheme could run in parallel to other pathways.* For example, a GGR obligation scheme may include government subsidies to help certain sectors meet their obligations.

[5] There is a rich economic literature around whether a price or quantity mechanism is optimal in climate policy. Fundamentally, this depends on whether the marginal benefit (value of CO_2 reduction) increases more rapidly than the marginal cost (abatement of GGR cost) per tCO_2. Broadly speaking, given the marginal benefit of CO_2 reduction does not change significantly per tCO_2 (as it is the stock of CO_2 that matters) whereas the marginal cost does change more rapidly, a price instrument is theoretically more efficient (Grodecka & Kuralbayeva, 2015). Given broader UK climate policy is, however, based around targets, the marginal benefit of GGR is more accurately represented as the avoided cost of mitigation options. The marginal benefit (avoid cost of emission reduction measures) and marginal cost of GGR should be roughly equal, and hence economic theory does not provide a clear answer on which policy type is optimal.

2.4 Taking a flexible approach

Deployment of GGRs will need to ramp up significantly in the 2030s; to prepare for this, policy frameworks will need to be put in place in the 2020s. Section 4 sets out a combination of short-term policy actions and the longer-term policy pathways to illustrate how policy may develop. Crucially, policy will need to be developed in the short term, while there remains significant uncertainty around GGR. This is necessary because, despite the uncertainty on individual GGR options, there is increasing consensus around the need for large-scale GGR deployment. To ensure this need can be met, GGRs need to be supported now, to prepare the ground for large-scale roll-out in the 2030s.

The uncertainty around GGR deployment potential and costs requires a flexible policy approach. Although policy frameworks need to be developed now, key to the policy pathways is a recognition of the need for flexibility. As GGR options are further developed, partly through UK innovation policy, new information will become available about their costs, environmental risks, and other performance characteristics. This should be incorporated into GGR policy as soon as possible. Key considerations include:

- *The suite of GGRs supported.* This report focusses on a set of the more mature GGRs (Table 1), but a wider suite of GGR options exists. If wider GGR options develop rapidly, these should be included within policy frameworks to provide deployment incentives.
- *Changes in the understanding of relative GGR performance.* GGR policy will need to reflect the latest scientific understanding of the environmental risks, costs (per tCO_2), permanence and reversibility, and other performance characteristics of GGRs. Any policy should include provisions for how such changes are handled which provide both certainty to GGR developers but also ensures incentives are based on the latest available information (see Box 8 and Section 5.1.1 for more detail).

In the short term GGR policy should focus on long-term dynamic efficiency; however, in the long term, the balance between GGR deployment and emission reductions will need to be optimised.

- *Dynamic efficiency:* GGR support in the short and medium term should be relatively distinct from emission reduction policy. Broadly separating GGR and emissions reduction policy enables government to incentivise emissions reductions and GGR so that investment (often with long lead times) occurs at the appropriate time to enable the UK to reach net zero around 2050. Government is likely best placed to play this coordinating role, given the relevant time horizons are beyond those of most market players.
- *Static efficiency:* In the long term, however, as the amount of GHG emissions and removal are of similar size, key innovation and large capital investment should already have occurred. At this stage, optimising the balance between the level of GGR and further emission reductions can increasingly be left to market actors. GGR policy design should be flexible enough to increasingly link GGR incentives with emission reduction incentives to allow the market to optimise between the two.[6]

[6] The underlying reasoning is that, at any point in time (i.e. *static* perspective), the total costs of meeting climate targets are minimised only when the extra cost of reducing a tonne of carbon emissions is equalised with the extra cost of removing a tonne of carbon dioxide. Or else, by definition, it is possible to achieve the climate target at a lower cost by shifting the balance between emissions reductions and greenhouse gas removal. This logic extends to policymaking in which it is preferable to have a policy instrument to equalise incentives across the many different ways of cutting net emissions. This is also a core advantage of having a single carbon price instead of multiple project-based subsidy schemes.

3 Review of current GGR policies

Globally, there are limited policy examples which explicitly incentivise the deployment of GGRs. Key policies promote established practices of afforestation, soil carbon sequestration, and habitat restoration. Although some emissions trading schemes (ETS) cover carbon capture and storage (CCS), the incentives they provide are inadequate and do not cover BECCS and DACCS. Below is a review of notable GGR policies both in the UK and abroad. The examples are split into three main categories: woodland and environmental schemes, broader schemes that indirectly support GGR, and innovation and demonstration schemes. Notably, there are no current examples of GGR policy which attempt to achieve large-scale deployment of a portfolio of GGR options.

3.1 Woodland and environmental schemes

A range of policy instruments has been used to encourage afforestation and conservation. Most of these schemes aim to promote biodiversity, protect soil and water quality, and maximise co-benefits with local development. Nevertheless, there are examples of woodland creation schemes with the explicit purpose of removing greenhouse gases.

- **Woodland Carbon Code (UK).** Established in 2011, the Woodland Carbon Code (WCC) is the UK's voluntary carbon standard for woodland creation projects (Forestry Commission, 2018a). Project developers following recognised procedures and standards can obtain rights to woodland carbon, which can be sold to companies seeking to compensate for their emissions and contribute to their environmental and social objectives.[7] Woodland Carbon Units (WCUs) are a type of voluntary domestic offset and companies cannot use them as an offset in the ETS or other international fora. As of October 2018, there is a total of 239 projects across all stages in the WCC's pipeline, with a sequestration potential of 5.8 $MtCO_2$ over the next century (UK Woodland Carbon Code, 2019b). Prices vary between £5-£10/tCO_2.

- **Environment Stewardship Scheme, Countryside Stewardship Scheme (UK).** Launched in 2005 and 2014 respectively, the Environment Stewardship (ES) and Countryside Stewardship (CS) are both agri-environmental schemes in England that provide funding for landowners to make environmental improvements through a range of activities, including afforestation and habitat restoration (Rural Payments Agency, 2019). The CS is open to all eligible farmers and land managers, but is more targeted and competitive than the ES. All applications for the CS are assessed in a competitive scoring process, and grants are offered to those who will achieve the most for their local environment.

- **Woodland Carbon Fund (UK).** Launched in 2016, the fund operates in a similar manner to the Woodland Carbon Grant component under the CS (Forestry Commission, 2018b). It offers capital funding for the creation of new productive woodland for carbon sequestration. This includes the planting of trees and costs of protection items including tree guards, fencing, and gates.

- **One Billion Trees Fund (New Zealand).** Launched in 2018, the fund provides two types of grants to support individuals and groups to plant trees or manage land sustainably (Forestry New Zealand, 2019).[8] The *direct landowner grants* set targeted grant rates ($ per hectare) for specific types of

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[7] Project developers initially hold Pending Issuance Units (PIUs), effectively a promise to deliver a WCU in a given period, based on predicted woodland growth. PIUs are tradeable but cannot be used to report against emissions until verified. When the project is eventually verified, PIUs are converted to WCUs.

[8] Replaces the previous Afforestation Grant Scheme.

planting by landowners. The *partnership grants* are offered to projects which enable increases in tree planting, whether through research, innovation, or sector development. Applicants for these grants have to submit standardised proposals and are screened against a set of environment and land use criteria set by the government.

- **Emissions Reductions Fund (Australia).**[9] Replacing the previous carbon pricing scheme in 2015, the fund provides incentives for organisations and individuals to reduce their emissions through a wide range of approved methods, including afforestation and soil carbon sequestration (Department of the Environment and Energy, 2019). Businesses can submit their projects to a competitive bidding process run by the Clean Energy Regulator. The Clean Energy Regulator selects projects with the lowest cost per tCO_2 and enters into contracts to purchase the emissions reductions from these projects.[10]
- **Conservation Reserve Program (US).** Launched in 1985, the programme is a private lands conservation programme with voluntary participation from landowners who remove sensitive lands from production and plant certain grasses, shrubs, and trees that improve water quality, prevent soil erosion, and increase wildlife habitat (Farm Service Agency, 2018). Under contracts that last between 10 and 15 years, the US Department of Agriculture provides participants with annual rental payments and cost-share assistance.

3.2 Relevant wider policy examples supporting GGR deployment indirectly

Although these policies have the primary goal of reducing carbon emissions, they incentivise deployment of related GGRs that fall under their scope. Their impact on GGR deployment is often limited because they are not explicitly designed to support GGRs.

- **45Q Tax credits (US).** Section 45Q of the US tax code provides a tax credit to power plants and industrial facilities that capture and store CO_2 that would otherwise be emitted into the atmosphere (26 U.S.C. § 45Q). The tax credits cover CCS in general and are applicable to BECCS and DACCS. The credit is tied to the amount of CO_2 captured, and goes directly to the entity doing the capture (i.e., the owner of the capture facility). Once captured, the facility can choose to permanently store the CO_2 in deep saline formations or provide it to companies that will use it in the production of goods ranging from plastics, concrete, other commercial materials, and enhanced oil recovery (EOR). In the latest revamp of the tax code, facilities can receive US$50/$tCO_2$ for permanent geological storage and US$35/$tCO_2$ for use in EOR or other products.
- **Forest project offsets in California Cap-and-Trade Program (US).** The Compliance Offset Program under the Cap-and-Trade regulation in California allows participants to offset their emissions with forest projects in the US (California Air Resources Board, 2019). Verified afforestation projects can receive registry offset credits, which can then be converted into Air Resource Board offset credits for use in the Cap-and-Trade Program.
- **CCS inclusion in EU ETS (EU).** Under the EU ETS, operators that undertake CCS are not required to surrender allowances where emissions have been verified as captured and transported for permanent storage (Council Directive 2018/410/EC). However, emissions from using biomass for electricity generation are not covered by the EU ETS. Consequently, the incentives for CCS do not extend to BECCS.
- **Forestry included in ETS (New Zealand).** Launched in 2008, the NZ ETS is the only ETS that includes forestry. Owners of post-1989 forest land can voluntarily enter the ETS and earn credits as their

[9] The fund was recently renamed as the Climate Solutions Fund and received a new round of funding from the Australian government.

[10] Project developers can earn an Australian Carbon Credit Unit (ACCU) for each tonne of emissions reduction, which can then be sold to either the Clean Energy Regulator or other buyers on a voluntary market. In practice, most ACCUs are purchased by the Clean Energy Regulator.

forests grow (New Zealand Ministry for the Environment, 2018). Owners of non-exempted pre-1990 forest land must participate in the scheme and face obligations under the scheme if they deforest. In effect, landowners under the scheme are incentivised to pursue afforestation as they can sell the resulting credits to other companies in the scheme.

- **CfDs for biomass (UK).** The UK Government auctions off CfDs for renewable generators as a way to protect them from volatile wholesale prices. In the two rounds of auctions so far, there have been two 'biomass conversion' and three 'biomass with CHP' projects. The CfD auction could be relatively easily adjusted to target BECCS specifically, but has to date not attracted any BECCS bidders.

3.3 Innovation and demonstration

In both the UK and abroad, policies that are most focussed on GGRs tend to be innovation and demonstration programmes. This reflects the relative immaturity of important technologies such as BECCS and DACCS.

- **Research Councils (UK).** UK Research and Innovation funds research and innovation in low-carbon technologies partly through the Natural Environment Research Council (NERC), Economic & Social Research Council (ESRC), and Engineering and Physical Sciences Research Council (EPSRC). In 2017, £8.6 million was allocated to the Greenhouse Gas Removal Research Programme, which evaluates the potential for various GGR options in the UK.

- **Horizon 2020 (EU).** The Horizon 2020 programme is an EU-wide programme supporting research and innovation in a range of priority areas, of which one is climate action. One initiative under the programme is called 'Accelerating CCS Technologies', which funds RD&D in CCS (ACT, 2019). As part of its 2018-2020 Work Programme, the European Commission is considering a €5-€7 million budget to assess negative emissions and land use-based mitigation options.

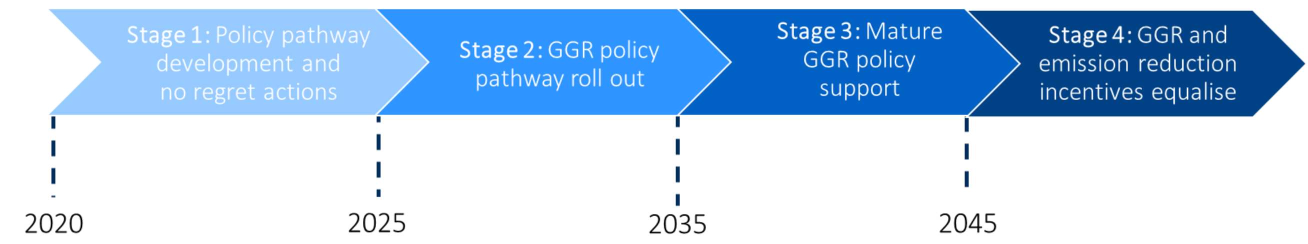
- **Innovation Fund (EU).** Announced in February 2019, the fund seeks to offer financial support to innovation projects in eligible sectors, including renewable energy and CCS, between 2021 and 2030. It will support up to 60% of the additional capital and operational costs linked to innovation, mainly via grants (European Commission, 2019). The fund is also a successor of the NER 300 programme and is expected to be more flexible with regards to financial support.

4 Policy pathways to support GGR

This section discusses policy pathways that can support GGR deployment in the UK. Moving from the current policy frameworks towards a longer-term pathway will require a combination of direct policies, enabling policies, and integrating policies. Designing and implementing such a framework takes time, as illustrated in Figure 6. In recognition of this broad timeline the discussion in this section is structured as follows:

- *Discussion of short-term 'no regret' policy actions* which can help develop immature GGRs and begin to deploy mature options.
- *Discussion of the four policy pathways*. Each policy pathway is discussed separately, highlighting strengths and weaknesses and an indicative timeline for the policy. The discussion of the policy pathway broadly indicates how the policy is rolled out, and how it operates when mature. Long term linking of GGR policy and wider emission reduction policy (stage 4) is not the focus of this report, but a brief discussion is provided in Section 2.4.

Figure 6 Indicative phases for GGR policy



Source: Vivid Economics

4.1 Short-term actions

There are several short-term policy actions which can help deploy mature GGRs, support the development of immature GGRs, and build the future policy framework for GGR. The suggested actions leverage existing policy frameworks or government programmes, expanding their scope to support GGRs. Pursuing these actions is relatively simple (no expansive new policy is required) and can provide an avenue to encourage initial GGR deployment in the short term. These short-term actions are discussed below, in line with the policy taxonomy:

- *Direct policy actions* include suggestions for changes to existing schemes to strengthen the incentive for deployment of mature GGR.
- *Enabling policy actions* to ensure that GGR technologies, infrastructure, and accounting frameworks are able to support scaling up in the 2030s.
- *Integrating policy actions* align the policy landscape of forestry and environmental regulations with the deployment of land-based GGRs.

4.1.1 Direct incentive provision

In the short term, GGR incentives can be strengthened through existing forestry policies and ETS coverage. The UK already has an established policy framework to encourage afforestation. The range of existing incentive policies in forestry include the Countryside Stewardship Scheme, Woodland Carbon Fund, and Woodland Carbon Code (WCC). They provide multiple channels for the government to increase its support for afforestation. In addition, when compared to other land-based GGRs, such as soil carbon sequestration and habitat restoration (e.g. peatland), there are fewer concerns around the permanence of carbon removal and emissions accounting in forestry. Meanwhile, ETS coverage is also a useful basis to provide additional incentives where accounting methods are reliable. Possible policy actions may include:

- *Strengthen payment schemes:* Existing incentives that provide upfront grants for afforestation, on the basis of 'payment per hectare', could be increased. A potential option will be to complement existing schemes by providing annual payments in return for afforestation. This can mitigate the return risks currently faced by landowners. In doing so, simplified application procedures would be important.
- *Enhance the recognition and demand for Woodland Carbon Units*: The WCC is an established certificate scheme, although demand for certificates is currently relatively limited given the scheme's voluntary nature. Government itself could buy an annual number of certificates, or obligate business (e.g. fuel suppliers) to purchase a certain number of certificates, providing the beginnings of the GGR obligations pathway described in Section 4.3.
- *Include BECCS and DACCS under existing emissions trading schemes:* Although this will not provide sufficient incentive on its own, inclusion in existing trading schemes provides a useful revenue source (with a provision that the cap in the trading scheme is lowered). The coverage of the ETS, or its replacement version post-Brexit, can be extended to BECCS and DACCS relatively easily given the relative ease of emissions accounting (similar to CCS) for these GGRs.

4.1.2 Enabling policies

Short-term policy actions to support innovation and critical infrastructure will lay the groundwork for at-scale deployment of GGRs in the future. Funds can be deployed through existing programmes, such as the Clean Growth Fund, and relevant Research Councils. Specific policy actions may include:

- *Pilot projects of immature land-based GGRs* (soil carbon sequestration, biochar, and enhanced weathering). Currently, these GGRs have either uncertain environmental impacts and/or uncertain negative emissions potential. Pilot projects can help establish repeatable and effective practices in deploying land-based GGR options. For land-based GGRs, certain aspects are particularly important to at the pilot stage:
  - ◊ *Accounting for land-based GGR:* At-scale pilots should significantly improve the understanding of t/CO_2 removed by different land-based GGR methods and allow for the development of monitorable proxies (such as tonne of silicate material spread) to which future policy incentives can be linked.
  - ◊ *The environmental impacts:* Viability of some land-based GGRs remains unknown given uncertainty around environmental impacts. Pilots will be critical to establish the risks and develop appropriate safeguards.
- *Support demonstration projects of BECCS and DACCS.* The purpose of the demonstration projects will be to test the technologies in the UK. Currently, the UK has one BECCS installation, which is a pilot plant built by DRAX, and no DACCS installations.
- *Coordinate investments in CCUS infrastructure* to create economies of scale for BECCS and DACCS along with other CCUS projects. This is also in line with the Government's action plan on CCUS, which has highlighted CO_2 storage and transport facilities as a priority.
- *Provide land managers with skills and information* to transition into new land management practices. This also includes supporting farmers to identify appropriate land uses and implementing low-carbon farming practices.

4.1.3 Integrating policies

In the short term, the Government can revise forestry and environmental regulations to shape a policy environment that offers flexibility for deploying GGRs in the future. Although some regulatory changes may involve a time-consuming process, the policy development process can begin now. Discussions with relevant policy teams have identified the following areas for action, *subject to further risk assessments*:

- *Relax the permanent land use change requirement in afforestation schemes.* Currently any land use change to forestry is required to be permanent. This is often a barrier for farmers to switch some of their agricultural land to forestry. To support production of biomass for BECCS (which for short rotation forestry may involve a ~10 year rotation) the permanence requirement could be removed, to enable farmers more flexibility to switch back to agricultural land use after an initial rotation.

More detail on integrating policy needs is provided in Section 5.2.

4.2 Evolutionary pathway

The policy suggestions are intentionally designed as evolutions of existing policy. This pathway represents an evolutionary approach, using existing policies. The following lists policy suggestions for key GGRs.

- **Afforestation** can be incentivised through existing schemes to support woodland creation in the UK. These include the Woodland Carbon Fund, Woodland Carbon Code, and the Country Stewardship Scheme.[11] As discussed in Section 4.1, some existing barriers can be removed, and greater incentives could be created through an obligation to purchase WCUs.

- **Habitat restoration and other land-based GGR options** could be incentivised through inclusion in the Environmental Land Management Scheme (ELMS) proposed in the Agricultural Bill set out in 2018. The timescale is suitable, as the government is planning to run trials up to 2022 and pilot schemes up to 2024, eventually establishing the ELMS in 2025 (Defra, 2018a). In terms of operations, this would be similar to existing agri-environmental schemes, such as the Country Stewardship and Environmental Stewardship Schemes, which fund some forms of soil carbon sequestration and habitat restoration (Rural Payments Agency, 2018a, 2018b). Similar provisions for biochar and enhanced weathering can be incorporated.

- **Construction with timber** can be made mandatory through requirements embedded within Building Regulations, specifying a maximum embodied carbon content in new builds (The Building Regulations 2010; UK Green Building Council, 2014). Exemptions could be offered to specific types of buildings where the use of timber is not as practical or safe. To ensure as much domestic timber as possible is used, government is likely to need to work with timber procurers and provide clear guidance on the required timber standards.[12] In a recent proposal set out by the Scottish government, no regulatory barriers to the use of wood engineered products in construction were identified (Scottish Government, 2018).

- **BECCS and DACCS** deployment can be incentivised via a contract-for-differences (CfD) scheme. Particularly for BECCS in power, this could be very similar to existing CfD scheme offered to project developers for renewable energy. As set out below, for DACCS and industrial BECCS a more innovative CfD would be required. From experience, CfDs can be effective in encouraging investments that involve high upfront costs and long payback periods by providing project developers protection from volatile electricity wholesale prices in the future.

    - ◊ *For BECCS in electricity generation a CfD linked to the electricity price could be effective*. Following the existing arrangement for awarding CfDs, contracts with successful bidders can be administered through the Low Carbon Contracts Company (BEIS, 2019).

    - ◊ *For industrial BECCS and DACCS*[13]*, a CfD could be linked to the ETS price.* This is a significantly different concept to existing CfD schemes, but is similar to proposed designs for UK CCS incentives. For BECCS, the strike price will need to be increased to reflect the additional cost of using biomass as a feedstock (Element Energy, 2018). Similarly, for DACCS the strike price will likely need to be higher than for CCS in general, reflecting DACCS costs.

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[11] Under the Woodland Creation Grant (WCG) element of Countryside Stewardship Scheme.
[12] Currently, most high quality timber (C24) used for building construction in the UK is imported. However, the proportion of lower quality timber (C16), which primarily grows in the UK, can likely be increased (BSW Timber, 2011). See Section 6 for more detail.
[13] Note, this would require DACCS to be included in the ETS which it currently is not.

Table 5 Evolutionary pathway strengths and weaknesses

Strengths	Limitations
• Implementation builds on existing policies and policy plans and is hence relatively simple. • Specific sectors and GGR providers can be targeted with individual policy and contracts to minimise producer surplus from GGR payments. • Low policy risk for project developers of land-based GGRs as they are secured by contracts with the government. • Accounting requirements are relatively low as there are no tradeable certificates across GGRs. • Costs are distributed progressively across the tax base. • Opportunity for coordination as the government can target land-based GGR projects at locations where co-benefits are maximised.	• Unless the proposed policies are funded through a general GGR levy on emitters, the policy would not abide by the 'polluter pays' principle. • Allocation of resources across GGRs is likely to be less efficient than market-based mechanisms. • Depending on the design of the above policy suggestions, cost to government could be significant as most evolutionary options are subsidy-based. • Costs to government could create fluctuations in support levels depending on the priority given to GGR by government, resulting in high levels of uncertainty.

Note: Although government is likely to provide significant subsidies (e.g. through CfDs) these need not necessarily be funded by government (i.e. the general tax base). As with current CfDs for renewables, they could be funded by specific levies.

Source: Vivid Economics

4.3 GGR obligation scheme

Companies in the scheme are required to secure negative emission certificates to meet their obligations. The obligation would be set at a fixed proportion of emissions associated with the obligated party's product, for example 5% of the carbon content in oil. The obligation scheme would begin as a narrowly defined obligation system and broaden over time. The percentage of emissions the obligated party is obliged to compensate for through the purchase of certificates would be ramped up over time, reaching 100% by 2050. This would ensure the UK reaches net zero GHG emissions.

Implementing the scheme would require a minimum accounting standard, to accurately measure the quantity of CO_2 removed, and only GGR options which meet this standard should be covered by the obligation. Although accounting for BECCS and DACCS is relatively straightforward, their technological immaturity means that they are unlikely to be taken up through incentives from the obligation scheme alone. Hence, initially the obligation would primarily incentivise GGR options that are mature and offer reliable accounting standards, such as afforestation, habitat restoration, and using wood in construction. The scope of GGRs covered by the obligations will gradually expand as monitoring, reporting, and verification (MRV) methodologies and technological maturity improve for each GGR option.

In the long term, if genuine certificates can be generated by a range of GGRs and exchanged, the scheme could form the basis of a negative emissions trading scheme. Entities that do not invest in sufficient GGRs to meet their obligations can purchase negative emission certificates from entities that have surplus negative emission certificates. The extent of GGR deployment can be adjusted through the level of obligations mandated under the scheme.

The obligations could be imposed on a range of different entities. However, we propose a scheme where they are imposed on wholesale suppliers of fossil fuels and agricultural products.[14]

- *Fossil fuel suppliers:* The obligation would be calculated as a percentage of the carbon content of fuels. Relative to the large number fossil fuel users, there are only 1,400 wholesale suppliers of fossil fuels in the UK (ONS, 2018).[15] Furthermore, by covering all fossil fuel-related emissions in the economy, the costs are shared widely across fossil fuel wholesalers who pass on most of the obligation's cost (see Section 1.2). Imposing obligations on fossil fuel suppliers would therefore be a practical way to spread the costs through the value chain. All UK fossil fuel users would hence (indirectly) pay for GGR deployment. This follows the 'polluter pays' principle. Given that the cost is widely distributed, final fuel prices will not increase significantly. However, the obligation does place an additional burden on emitting sectors, some of which are already relatively heavily taxed (see Section 6 for further discussion).

- *Wholesale distributors of agricultural products:* The obligation would be based on a percentage of the GHG emissions associated with agricultural activities, e.g. production of dairy or grains, which represent a significant segment of remaining emissions by 2050. There are benefits to reflecting the societal costs of these emissions in the value chain, to provide correct final price signals to consumers. As with obligation on fossil fuel wholesalers, the costs can be spread more widely by placing the obligations upstream – on wholesalers of agricultural products. Furthermore, it would avoid burdening farms (many small farms will have limited ability to pay or take on the administrative burden).

The obligation is unlikely to create a significant competitiveness impact for UK industry and agriculture. The benefit of placing the obligation upstream is that passed-through costs are spread over a wide base, hence

[14] Other end users of fossil fuels, such as industrial facilities, would not be covered in the obligation scheme because they will be 'double-taxed'. This is because industry and other end users will already be paying for GGRs indirectly through higher fuel prices. See Box 4 for discussion on cost pass-through.

[15] With about 160 registered firms in the mining of coal and the extraction of crude petroleum and natural gas.

limiting competitiveness impacts on any specific sector. However, scheme design should carefully consider competitive impacts for particularly energy-intensive and trade-exposed sectors, especially when total GGR costs ramp up over time (see Section 6 for further discussion).

The policy can incentivise efficient deployment of GGRs. The price on negative emission certificates acts as an incentive for companies to internalise the social benefits of deploying GGR. The trading scheme thus creates a market that allocates resources efficiently because GGR projects would be undertaken by those who can remove carbon at the lowest costs. Although having a common carbon price on emissions would be more efficient, its effectiveness is constrained at least in the short term as GGR technologies are not yet mature, as shown in assessment in the Appendix.

Box 6 A parallel negative emissions trading system, rather than inclusion in the ETS

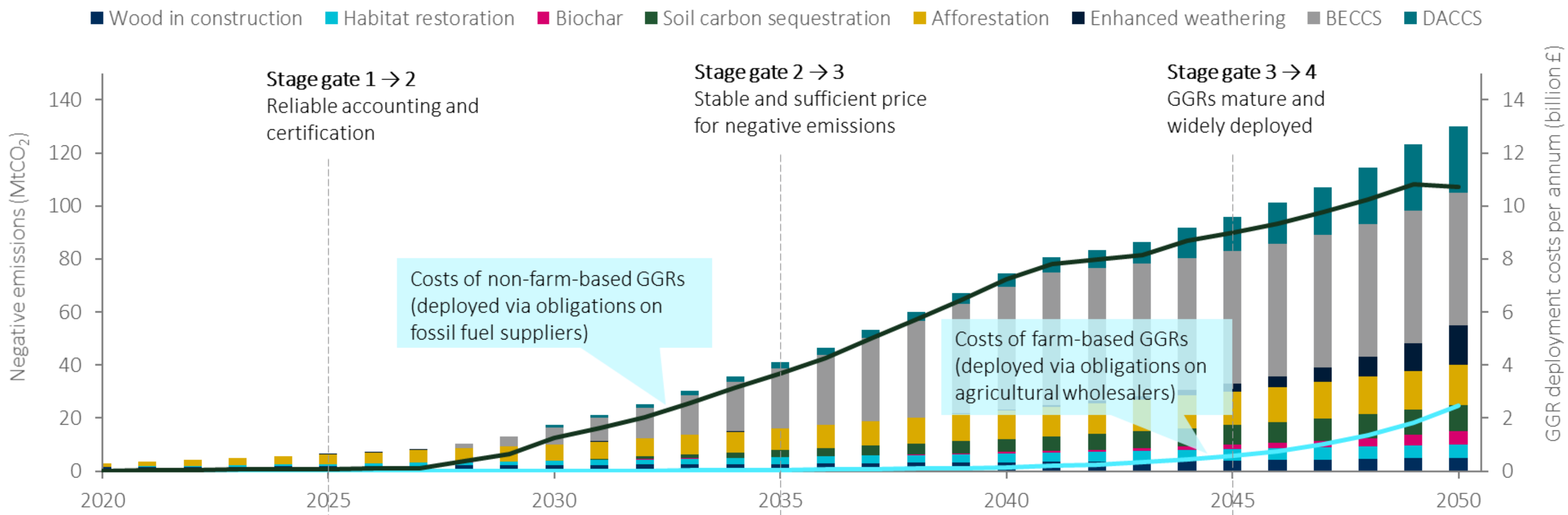
- From an economic perspective, including GGR into the established EU ETS is attractive as it encourages an efficient allocation of resource between emission reduction and removing GHG.
- However, the difference in accounting rigour between GGR and emission reductions is an ongoing issue. Emission reductions covered by the ETS can be measured accurately and reliably because of the fixed carbon content in fuels and standardised industrial processes. By contrast, the potential for removing carbon dioxide is uncertain for most land-based GGRs (see section 5.1.1). The credibility of EU ETS allowances is critical to its function, and could be undermined by the inclusion of GGR.
- A parallel GGR obligation scheme, while somewhat less efficient across the economy, can mitigate the market risks arising from uncertain accounting, as described in more detail in Section 5.1.1.

Table 6 Obligation scheme pathway strengths and weaknesses

Strengths	Limitations
• Revenue-neutral for government because the scheme creates a transfer of income between companies seeking to meet their obligations. • Costs of GGR deployment are shared widely because the obligation is put upstream, covering all emitting sectors. • The 'polluter pays principle' is adhered to, which is likely to make this a politically palatable scheme. • Emission reductions are incentivised through an increase in fuel prices as fuel suppliers pass on obligation costs. • Effective in targeting specific quantities of GGR because the policy is delivered in a quantity mechanism, so the amount of GGR can be calibrated in accordance with carbon budgets.	• Price fluctuations of certificates create risks that could weaken incentives to invest in GGR projects, especially in the early stages of the scheme when liquidity is relatively low. • Rigorous accounting standards are needed for the negative emission certificates to be credible. • Potentially significant windfall gains for project developers of low-cost GGR options, such as afforestation. • Possible competitiveness impacts on energy-intensive industries may require complex design details (e.g. exemptions for exports and carbon border adjustments for imports) for trade exposed sectors. • Regressive impact of pass-through costs. Increases in fuel prices, for example, would disproportionately affect low-income households.

Source: Vivid Economics

Figure 7 Obligation scheme implementation timeline



Stage	1. Accounting methodology development	2. Obligation on some GGRs	3. Obligation on most GGRs	4. Incentives for GGRs equalized with emission reductions
Direct policy	Policy design	Obligation placed on fuel suppliers	Obligation extended to wholesalers of agricultural products	
Enabling policy	Market creation of GGR certificates, using public procurement. Infrastructure development.	Ongoing innovation support	Enabling policies phased out	

Note: GGR costs are calculated by taking the mid-point between the lower bound and higher bound of cost estimates. Timing of stage gates are indicative.
Source: Vivid Economics

4.3.1 Links with enabling and integrating policies

This section discusses links with enabling and integrating policies unique to this policy pathway. A more extensive description of the enabling and integrating policies generally required for GGR is provided in the Enabling and Integrating policies section (Section 5).

- *Accounting pre-conditions to operationalise policy:* A certification mechanism for negative emissions must be established to allow for the trading of negative emissions. Certificates would be awarded to GGR projects, with an approved monitoring plan. A competent authority needs to be established which can approve accounting methodologies of GGR projects and award certificates. Given the certificates are tradeable, the accounting requirements for this policy are high.[16] As described in Section 5.1.1, the certification authority may need to provide guarantees around the issuance of certificates based on approved accounting methodologies to ensure a predictable supply and minimise price volatility.
- *Initial public procurement, to establish market liquidity:* The intent of this initial phase is to establish the credibility of certificates, create some liquidity in the certificate market, and broadly demonstrate the revenue streams available in the certificate market. To do so will likely require some initial publicly funded GGR projects. Given its maturity, initial publicly procured projects could include afforestation. However, the public procurement could also naturally flow out of, for example, demonstration projects for BECCS and other GGR options (see Section 5.1.2).
- *Certificates as a tool to integrate with wider policy framework:* The certification scheme provides a natural tool to integrate GGR deployment policy into wider policy frameworks. The approval of accounting methodologies and issuance of certificates could be made conditional on wider requirements, including environmental standards.

[16] Though the accounting requirements in this obligation scheme would still be lower than integrating GGRs into the ETS. See Box 6 for details.

4.4 GGR tax credit funded by a carbon levy

Tax credits for carbon removal can provide an effective incentive to deploy GGR. The tax credits would be available in two forms: £/tCO_2 and on capital investment.

- **The primary incentive consists of a banded set of available tax credits paid for £/tCO_2 of greenhouse gas removed.** For example, the tax credits can be modelled after the 45Q tax credit for CCS in the US and made available for BECCS and DACCS. Different tax credit bands would be available, for example, for afforestation and other GGR options, based on their relative costs.

- **An additional tax credit is made available for initial (capital) investment for GGR.** This type of tax credit, to spur investment, is common in the UK and would complement the £/tCO_2 tax credit available per tCO_2. In effect, this is similar to the 48a/b tax code in the US (credit for investment in gasification equipment)[17]. This is particularly useful for capital-intensive GGRs such as BECCS, but would also help spur investment in forestry, for example, where the bulk of the costs are upfront ones. Receipt of the credit could be smoothed over multiple tax years to ensure the credit does not exceed total tax liability.

By making the tax credits tradeable, the tax credits are available to any large tax-paying entity, which is not necessarily the entity deploying the GGR. In the simplest case, large oil and gas companies may reduce their tax liability through deploying GGR options such as BECCS or DACCS directly (akin to 45Q). However, by making the tax deduction available to GGR investors (through trade), the scheme is opened up to other companies with a large tax liability. For example, a supermarket or bank could reduce their tax bill by investing in the roll-out of GGR options on farms.

When combined with a carbon levy, a broad series of tax credits can be revenue-neutral for government. The carbon levy would be set on greenhouse gas emissions across the economy.[18] We distinguish between this levy and a commonly referenced carbon tax, as the levy proceeds would be directly used to finance GGR tax credits. The estimated costs of GGRs will determine the height of the levy (see Box 7).

Box 7 The level of tax credits and levy required

- The banded tax credits would be set at a rate that is marginally higher than the unit costs of a GGR option. This serves to incentivise GGR deployment across the full range of technologies while ensuring low-cost GGR options do not receive excessive support (this may be efficient in the short run, but not in the long run). As the tax credit rates are dependent on technology costs, they will need to be revised periodically so that the strengths of incentives remain appropriate.

- To finance the tax credits, this policy portfolio includes a levy set at a level to fully fund the tax credits. For the policy portfolio to remain revenue neutral, the levy on carbon emissions (£/tCO_2) increases over time as UK-wide GGR deployment grows and carbon emissions fall. Figure 8 below illustrates the pathway for the levy rates such that revenues from the levy can exactly offset the costs of offering GGR tax credits.

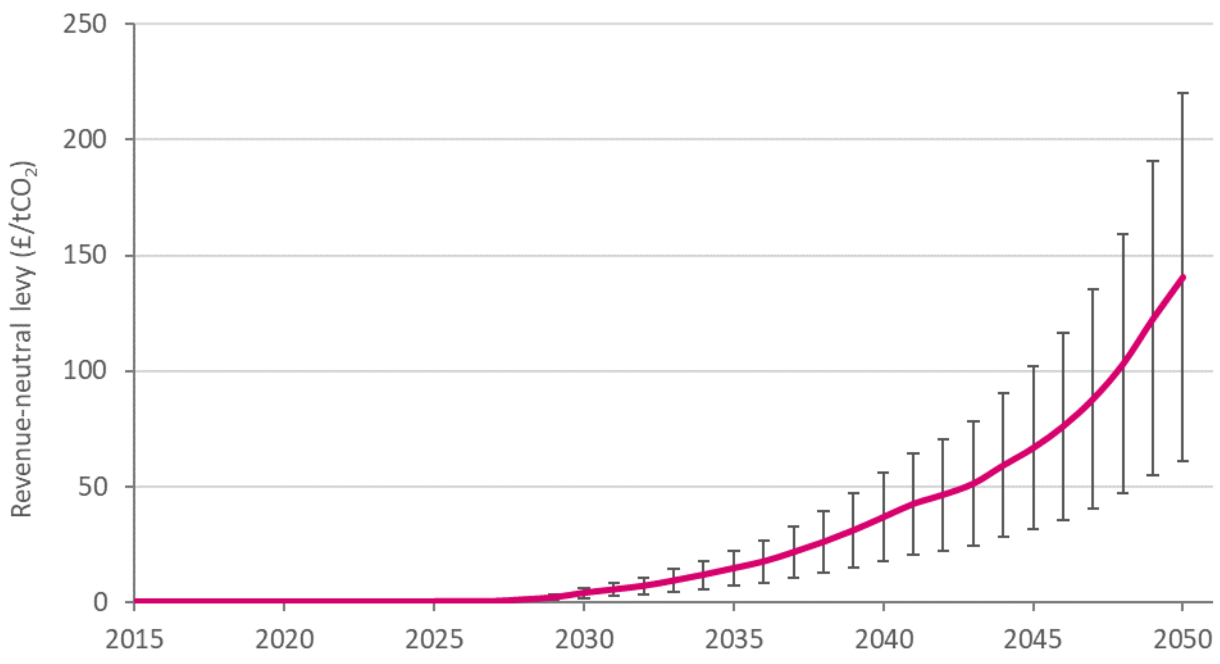
[17] More details available here: https://www.law.cornell.edu/uscode/text/26/48A
[18] With the possible exception of LULUCF, where verification is likely to be difficult.

Table 7 Tax credit pathway strengths and weaknesses

Strengths	Limitations
• Revenue-neutral for government because the carbon levy is designed to generate sufficient revenue to finance the tax credits. • Relatively strong incentive for capital intensive GGRs through the combination of credits for investment and operating costs. • Accounting requirements are lower than the GGR obligation scheme. This is because the government can choose not to apply updated accounting methods (that alter estimates of negative emission) to existing projects. • Costs borne by emitters would be politically acceptable. • Levy incentivises emission reductions in addition to encouraging GGR deployment.	• Perceived policy risk may hold back capital-intensive GGR projects. For projects with long payback periods, investors will require certainty that the tax credit will persist over time. Given the relative ease with which tax credits can be changed, government may need to provide additional guarantees. • Monetary benefits (via tax credits) are likely to primarily accrue to large corporates as they have the largest tax liabilities to offset with credits. • Regressive impact of passed-through costs. Increases in electricity prices, for example, would disproportionality affect low-income households, restricting public support for the scheme. • Like the obligation scheme, possible competitiveness impacts on energy-intensive industries may require complex design details (e.g. exemptions for exports and carbon border adjustments for imports) for trade-exposed sectors.

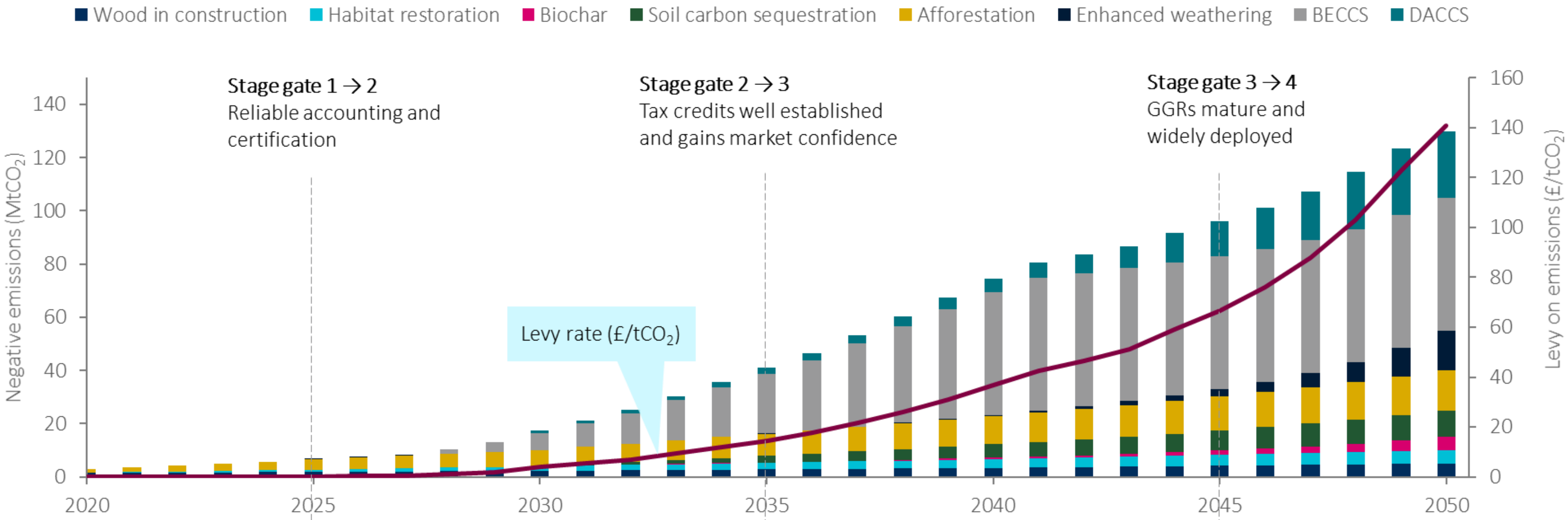
Source: Vivid Economics

Figure 8 Revenue-neutral levy rates on carbon emissions to fully fund GGR tax credits



Note: The error bars indicate the lower and upper bounds of cost estimates.
Source: Vivid Economics

Figure 9 Tax credit scheme implementation timeline



Stage	1. Accounting methodology development	2. Tax credits available for GGRs with established accounting methodologies	3. Tax credits available for most GGRs	4. Incentives for GGRs equalized with emission reductions
Direct policy	Policy design	Banded tax credit for each GGR deployment; tax credit for capital investment		
Enabling policy	Public procurement to establish market for certificates	Continued innovation support and potential co-investment in immature GGR options		

Note: GGR costs are calculated by taking the mid-point between the lower bound and higher bound of cost estimates. Timing of stage gates are indicative.
Source: Vivid Economics

4.4.1 Links with enabling and integrating policies

This section discusses links with enabling and integrating policies unique to this policy pathway. A more extensive description of the enabling and integrating policies generally required for GGR is provided in the Enabling and Integrating policies section.

- *Accounting pre-conditions to operationalise policy:* A certification mechanism for negative emissions must be established for tax credits for negative emissions to function. The accounting requirements for operationalising the tax credits are less stringent compared to the GGR obligation scheme. This is because incentives to pursue negative emissions are fixed by the tax credits, which are set by government. The government can choose not to apply new accounting standards when negative emission estimates for existing GGR projects are revised downwards. This is unlike in an obligation scheme, where changes in accounting methods can significantly impact supply of certificates and destabilise the market. Nonetheless, accounting and monitoring needs to be sufficiently robust to ensure the negative emissions can be included in national emissions accounting.

- *Initial public procurement, to establish market liquidity:* Like the obligation scheme described above, some initial publicly funded GGR projects would help establish the credibility of certificates and create required certainty for private investors. Given the price certainty provided by a tax credit (as opposed to a market-set price in an obligations scheme) the level of initial public procurement required to initialise trading is likely to be lower.

- *Certificates as a tool to integrate with wider policy framework:* As with the certificates for the GGR obligation scheme, the certificate scheme included in this policy pathway provides a natural tool to integrate GGR deployment policy into wider policy frameworks. The approval of accounting methodologies and issuance of certificates could be made conditional on broader requirements, including environmental standards.

4.5 GGR subsidies

GGR subsidies can provide a significant incentive to deploy GGR. The subsidies would be available in two forms: targeted grants and service contracts.

- **Targeted grants would be aimed at individual landowners who deploy small-scale GGR projects**, such as tree planting, enhanced weathering, biochar, and soil carbon sequestration. Applicants for these grants are required to submit project proposals which follow a relatively simple template. A government body responsible for the programme will screen the proposals and issue contracts to applicants that meet a set of criteria around land use and GGR feasibility. This would be similar to the *direct landowner grants* under the One Billion Trees Fund in New Zealand, but expanded to cover a range of land-based GGRs that landowners could pursue.

- **Service contracts would be aimed at businesses that deploy large-scale GGR projects**, covering all types of GGR. To secure the contracts, businesses would first be required to submit project proposals that outline the volume of GGR removal that they expect to achieve and the timeframe for delivery. A government body would screen those proposals based on feasibility, select projects through a competitive bidding process, and enter into contracts with successful bidders. This would be similar to the Emissions Reductions Fund in Australia. The primary difference between these contracts and the targeted grants is the scale, with service contracts designed to be bespoke, depending on the needs of large projects, such as a BECCS power station.

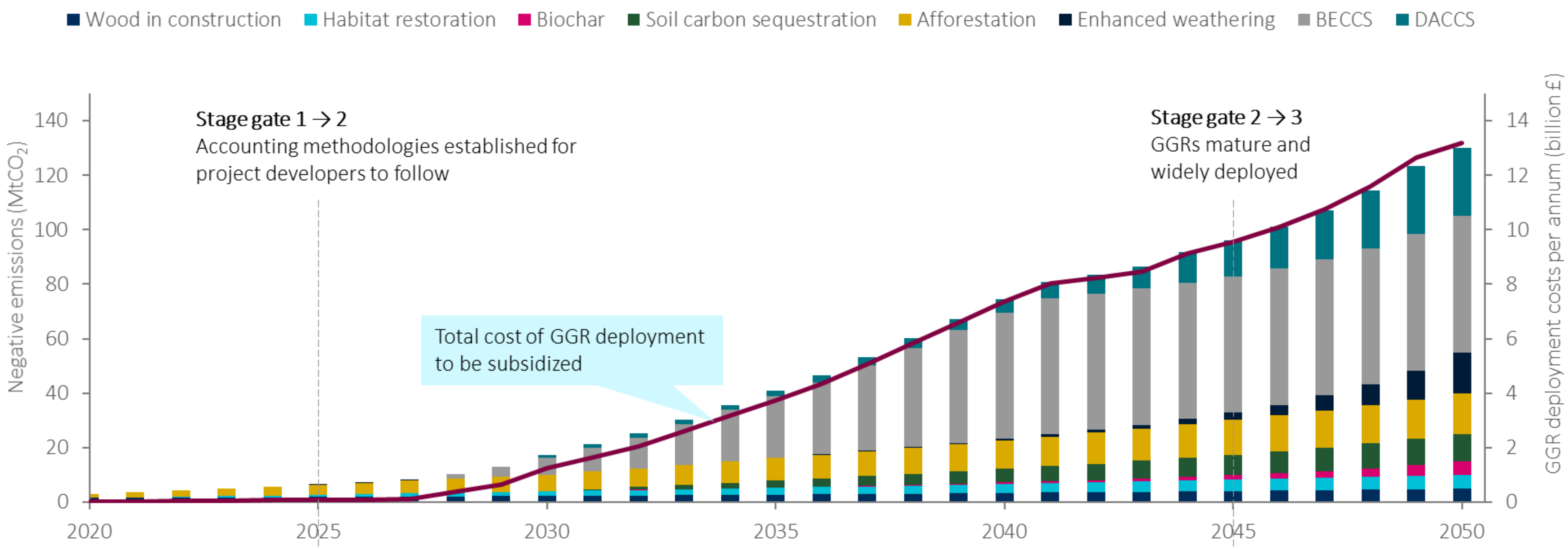
Efficiency is maintained through competitive bidding for large-scale GGR projects. This would eliminate rents available to project developers and ensure that GGRs are deployed in a cost-efficient way. However, this scheme is unlikely to be as efficient as tax credits and obligations, which have a greater element of competition. On the other hand, its simplicity is attractive and possibly more effective in quickly establishing GGR deployment at scale, particularly in the short-to-medium term.

Table 8 Subsidies scheme pathway strengths and weaknesses

Strengths	Limitations
• Policy risk is lower than tax credits, as subsidised entities are secured by contracts with the government. • Accounting requirements low and purely driven by a national emissions accounting requirement. • Costs are distributed progressively across the tax base. • Opportunity for coordination as government has significant control over location of GGR projects, so it can ensure they are targeted where co-benefits are maximised.	• Significant cost to government, plausibly at around £6-£20 billion per annum by 2050. • Difficult to scale up policy ambition given the legislative constraints on budget allocation. • No or limited incentives for emissions reductions. • Allocation of resources across GGRs is less efficient than other market-based policy pathways.

Source: Vivid Economics

Figure 10 Subsidies scheme implementation timeline



Stage	1. Accounting methodology development	2. Subsidies are provided to selected GGR projects	3. Incentives for GGRs equalized with emission reductions
Direct policy	Policy design	Targeted grants for small-scale GGR projects; service contracts for large-scale GGR projects	
Enabling policy	*No specific policies needed beyond those in section 4.1*	Continued innovation support and potential co-investment in immature GGR options	

Note: GGR costs are calculated by taking the mid-point between the lower bound and higher bound of cost estimates. Timing of stage gates are indicative.
Source: Vivid Economics

4.5.1 Links with enabling and integrating policies

- *Accounting pre-conditions to operationalise policies:* This policy pathway requires the least onerous accounting methodology. Methodologies will be required on a project-by-project basis, with project developers to submit monitoring plans for each project. Methodologies for individual projects must be sufficiently credible for inclusion in national accounts, though the risk of future changes in accounting methodology would not adversely affect the scheme (unlike the obligations and tax credits, where this is a risk which must be mitigated).
- *Screening of project proposals as a tool to integrate with the wider policy framework:* Given the government's direct control over which GGR projects are funded, there is a smaller need to establish regulatory safeguards. The provision of subsidies can simply be directly tied to environmental requirements within each bid for subsidies.

5 Enabling and integrating policies

5.1 Enabling policies

Direct policies alone are unlikely to incentivise significant GGR deployment without a wider suite of enabling policies. The following sets out the key enabling policies required, detailing why they are necessary. The suite of enabling policies required are mostly independent of the policy pathway used to support GGR. Instead, they are driven by the barriers faced by GGR options. The following therefore describes the generic enabling policies required to support GGR. Specific options to link enabling policies to the wider policy pathway are discussed within Section 4.

5.1.1 Project Accounting

GGR (negative emissions) accounting improvements are necessary to meet three key requirements: The need for certainty of climate benefits, practical accuracy requirements for inclusion in the UK inventory and targets, and measurement requirements to link policy to tCO_2 removed.

1. **Certainty of climate benefits:** Significant uncertainty remains about the quantity of CO_2 removed through different GGR techniques when implemented. In addition, the varying permanence of different GGR techniques raises questions around how, for example, a tCO_2 removed through soil carbon sequestration (possibly re-emitted if the soil is not maintained) affects the global carbon balance and climate change[19]. Before supporting GGR options at scale, the climate benefits need to be well understood and demonstrated. Notably, it is not immediately necessary to understand in depth the local differences in the effectiveness of removing CO_2 for different GGR options, as long as the aggregate effect can be accurately modelled.

2. **Practical inclusion in UK emissions inventory:** How GGR can be included in national emission accounts is driven by UNFCCC reporting guidelines, which are based on 2006 IPCC guidelines (IPCC, 2006). Currently, guidelines exist to account for forestry and BECCS; however, there are not yet UNFCCC accounting guidelines for most GGR options. IPCC guidelines are currently being refined, and are likely to go through several further updates by 2050, providing an opportunity for GGR to be more fully included in international emissions reporting (IPCC, 2019). Note that, in the absence of new guidelines, the UK can start rolling out, or at least demonstrating, immature GGR options and include their CO_2 removals in its inventory.

3. **Policy incentives linked to CO_2 removed:** Different policies will have different requirements for the verification and monitoring of CO_2 removed. In the case of negative emission certificates, the accounting needs to be sufficiently robust to ensure that a certificate issued for $1tCO_2$ removed through afforestation is equal to a certificate for $1tCO_2$ removed through DACCS. For certificates to be traded, the market needs to be confident that the certificate equivalence holds. This requires a high degree of accounting accuracy.

Accounting for GGR presents several challenges beyond those currently faced in emissions accounting. The technological immaturity of various GGR options means that accounting principles are not yet well established. Moreover, GGR accounting presents several wider challenges, as outlined in Box 8.

[19] See Box 3 for more detail on the uncertainty around soil carbon sequestration.

Box 8 Challenges to GGR project accounting

- **The importance of local conditions:** Significant uncertainty remains around the GGR potential of the various options. This is largely due to the importance of local conditions to CO_2 absorption. For example, the rate of GGR from enhanced weathering will depend on rainfall, temperature, soil type, and so on (Hartmann et al., 2013).
- **Permanence:** GGR techniques vary in the permanence of the CO_2 stored and the risk of re-emission (reversal). Long-term or permanent storage is clearly preferred over temporary storage, but frameworks need to be established to account for this. Permanence issues can be categorised as follows:
    1. *Valuation of permanence:* There are no established frameworks which value the length of storage. A threshold of 100 years is typically used to qualify storage as ‘permanent’ (Unger & Emmer, 2018). Alternative options include the potential use of tonne-years of CO_2 rather than tCO_2 as the key unit of measurement, to explicitly value the length of storage (Marshall & Kelly, 2010).
    2. *Accounting for reversal risk:* Accounting standards need to explicitly address reversal risks. This could be done through, for example, the incorporation of accounting buffers (as discussed below).
- **Monitoring and verification:** As with emissions, GGR will be primarily self-reported, with occasional enforcement inspections. Verification is likely most challenging for farm-based GGR, where it is not easy to establish whether, for example, biochar has been applied to the soil. It is possible this is verified purely by monitoring sales of biochar material, but some soil sampling may also be required. Regardless, this will likely require significant effort beyond the current light-touch monitoring of farming activity by DEFRA.
- **International supply chains:** Accounting for emissions associated with international supply chains presents a challenge for existing emissions accounting, and has been the subject of extensive negotiation. GGR will add additional complications. For example, it remains unclear how negative emissions are attributed between countries supplying biomass and countries constructing with timber or performing BECCS. Accounting for possible re-emissions, e.g. of CO_2 captured in France but stored in the UK, may be a particular challenge.

Table 9 GGR accounting practices

GGR options	Included in IPCC guidelines?	Included in established schemes?	Likely path towards inclusion in accounting
Afforestation	✓	✓	N/A
Wood in construction	Partial	Partial	Likely requires additional data collection to enable domestic use of timber in construction to transparently account for the extra removals in the Harvested Wood Products pool, and if required an alternative half-life (currently 35 years for sawn timber).
Habitat restoration	✓	✓	N/A
BECCS	Partial	Partial	Biomass combustion can be accounted as CO_2-neutral under UNFCCC, and established mechanisms exist for CCS accounting.[20] However, the combination of the mechanisms to account for negative emissions has not been implemented yet.
Soil carbon sequestration	✓	✓	N/A
Enhanced weathering	×	×	Improvement in modelling to simulate t/CO_2 removed per tonne of silicate rock spread (Taylor, Beerling, Quegan, & Banwart, 2017).
Biochar	×	×	Improvement in modelling to simulate t/CO_2 removed per tonne of biochar spread (Koper et al., 2012).
DACCS	×	×	Accounting likely to be very similar to established CCS accounting, although as with BECCS, administrative changes are required to allow for negative emissions accounting.

Note: This table is indicative and accounting practices may evolve differently as new methods become available.
Source: Vivid Economics

Given the challenges with GGR accounting, emissions accounting for GGR is likely to be project-based in the short term. At a high level, there are two broad methods to account for and monitor emissions.

- *Policy wide accounting rules:* Akin to the guidelines for national emissions accounting, there are several policies or schemes which include detailed rules around emissions accounting. For example, the monitoring, reporting and verification (MRV) cycle associated with the EU ETS is tightly defined. Emitters have to submit a monitoring plan based on pre-defined monitoring approaches (European Commission, 2015). This approach ensures consistency in reporting and provides credibility to the allowances traded in the scheme. However, to achieve a universal set of monitoring approaches is onerous and requires extensive and detailed technical knowledge.

[20] For example, an emitter does not have to surrender EU ETS allowances for any CO_2 captured and stored through CCS. The EU's CCS directive provides more detail on the legal framework for CCS in the EU.

- *Project-based accounting:* For GGR, a project-based accounting approach is likely to be the most viable, particularly in the short term. The clean development mechanism (CDM) is an example of such a scheme (Unger & Emmer, 2018). Project-based accounting provides broad principles to which accounting must adhere, but allows projects to submit a specific methodology to account for emissions. This methodology must be verified by a competent authority (CA) to ensure robustness, but allows different methodologies to be applied depending on the project context. This flexibility is useful for GGR, particularly for land-based GGRs, which are heavily impacted by local conditions.

Project-based accounting could support a traded GGR certificate, but will require several measures to ensure credibility of the certificate. The required measures and institutions will need to be established before a market for certificates can operate. Two aspects are likely to be especially important for credible GGR accounting:

- *Establish upfront clarity over treatment of permanence:* This is crucial to allow potential GGR providers to assess the risk associated with their project. Establishing clarity would involve requirements for the minimum duration of storage, standards for the mitigation of re-emission risk, and clear liability frameworks. To establish the required clarity, policymakers can draw on existing frameworks such as:
    - ◊ *Accounting buffers*, as is currently done in the Woodland Carbon Code (WCC) to ensure integrity of certificates. The WCC requires 20% of issued certificates to be surrendered to a buffer managed by Scottish Forestry. The buffer provides a level of scheme-wide insurance, and can be drawn down in case of unexpected reversal (UK Woodland Carbon Code, 2019a).
    - ◊ *Establish clear liability frameworks* for re-emission of stored CO_2 (in soils, forests, and geological storage). There are numerous reasons for possible re-emission, some of which could be reasonably considered to be beyond the control of GGR certificate recipients (e.g. forest fire), whereas others may be considered within the remit of certificate recipients (e.g. CO_2 leakage through inadequate closing of geological storage wells). Establishing clarity over the distribution of liability is crucial to allow GGR providers to appropriately price in risk. Examples of emerging liability mechanisms include:
        - The WCC, which defines when schemes are liable for replenishing the WCC buffer.[21]
        - The EU CCS directive, which sets out the liability of operators for CO_2 storage sites during and after operation (UCL Carbon Capture Legal Programme, 2019).[22]
- *Establish a CA with the power to guarantee certificate value:* The CA can influence the supply of GGR certificates through its power to approve accounting methodologies (and hence GGR projects). This gives it significant control over the price of GGR certificates in a traded scheme. To ensure the certificates accurately reflect a negative tCO_2, the CA will have to be prudent in accepting methodologies. Even so, it is possible that scientific advances imply significant changes to our understanding of how a greenhouse gas is removed, or how permanently it is stored, through certain options. This could imply a shock to the value of GGR certificates. This risk would hamper the effectiveness of a policy rewarding t/CO_2 through certificates. To mitigate this problem, the CA could

[21] For example, re-emission due to natural disaster does not require the scheme to replenish the buffer. However, in cases where re-emission is deemed to be due to poor management, the individual scheme is required to replenish the WCC buffer. This is typically done by increasing the % of certificates handed over to the WCC buffer at the next verification (UK Woodland Carbon Code, 2019a).
[22] It is a matter of ongoing debate whether it is reasonable to place the long-term liability for closed geological storage sites on private storage operators, or whether there is a role for government to assume liability after a defined number of years. As this is critical for CCS policy more broadly, it is not considered in detail here.

be given the power to guarantee the value of certificates (in terms of tCO_{2e}) based on an approved accounting methodology.[23]

As GGR options mature, accounting practices can evolve. As more GGR projects are undertaken, best-practice accounting methodologies will naturally emerge. Over time, these can be used to provide template monitoring plans for all the GGR options, naturally moving closer towards an ETS style of accounting.

5.1.2 Innovation policy

The innovation support provided to GGR can come from the UK's established innovation ecosystem. As described in Section 2, GGR options will require significant innovation support to bring them to a TRL at which private investors are able to invest in response to incentives from a direct policy. Innovate UK, the UK's innovation agency, is well placed to provide the required combination of early stage research support and more commercially minded innovation support. Innovate UK's annual budget of approximately £600 million is invested in innovation support through various programmes including: grants, innovation vouchers, knowledge transfer networks, feasibility studies, and pre-commercial procurement programmes. All of these are likely to be required to support the spectrum of GGR options. In particular, two institutions are well placed to help support GGR innovation.

- *The Research Councils can play a key role developing accounting methodologies through targeted grants.* Several councils are currently jointly funding (£8.6 million) an ongoing programme on GGR.[24] The Research Councils' natural focus would be particularly on immature GGR and the development of models to help with accounting. For example, research could be supported to develop models which provide accurate proxies linking tonnes of silicate rock spread to tonnes of CO_2 removed from the atmosphere, considering field conditions, average weather patterns etc. Development of such models would enable enhanced weathering to be incorporated into emissions accounting and would allow deployment policies to reward enhanced weathering based on tCO_2.

- *The Catapults, potentially through a specific GGR catapult, can help drive demonstration and commercialisation of GGR in the UK.* Particularly for GGRs with relatively low capital intensity (such as enhanced weathering and soil carbon sequestration), a Catapult would be well placed to support a series of demonstration programmes. This could de-risk these options to a level at which private investors are willing to invest, incentivised through the direct GGR support policy. More broadly, a catapult could provide a key knowledge-sharing function.

Providing innovation support to GGR options is necessary, but should balance technology push and market pull. Given the various market barriers to GGR innovation, there is a clear argument for government support for pilot programmes.[25] Government support or innovation is also likely to be required for initial commercialisation of GGR options. Support at this stage of technological development may be provided in conjunction with support from a direct policy pathway, as described in Section 4. For example, support for a first-of-a-kind (FOAK) commercial scale BECCS plant could be provided partly through government innovation grants and partly through the sale of GGR certificates in a GGR obligation scheme (as described in Section 4.3). This form of mixed support for more mature technologies introduces market-based incentives (remuneration per tCO_2) relatively early on and minimises the risk of government picking winners.

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[23] The CA may not need to guarantee tCO_2e value in perpetuity and could include a tapering mechanism (e.g. the tCO_2e value of a certificate gradually decreases towards the level coherent with latest scientific evidence). The strength of the CA's guarantee should be tested against 1) Does it preserve the stability of certificate value in the market? 2) Does the CA sufficiently reduce the impact of accounting changes on certificate value over the payback period of private investors?

[24] More information available here: https://nerc.ukri.org/press/releases/2017/09-greenhousegas/

[25] Market barriers include GGR-specific barriers, such as uncertainty around future remuneration for negative emissions, the 'public good' characteristics of accounting methodologies, environmental externalities, and broader established barriers to innovation.

For capital-intensive GGRs, particularly BECCS and DACCS, specific demonstration programmes may be required to bring the technologies to full commercial viability. Given the capital intensity of BECCS and DACCS, Catapult funding may not suffice to support demonstration or first-of-a-kind commercial-scale plant. Specific programmes can be established to support this stage of development, akin to the CCUS action plan, which includes a specific CCU demonstration programme (HM Government, 2018b). In the short term, this is particularly relevant for BECCS, which is already being piloted in the UK and could move towards commercial-scale demonstration in the short term.[26]

5.1.3 Supply chain and infrastructure

The government will, at least initially, need to be involved in the procurement of infrastructure required to enable the roll-out of DACCS and BECCS. The upfront capital cost of the required infrastructure (i.e. CO_2 pipelines and/or shipping and CO_2 stores) is significant, and GGR policy incentives (from direct policies) are unlikely to be high enough to incentivise investment. Furthermore, government can coordinate the installation of CO_2 transport and storage infrastructure for BECCS and DACCS with that for CCUS more generally, to ensure the infrastructure acts as a 'public good'. There are options around how the government chooses to procure and subsequently operate the CO_2 transport and storage assets. As recommended by the CCUS Cost Challenge Taskforce, the transport and storage of CO_2 could follow the regulated asset base (RAB) structure used in other industries (CCUS Cost Challenge Taskforce, 2018). To kickstart infrastructure investment, one option is to establish a public company for CO_2 transport and storage infrastructure (Parliamentary Advisory Group on CCS, 2016). Once the initial network is established, operation and further expansion could be managed through an RAB scheme, like the national grid is today (EY, 2013).

The government may also play a role in establishing the required supply chain for enhanced weathering and biochar. Some investment will be required in pyrolysis facilities, for biochar, and silicate rock mining/silicate recycling for enhanced weathering. Although the capital investment required is not as significant as that for CO_2 infrastructure, it may be difficult to establish the supply chain, nonetheless. Government may play a coordinating role by, for example, coordinating the establishment of cooperatives between farmers to invest in a pyrolysis facility to supply biochar. The government could co-invest in early schemes to help establish the supply chain and demonstrate the viability of business models.

5.2 Integrating policies

Given the significant impact of GGR on UK land use, integrating policies are essential to ensure large-scale GGR deployment is achieved while maximising co-benefits and minimising associated risks. To achieve this, the Environment Agency is likely to play a key role, minimising local environmental risks. Furthermore, large-scale GGR deployment will have to be included in broader strategies. Relevant strategies include the UK-wide land use strategy (CCC, 2018), but also more specific strategies, such as the UK's biodiversity framework and the devolved nations specific biodiversity strategies (JNCC & DEFRA, 2012). Significant policy coordination will be required, both between devolved administrations and internationally, to reduce the risk of negative impacts on social development. Box 9 provides some detail on the devolved nature of key regulation and policy. The remainder of this section will primarily abstract away from devolution considerations, focussing on the English context.

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[26] BECCS is currently being piloted at the Drax facility in the UK. See https://www.drax.com/press_release/world-first-co2-beccs-ccus/

Box 9 Devolution and GGR policy

- Key policies and strategies relevant to GGR deployment have been devolved to national administrations. In particular, Scotland has independent regulation and enforcement agencies, including the Scottish Environment Protection Agency (SEPA), the Scottish Forestry Commission, and a Scottish land use strategy.
- To ensure an appropriate distribution of GGR deployment across the UK, integrating policy will have to be coordinated across England, Wales, Scotland, and Northern Ireland. For example, relevant environmental standards should be harmonised as much as possible, to ensure fair competition between land-based GGR projects (and avoid a direct GGR policy disproportionately incentivising GGR in a particular nation).
- Large-scale GGR deployment will also have implications across the UK's and the devolved nations' land use strategies (see section 5.2.2); these should align, ensuring both a fair distribution of GGR across the UK, and a coherent strategy towards achieving the total GGR level required for UK and national climate targets.

5.2.1 Integration into environmental regulation to minimise local environmental impacts

Within the policy pathway to support GGR, environmental safeguards are necessary to ensure GGR is deployed responsibly. Large-scale GGR deployment involves several environmental risks. These include risks to biodiversity from monoculture afforestation, air quality risks from pyrolysis, and soil and water quality risks associated with the spreading of biochar and silicates (enhanced weathering). To mitigate these, environmental regulation will have to be adapted in places to accommodate the scale of GGR required while maintaining environmental safeguards.

The environmental regulatory architecture in the UK is broadly appropriate for accommodating large-scale GGR deployment. Two key processes which apply to GGR (or can be broadened to apply to it) are:

- *The environmental impact assessment (EIA)*. This assessment is required before making changes to uncultivated land, but is also mandatory before projects with associated environmental risks can begin (notably, this includes CCS-related projects). All projects need to be approved, based on the outcome of the assessment, before the landowner can start work (MHCLG, 2017). This process should help safeguard against GGR deployment in environmentally sensitive locations.
- *The environmental permit.* This permit is required for activities carried out during the deployment of GGRs that might impact soil quality, water quality, or biodiversity. This includes facilities that emit non-CO_2 pollutants, waste operations, waste incineration plants, and biochar/enhanced weathering that include spreading (waste) materials. The Environmental Agency performs a risk assessment before issuing permits and may choose to withhold a permit if risks are too large (Environment Agency, 2019).

Biodiversity and air quality risks are unlikely to require significant regulatory change, with existing frameworks directly applicable to GGR options. In particular:

- *Air pollution* from BECCS and pyrolysis plants (to produce biochar) can be regulated equivalently to industrial air pollution. Under the Environmental Permitting Regulations (EPRs), industrial installations must obtain permits to operate, and the award of permits is decided in relation to Best Available Techniques (BATs) (Environmental Protection UK, 2018). Establishing relevant BAT standards for GGR-related technologies should allow these plants to be regulated similarly to other industries.

- *Biodiversity* risks from monoculture planting can be mitigated through the UK Forestry Standard, which includes biodiversity considerations (Forestry Commission, 2017). The standard, and broader forestry regulation, may require some rebalancing to appropriately reflect the benefits of afforestation (biodiversity, recreational benefits, CO_2 removal etc.) as forests are increasingly planted with the express purpose of capturing carbon.

Regulations regarding soil quality and water quality, relevant for farm-based GGR, could be modelled after existing considerations for fertilizers and waste spreading. Currently, environmental permits are required by farmers for any waste spread on land at a rate greater than 1 tonne/ha. Spreading of biochar and silicate rock would exceed this rate significantly to make a meaningful contribution to GGR. Farmers would hence have to apply for permits for these practices. This may be feasible in the short term, but if land-based GGRs are adopted, the administrative burden is likely to become excessive. To protect environmental standards while at the same time maintaining an administratively tractable system, standards could be devised which, if met, would remove the need for farmers to apply for specific permits.

- *Soil quality* impacts from GGRs can be mitigated through the existing permitting system. Baselining[27] would have to be carried out to establish good practices for permitting, but the permits would provide a system to limit the spreading of biochar and silicate rock (by imposing upper t/ha levels) to levels with no or acceptable levels of environmental impact (Environment Agency, 2013). Similar to fertiliser legislation (Agricultural Lime Association, 2019), standards can be established for silicate materials and biochar which are acceptable for use on agricultural land.

- *Water quality,* of both surface and groundwater, can be affected by intensive spreading of biochar and silicates. Although risks are limited in the short term, widespread application could have implications at the watershed level. Existing rules for manure and fertiliser to minimise runoff and leaching would also be applicable to biochar and silicates. Although aggregate risks to water quality by GGR are not yet well understood, a potential mode to mitigate aggregate risk is to establish e.g. ‘low silicate zones’ where enhanced weathering is limited, similar to the current ‘nitrate vulnerable zones’ system, which limits fertiliser application in vulnerable areas (Defra & Environment Agency, 2018).

5.2.2 Optimising land use across the UK

There is currently an opportunity to improve the UK’s overall land use strategy (CCC, 2018); this also provides an opportunity to include key GGR-related considerations. As described by the CCC, the strategy could set out the appropriate high-level distribution of afforestation across the UK and the distribution of bioenergy crops. More broadly, a UK land use strategy would allow policymakers to appropriately balance the significant land demand from GGR against competing lands claims.

Strong GGR policy could have a significant impact on relative land prices, which should be taken into account in the development of the UK’s land use strategy. Strong policy support for afforestation, for example, could have a significant impact on relative land prices. Left unchecked, this could result in land use changes which, while desirable from a GGR point of view, do not maximise other co-benefits and ecosystem services. To prevent this, the UK’s land management strategy, and corresponding devolved strategies (see Box 9), should be closely linked with any GGR policy.

5.2.3 International policy linkages

There are several opportunities for international cooperation on GGR policy. These include:

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[27] To establish the exact environmental risks associated with different forms of biochar and silicates. Akin to the work carried out for other wastes commonly spread to land (Defra, 2010).

- *A link with international trading schemes:* As a domestic trading scheme matures, it could be linked to other international GGR trading schemes (if these emerge). Linking with established trading schemes is also possible, although accounting challenges will likely prevent linking with large emissions trading schemes.
- *International innovation cooperation:* The UK could play a leading role in international GGR innovation, both to develop robust accounting methods for UNFCCC reporting, and to develop the technologies themselves. As a member of Mission Innovation, the UK is already taking a lead in funding clean energy technologies and collaborating with countries such as South Korea and Saudi Arabia. These forms of partnerships can be leveraged to support the development of GGR technologies.

Large-scale UK GGR deployment will require safeguards to ensure that supply chains do not adversely affect progress towards sustainable development goals. This is particularly relevant for BECCS, which if deployed at scale in the UK, would imply significant biomass imports. The UK would have to work closely with partner countries to ensure these imports are sustainably sourced.

6 Frequently Asked Questions

Q: How can policies be made credible to investors hesitant about GGR projects with long payback periods?

A: As a general principle, for GGRs with long payback periods, incentives should be structured to provide high levels of certainty around the annual payments received. Different policy mechanisms vary in the ability to provide this certainty.

- *Any contracting mechanism (such as CfDs) provide a particularly high level of certainty.*
- *A large scheme, such as an obligation scheme, can provide certainty, particularly once the market for certificates is mature. However, while the market matures, additional government support may be required for capital-intensive GGRs with long payback periods.*
- *Yearly tax credits are likely not to provide enough certainty for capital-intensive projects. Therefore, the proposed tax credit scheme includes credits for both annual tCO_2 removed and a proportion of the initial capital expenditure, to reduce the overall payback period.*

Q: In light of fire safety, to what extent is it feasible to require greater timber usage in buildings?

A1: The risk of fire hazards is likely to be a public concern regarding the increased use of timber. Following the Grenfell Tower fire, the Government has banned the use of combustible materials on new high-rise homes (MHCLG, 2018)*. Nonetheless, the scope for using cross-laminated timber (CLT) remains large and is gaining popularity in the industry. CLT is a multi-layer wooden panel, in which each layer is placed cross-wise to the adjacent layers to increase the panel's rigidity and stability. Here in the UK, the "Timber Frame 2020" research demonstrated that CLT frames could meet the functional safety requirements that would be required for non-combustible steel or concrete buildings, and prompted changes to the prescriptive code to increase the height limit to six storeys for buildings using CLT structural elements (FireRescue1, 2017). In short, despite public concerns regarding fire safety, there is scope for increasing timber usage in buildings.*

Q: Given limited domestic timber supply, to what extent is it feasible to require greater timber usage in buildings?

A: The UK imports the majority of its timber. The construction industry tends to procure C24 graded timber, which is of a higher density than the C16 type that is more widely available in the UK. C24 is of a higher grade and can be used for structural purposes, whereas C16 cannot. However, the C16 timber is appropriate for many building applications for which C24 is currently used, and could be used more widely. One of the policy challenges will be to encourage a shift to C16 timber for construction. This would require overcoming barriers, such as the procurement convenience of only procuring C24. However, it would relax the need for imported timber. More broadly, the UK's 25 Year Environment Plan sets out how the UK could increase the capacity of UK timber production (HM Government, 2018a), through, for example, the creation of forestry investment zones.

Q: In an obligations scheme where obligations are imposed on fossil fuel suppliers and food wholesalers,[28] will the level of *imported* fuels and food influence obligation levels?

A: Yes, the obligation would also apply to imported fuel and agricultural products. By placing the obligation on fuel suppliers and wholesalers, the obligation can be defined based on UK sales, independent of whether the product is produced domestically or imported. This a major advantage of placing the obligation at this stage of the value chain: there is no potential for carbon leakage.

[28] Based on the amount of embodied carbon in fuels and agricultural products.

Q: With large variations in the costs of different GGRs, how can policies be designed to reduce the surplus (i.e. economic rents) to project developers that can remove carbon dioxide at low costs?

A: Some differential treatment across GGR methods may be needed, such that project developers in, for instance afforestation, are compensated at a lower £/tCO_2 than a project developer for BECCS or DACCS. In practice, this may be done through banded tax credits or setting exchange values between negative emission certificates from different GGRs. For example, a certificate for BECCS may be valued at 10 certificates for afforestation. These bandings or exchange values will have to be adjusted periodically to reflect changes in technology costs.

In the longer term, when the gains from learning by doing (i.e. reducing future deployment costs by encouraging early stage projects) dissipate, differential policy treatments across GGR methods can be removed so that greenhouse gases can be removed at the lowest £/tCO_2 cost, irrespective of the technology choice.

Nonetheless, it should be noted that allowing some surplus for project developers may be desirable to stimulate market response in early stages of the policy.

Q: Given the existing use of carbon pricing (e.g. ETS or carbon tax), would creating a GGR obligation or levy imply 'double climate taxation' on certain sectors?

A: Yes, it does create 'double climate taxation' because some emitters, such as an industrial facility covered by the ETS, are required to pay (i) a carbon price for their emissions, and (ii) a higher fuel price when fossil fuel suppliers pass through the costs from a GGR obligation or levy.

The key point is to note that double taxation in this context is no different from having a single, but higher, carbon price.

The first concern regarding this is whether the additional costs will be excessive to producers and consumers. This issue is addressed in Section 1.2, in which the key point is that costs of deploying GGR can be distributed widely to consumers such that the burden on upstream suppliers is not a major concern (Element Energy and Vivid Economics, 2018), while increases in consumer prices are limited to around 10% in 2050. However, there is the broader issue of fairness and political acceptability associated with the distribution of costs across the economy. A double climate taxation may be perceived as unfavourable to polluters.

A second concern is whether the resulting price on emissions would be too high and therefore inefficient. This is an entire field of study on its own – the marginal social cost of emissions is estimated at between \$40-\$270/tCO_2, depending on modelling assumptions (Nordhaus, 2017).[29] *Nevertheless, consensus opinion is that the current EUA price in the EU ETS is too low to meet climate targets. Therefore, in the short term, creating a GGR obligation or levy equivalent to £15/tCO_2 (by 2035, see Figure 8) is unlikely to overshoot the efficient carbon price, but rather bring it closer to the optimal level. It should also be noted such double climate taxation already exists, for instance a fuel tax that consumers pay on top of costs passed-through from a carbon price. However, in the longer term, the equivalent carbon price created by a GGR obligation or levy could be high, reaching £140/tCO_2 in 2050. By then, GGR policy must be coordinated with carbon pricing to ensure that polluters are not paying an equivalent carbon price that exceeds the optimal level. This requires a thorough review of policies when GGRs such as BECCS and DACCS become mature and widely deployed.*[30]

[29] In 2010 US prices. Assumptions required for estimating the social cost of emissions are complex, and to a large extent depend on judgment of how much one should discount future welfare (i.e. discount rate).
[30] See Section 2.4 for a discussion on optimising the balance between emission reductions and negative emissions in the long term.

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8 Appendix: Assessment of direct policies

This appendix provides the assessment of a wide array of direct policy options considered to inform the writing of this report. The assessment is provided for context and as an intermediate output of our analysis, this assessment should be treated as such. In particular, this assessment is intended as providing a useful steer on strengths and weaknesses of different policies but should not be used to draw strong policy conclusions. It purposefully makes strong assumptions around how the assessed policies may be designed. This is intentional to allow an assessment of likely policy performance, which often directly depends on design detail. However, these assumptions can be legitimately challenged. This project held several expert workshops where the dependence on particular (assumed) design details were highlighted. However, for brevity, this appendix does not set out all possible variations.

8.1 Potential direct policies to support GGR

The following sets out the key messages from our assessment of a list of direct policies. The full description and detailed assessment of each policy are set out in Sections 8.3-8.9. The following is intended to illustrate the landscape of potential policies to support GGR, and the broad strengths and weaknesses of each.

- **A carbon disposal obligation can incentivise efficient and effective deployment of GGRs.** Design can be tailored to encourage particular GGRs (e.g. an early focus on BECCS, but later modification could expand to all GGRs) or provide differential treatment via banding of the incentive (e.g. to compensate early stage options). If used to encourage multiple GGRs, it relies on strong accounting mechanisms such that compliance units from different GGRs are fungible.

- **A BECCs obligation performs similarly to a broader GGR obligation** but the focus on a single GGR limits total negative emission potential of the policy. Furthermore, the obligation will affect a limited group of consumers, creating a more regressive burden.

- **A GGR obligation for supermarkets also performs similarly to a broader GGR obligation** but only covers farm-based GGRs, which includes biochar, soil carbon sequestration and enhanced weathering. Effective implementation would further rely on strong accounting mechanisms and coordination with land-use policies.

- **A fertilizer tax provides a weak incentive for farmers to deploy farm-based GGRs** because the substitutability between farm-based GGRs and fertilizer is low and the level of tax (and hence incentive) that can be realistically levied on farmers is limited. Overall, this policy would only marginally support enhanced weathering or biochar take-up.

- **A carbon tax on fossil fuels in electricity generation provides a weak incentive for BECCS** because of the availability of alternative low carbon generation options. Furthermore, the tax rate required to incentivise BECCS would be significant and appreciably raise consumer electricity bills.

- **Tax credits on GGRs can incentivise efficient and effective deployment of GGRs.** Tax credits rates can be banded to each GGR to compensate for the higher costs of early stage options. However, for large capital cost options such as BECCS and DACCS, a large tax bill is required for the tax offset to be meaningful, restricting the beneficiaries to larger companies.

- **Payment for services for land-based GGRs can be highly effective in incentivising GGR deployment** but remains inefficient because separate biddings for different GGR projects do not encourage optimisation across the available range of GGR options.

- **Inclusion of all GGRs in ETS is likely not practical due to the rigorous accounting required.** Furthermore, low carbon prices in the near term would provide limited incentives for GGR uptake. However, there are opportunities for the inclusion of BECCS and DACCS, for which appropriate accounting could be established and the ETS, particularly in the long term, could provide a useful incentive (potentially with the support of further CfDs).

- **Building standards with timber content is effective in increasing timber usage in construction.** However, its focus on a single GGR limits total negative emission potential of the policy.
- **Incorporating GGRs in soil protection standards is similarly effective in increasing farm-based GGR.** Implementation is both politically and technically challenging due to the significant financial burden on farmers and the costs of monitoring and enforcing the standards. The narrow policy focus on farm-based GGR also limits negative emission potential.
- **Grants for landowners provide some incentives for GGR uptake** by covering some capital costs. It is inefficient because it does not provide incentives for landowners to choose the optimal GGR.
- **Co-investment with private investors provides negligible incentives for GGR uptake** as it does not increase the returns of investing in GGR projects. Nonetheless, it has the advantage over grants and loans of leveraging private capital, which results in a more efficient allocation of resources across GGR projects.
- **CfD instruments for BECCS and DACCS can provide incentives through the removal of market risks.** However, the policy represents financial support for polluters and therefore would receive limited public acceptability.

Table 10 Score overview

	Criteria	Carbon disposal obligation	BECCS obligation	GGR obligation for super-markets	Fertilizer tax	Carbon tax on fossil fuels in electricity generation	Tax credits on GGRs	Payment for services for land-based GGRs	Include GGR in ETS	Building standards with timber content	Incorporate GGRs in soil protection standards	Grants for land owners	Co-investment	CfD for BECCS and DACCS
Effectiveness	Strength of incentive								2020- 2030-					
	Addressable risk													
	Positive track record													
Efficiency	Efficient deployment of GGRs													
	Moral hazard to emission reduction													
Feasibility	Progressive distribution of costs													
	Public acceptability													
	Tractability of accounting								for land-based GGR					
Strategic fit	Complementarity with enabling policy													
	Complementarity with integrating policy													
	Flexibility													

Note: The assessment criteria and the overarching assumptions are explained in Section 8.2. The assessment is performed on a *specific* variant of each policy. The policy design specifications used in each variant are described in detail in Sections 8.3 to 8.9.

Source: Vivid Economics

8.2 Framework for policy assessment

The assessment provides an overview of key aspects of direct GGR policy, but to maintain simplicity not all aspects of GGR policy are assessed. Several high level assumptions are made:

- **We assume that appropriate enabling policies are implemented** to address barriers to GGR take-up beyond those related to a lack of profit incentive and/or financial risk. In particular, we assume the following policies are in place:
  - ◊ *Accounting:* At a minimum, a sufficiently accurate and monitorable proxy for negative emissions is available for the GGRs targeted. Given the importance of accounting for policy to be effective, the policy reliance on accurate accounting is explicitly assessed.
  - ◊ *Innovation policy:* Where there are barriers to innovation beyond a lack of revenue for negative emissions, targeted support for innovation in immature GGRs is provided to progress the technological readiness of GGR options at least up to successful commercial scale demonstration in the UK.
  - ◊ *Supply chain and infrastructure:* Targeted support is provided where there are market barriers (beyond a lack of revenue) which would prevent deployment of required infrastructure.
- **We assume that appropriate integrating policies are implemented** to minimise the wider risks associated with large scale GGR deployment. In particular, we assume:
  - ◊ Environmental risks are mitigated to within acceptable levels.
  - ◊ UK land use allocation for GGR is appropriately balanced against other priorities.
  - ◊ International SDG impacts are minimised.

These high level assumptions are made so that it is possible to focus the assessment on direct policies. This is because some direct policies should not even be implemented if these conditions are not satisfied. For example, if there are no minimum accounting standards for negative emissions from soil carbon sequestration and biochar, it is inappropriate to establish obligations covering them.

In recognition that some direct policies would require stronger support from enabling and integrating policies than others, the assessment framework in Table 11 includes the ease for which the direct policy can be complemented.

The intention of the assessment framework is to provide a basis for easy comparison between direct policies. In recognition that policy effectiveness and other characteristics can vary significantly depending on implementation detail and broader context, the assessment of each direct policy is complemented by:

- Detailed notes on key design features assumed for the policy variant
- A high level timeline for the roll-out of a policy
- Scoring notes to justify assigned scores including, where relevant, notes on the sensitivity of the assessment to policy design detail

8.2.1 Assessment criteria

Table 11 Scoring notes

	Criteria	Criteria definition
Effectiveness	Strength of incentive	Does the policy provide sufficient revenue (or threat of penalties) to incentivise GGR deployment?
	Addressable risk	Does the policy provide sufficient certainty to attract private investment?
	Positive track record	Is there a track record analogous policy incentivising significant deployment in other sectors or countries?
Efficiency	Efficient deployment of GGRs	Does the policy allow for market players to deploy the most efficient (£/tCO_2) GGR option?
	Moral hazard to emission reduction	Does the policy incentivise optimisation across both negative emissions and emissions reductions?
Feasibility	Progressive distribution of costs	Does the policy imply costs fall on those with the greatest ability to pay?
	Public acceptability	Does the policy broadly follow the 'polluter pays' principle? Does the policy involve any contentious elements?
	Tractability of accounting	The degree to which the policy requires accurate and closely monitored and verified accounting practises to be effective.
Strategic fit	Complementarity with enabling policy	Does the policy require extensive enabling policy? Or does the policy help reduce some of the barriers to GGRs (e.g. innovation) enabling policies are designed to overcome?
	Complementarity with integrating policy	Can the policy be easily integrated with wider policy frameworks to: • Maximise wider benefits (e.g. water regulation, amenity value with positive impact on SDGs 6, 11 and 15) • Appropriately allocate land • Integration with international mechanisms (e.g. CDMs) • Avoid environmental risks and wider unintended consequences
	Flexibility	Can the policy be adjusted over time to reflect increasing GGR scale and maturity, allowing support up to scales required to achieve net zero?

Source: Vivid Economics

8.2.2 Scoring notes

Scoring is done as follows, based on the answer to the criteria definition question.

- Black: No, and instrument disqualified on this basis
- Red: No, but can be overcome
- Amber: Likely to be a yes some of the time
- Green: Clear yes most of the time

8.3 Obligations: general design notes

Applied to GGR, an obligation requires market actors (e.g. wholesalers or retailers of food and fossil fuels) to deploy a defined level of a GGR option or face a penalty. The obligated party would pay the initial cost, although this cost can typically be passed onto consumers.

Examples of policy in the UK

- Renewable transport fuel obligation in the UK: An obligation for fuel suppliers supplying over 450,000 litres a year to mix at least 12.4% biofuel into the fuel they supply by 2032 (DfT, 2012).
- UK Renewables obligation (closed as of 31/03/2017).[31] This placed an obligation on electricity suppliers to source a proportion of the electricity they supplied from renewable sources. The policy used renewable obligation certificates (ROC) to demonstrate the obligation was met. Suppliers could trade ROCs.

Key design features

- Scope: The obligation could be applied upstream, e.g. on farmers, or downstream, e.g. a negative emission obligation on supermarkets. This will significantly impact who bears the burden of GGR costs.
- Obligation level and phase-in: A high obligation level can impose significant costs; hence the level of the obligation is typically ratcheted up gradually.
- Combination with certificate scheme: The obligation may be paired with a tradeable certificate scheme to allow the obligated party to pay others to deploy the GGR.

Enabling and integrating policies

- Links with enabling policies
  - ◊ Innovation: Obligations are more effective with incentivising take-up of the cheapest available GGR. Complementary innovation policy will be necessary to allow immature GGRs to be phased into the scheme.[32]
  - ◊ Infrastructure: Policies to support the construction of infrastructure for BECCS and DACCS would help bring these GGR options into the scheme, with these policies covering some of the up-front capex cost, while the obligation (price of certificates) can cover opex.
- Links with integrating policies
  - ◊ A certificate scheme could be limited to certified issuers, with certificates only issued to actors (farmers, etc.) who remove and store CO_2 in accordance with minimal environmental standards.
- GGR for which relevant
  - ◊ An obligation can be used to incentivise all GGRs

[31] More detail available from: https://www.ofgem.gov.uk/environmental-programmes/ro/about-ro

[32] Obligations can also be applied on immature GGRs, but are less effective because of the high costs involved. While tax credits and other forms of subsidies can be provided by the government to directly support research and upfront investments, obligations cannot.

8.3.1 A carbon disposal obligation, with tradeable certificates, on fuel suppliers

Policy detail

- *Scope*: The obligation is placed upstream, i.e. on large fossil fuel wholesalers.[33] They are obligated to 'dispose' of a fixed percentage of CO_2 embedded in the fuel they sell within the UK. This could be extended beyond negative emissions (via GGRs) to also reward CCS.[34]
- *Obligation level*: The obligation level would initially be low, at approximately 5 $MtCO_2$, but is ratcheted up over time. It would eventually be set at near 100% of carbon content of fuel.
- *Certificates*: The obligation can be met through certificates for each tonne of carbon dioxide stored. The certificates would carry equal value between different GGRs. Some simplifying assumptions around GGR permanence would need to be made.
- *Implementation timeline*: limited to mature GGRs like afforestation and BECCS initially, with scope widened as CO_2 certificates can be issued with sufficient credibility for less mature GGRs.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Provided the penalty for violating the obligation and the level of the obligation are high enough, an obligation provides a strong incentive. However, given CCS is included in the obligation, the policy is unlikely[35] to incentivise GGRs more expensive than CCS.
	Addressable risk		Fuel suppliers (the obligated party) typically have large balance sheets and could bear the risk. However, uncertainty over prices of certificates can still deter investment.
	Positive track record		Several successful UK examples of obligations to incentivise renewable deployment.
Efficiency	Efficient deployment of GGRs		Assuming new GGRs are included within the tradeable certificate schemes once they reach maturity, resources should be allocated efficiently.
	Moral hazard to emission reduction		The policy allows the market to trade-off between CCS and GGR and does not provide an opportunity for reduced deployment of mitigation measures.
Feasibility	Progressive distribution of costs		Costs would be divided between fuel suppliers (shareholders) and fuel consumers. There is a regressive effect as increases in fuel prices will disproportionality affect poorer households, although the impact is likely very small.
	Public acceptability		Although this is not a tax directly on consumers, there is pass-through impact on fuel prices. This effect is however limited.[36]
	Tractability of accounting		The scheme would require detailed accounting to enable trade of certificates. The scheme would likely be limited to GGRs for which monitoring is established or relatively easy (afforestation, BECCS and DACCS).

[33] A minimum quantity of fuel supplied can be set to avoid obligating small suppliers who are less able to bare risks and costs
[34] An alternative version of the obligation scheme would be one where negative emissions from different GGRs are *not* equally rewarded. This will involve setting an exchange value across GGRs in line with their relative costs. Such banding can provide a stronger support for GGRs that are less mature hence require stronger incentives to overcome deployment barriers.
[35] Unless the obligation is set so high that it exceeds CCS deployment potential, but this is unlikely to be bearable by fuel suppliers
[36] See discussion on cost pass-through in Section 1.2

	Criteria	Score	Scoring notes
Strategic fit	Complementarity with enabling policy		An obligation scheme can effectively operate as an umbrella policy and source of revenue across GGRs, with additional enabling policies to support GGRs which require further innovation, infrastructure etc.
	Complementarity with integrating policy		Issuance of certificates could be tied to responsible land use, environmental standards etc.
	Flexibility		The obligation level and the GGRs included in the scheme can be adjusted over time to potentially support a GGR pathway required to reach net zero, with certificate banding a strong tool to target development (and cost reduction) of selected GGRs.

8.3.2 A BECCS obligation, with tradeable certificates, on electricity suppliers

Policy detail

- *Scope*: Like the renewable obligation scheme, electricity suppliers are obligated to purchase a % of the electricity they supply from BECCS power stations.
- *Obligation level*: The obligation levels would initially be low, at approximately 5 $MtCO_2$ to incentivise the first BECCS station but is ratcheted up over time. It would eventually be set at a level equivalent to roughly 50 $MtCO_2$.
- *Accounting*: The obligation can be met through CO_2 certificates of carbon stored.
- *Implementation timeline*: This scheme could be implemented immediately.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Provided the penalty for violating the obligation and the level of the obligation are high enough, this would strongly incentivise BECCS.
	Addressable risk		Would place a significant financial burden on electricity suppliers, who typically are less able to bear risk than fuel suppliers.
	Positive track record		Several successful UK examples of obligations to incentivise renewable deployment.
Efficiency	Efficient deployment of GGRs		Narrowly focusses on BECCS but should ensure efficient allocation of resource within BECCS deployment.
	Moral hazard to emission reduction		Narrowly focusses on BECCS and hence no risk of moral hazard.
Feasibility	Progressive distribution of costs		Places the costs of BECCS primarily on electricity consumers.
	Public acceptability		Although this is not a tax directly on consumers, the pass-through impact on electricity prices could be noticed by the public.

	Criteria	Score	Scoring notes
	Tractability of accounting		CO_2 certificates would be tied directly to CO_2 stored, which is easily measurable. Difficulties in forestry carbon accounting are addressed in latest UNFCCC guidelines.
Strategic fit	Complementarity with enabling policy		A narrowly focussed obligation such as this would likely require less enabling policy, as the certificate price for BECCS would be relatively high.
	Complementarity with integrating policy		Issuance of certificates could be tied to responsible land use, environmental standards etc.
	Flexibility		This policy could potentially be used to incentivise a significant scale of BECCS deployment, but unlikely to be used beyond BECCS as this would involve obligating the power sector to bear the cost of negative emissions to offset emissions from other sectors.

8.3.3 A GGR obligation on supermarkets

Policy detail

- *Scope*: Supermarkets could be obligated to purchase a percentage of their produce from accredited farmers, who apply GGR techniques on their land. This is done through GGR certificates, purchased from farmers.
- *Certificates*: The GGR certificates would be awarded to farmers based on verified application of GGR options. The prices would reflect the demand from supermarkets as well as the costs of deploying GGR.
- *Implementation timeline*: This scheme could be implemented immediately.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Provided the penalty for violating the obligation and the level of the obligation are high enough, the price of GGR certificates could provide sufficient incentives for farmers to deploy land-based GGRs.
	Addressable risk		Farmers face limited risks as the obligation provides certainty on the level of GGR deployed.
	Positive track record		There are no analogous policies relating to agriculture. Nonetheless, obligations on supermarkets to incentivize waste packaging recycling in the UK has been successful.
Efficiency	Efficient deployment of GGRs		Self-selection of farmers in deciding whether to get accredited for GGR ensures cost-efficiency of projects. However, there will not be optimization across other GGRs.
	Moral hazard to emission reduction		The policy has no impact on incentives to reduce emissions.
Feasibility	Progressive distribution of costs		Supermarkets would face the cost of GGR deployment but are likely to pass it onto consumers.

	Criteria	Score	Scoring notes
	Public acceptability		It would not be clear to the public why supermarkets are responsible for funding GGR deployment.
	Tractability of accounting		It is costly to monitor and verify land-based GGR. The administrative burden would likely be significant.
Strategic fit	Complementarity with enabling policy		A narrowly focussed obligation such as this would likely require less enabling policy
	Complementarity with integrating policy		Potentially synergies with wider efforts to reduce fertilizer use.
	Flexibility		The policy can only be used to incentivise a limited set of GGRs.

8.4 Taxes: general design notes

Taxes are a mandatory charge levied by government, for which there is a penalty for non-payment. A direct tax is collected by government and an indirect tax is collected by a third party. The government would not have to provide any funding and the cost would be borne by the sectors that are taxed. However, these sectors might pass on the cost of the tax to consumers.

Examples of policy in the UK

- Carbon Price Support (UK – a tax on fossil fuels used in electricity generation)
- Fuel Duty (UK - a tax on petrol and diesel; fuels with lower emissions are taxed at lower rates)

Key design features

- Scope and tax rate: The government can levy taxes either economy-wide or on specific sectors and sets the rate of tax.
- Revenue recycling (optional): Depending on the amount of revenue raised, the government can reinvest this revenue to support other GGRs.
- Compensation: Taxes can be regressive and can produce distributive consequences that can be offset through compensation (potentially using the tax revenues) or tax exemption (Policy Exchange, 2018). The latter can also be a policy to incentivise GGRs, which we address under subsidies.

Enabling and integrating policies

- Links with enabling policies
    - ◊ Innovation: Taxes are unlikely to incentivise significant innovation in GGR and would need to be complemented by significant innovation policy to make GGR options a viable substitute for the taxed activity (and hence incentivise deployment of GGR).
    - ◊ Infrastructure: Policies to support the construction of infrastructure for e.g. BECCS and DACCS would be required as the payback time of a reduced tax burden is lengthy and hence typically insufficient to justify large capital investments.
- Links with integrating policies

  - ◊ Taxes can potentially help achieve wider policy objectives and incentivise (some) GGR take up by encouraging substitution from e.g. fossil fuels to biomass (for BECCS) in power generation.
- GGR for which relevant
  - ◊ A tax can only incentivise GGR where 1) there is a significant revenue stream to tax, and 2) GGR provides a viable route for the taxed actor to reduce the tax liability. Opportunities for this are likely primarily related to BECCS, CCU and low carbon concrete.

8.4.1 Fertilizer tax to support biochar and enhanced weathering

A tax could be applied to traditional fertilizers to incentivise GGR methods that improve soils such as biochar and enhanced weathering. Adding biochar to soils can increase its fertility and adding minerals to the soil in weathering can increase nutrient levels, boosting crop yields.

Policy detail

- *Scope and tax rate*: The tax would be on traditional fertilizer and could likely not be higher than 100% to avoid excessive costs for farmers.
- *Revenue recycling (optional)*: The revenue could be recycled to fund GGR subsidies by government.
- *Compensation*: None.
- *Implementation timeline*: The tax could be implemented once biochar and enhanced weathering are deemed commercially mature, likely by around 2025.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		The substitutability between biochar/enhanced weathering is likely to be too low to incentivise meaningful take up. The main effect would likely be a reduction in fertilizer use.
	Addressable risk		The tax rate is purposefully limited to a level that would not significantly increase production costs for farmers.
	Positive track record		Typically changes to subsidy levels, rather than taxes have been used to incentivise farmer behaviour.
Efficiency	Efficient deployment of GGRs		Does not encourage optimisation across GGRs, nor does it ensure that the recycled revenue raised is targeted at the most cost efficient land-based GGR schemes.
	Moral hazard to emission reduction		Does not reduce incentive for emission reductions.
Feasibility	Progressive distribution of costs		Places an additional cost on farmers, which disproportionality affects smallholders.
	Public acceptability		Likely highly contentious in farming sector.

	Criteria	Score	Scoring notes
	Tractability of accounting		A tax on fertilizers would not require accurate accounting and monitoring of CO_2 removed through GGR measures. This also means that it is difficult to evaluate the actual effect on carbon abatement.
Strategic fit	Complementarity with enabling policy		This tax will not meaningfully drive innovation in enhanced weathering or biochar and puts the onus on enabling policy to do so.
	Complementarity with integrating policy		Potentially synergies with wider efforts to reduce fertilizer use.
	Flexibility		The policy can only be used to incentivise a limited set of GGRs and will likely only support minimal take-up.

8.4.2 Increasing the carbon tax on fossil fuels used in electricity generation to support BECCS

A carbon tax on fossil fuels could be introduced to drive support for BECCS. The carbon tax could be part of an economy-wide carbon tax (levied on emissions, or 'upstream' on carbon content of fuels) or be focussed on the electricity sector.

Policy detail

- *Scope and tax rate*: The tax would be on carbon content of fossil fuels used in electricity generation, and would have to be set significantly above the current carbon price floor to incentivise BECCS
- *Compensation*: None.
- *Implementation timeline:* The tax would be slowly ramped up from the current price floor and reach a level sufficient to incentivise BECCS once an initial demonstration plant and some of the required infrastructure for CO_2 transport and storage is available.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Assuming the tax is set sufficiently high, this incentivises BECCS but also wider low carbon alternatives, and hence may not spur significant BECCS deployment.
	Addressable risk		This would place a significant additional cost on generators in the UK.
	Positive track record		Limited track record of strong taxation used to drive a specific technology (while other alternatives are available).
Efficiency	Efficient deployment of GGRs		Generators will self-select into the most cost-efficient methods to avoid the fossil fuel tax, such that the generators who end up adopting BECCS will be those who are most efficient at it. However, there will not be optimization across other GGRs.
	Moral hazard to emission reduction		Strongly incentivises emissions reductions.

	Criteria	Score	Scoring notes
Feasibility	Progressive distribution of costs		Imposes significant costs on electricity suppliers which will feed through to consumers regressively.
	Public acceptability		The impact on electricity bills will likely be contentious.
	Tractability of accounting		Carbon content of fuel burned is relatively easy to monitor and tax.
Strategic fit	Complementarity with enabling policy		This tax will not meaningfully drive innovation in BECCS and puts the onus on enabling policy to do so. Furthermore, capital investment would need to be supplied by government.
	Complementarity with integrating policy		Potential synergies with wider efforts to decarbonise power sector, although would require wider policy to ensure bioenergy for BECCS is responsibly sourced.
	Flexibility		Only incentivises BECCS and likely to a limited level given availability of other low carbon generation technologies.

8.5 Subsidies: general design notes

Subsidies are payments made by government or a public body to help an industry or business recover costs and thereby keep the price of a commodity or service low. They are usually in the form of a cash payment from a fund or a tax reduction. In the context of GGRs, this could be a payment for each tonne of CO_2 stored, or for another service provided (e.g. the electricity generated from BECCS). Subsidies can be provided through a range of different delivery mechanisms – auctions, or a payment for services, or tax offsets. In the case of tax offsets, for the incentive to be high enough for the private sector to invest, the tax credit would need to be set at or above the cost of implementing GGRs.

Subsidies compete with other uses of public funds and can be difficult to sustain. To minimise issues associated with the use of public spending, funds could be raised through an alternative mechanism such as the issuance of bonds (‘negative emissions bonds’) or a new levy.

Examples of policy in the UK

- Capital allowances for energy-efficient, low- or zero-carbon technology for businesses[37]
- Rural Payments Scheme[38]

Key design features

- A range of delivery mechanisms: A variety of delivery mechanisms for subsidies are possible, including tax offsets, auctions for a limited pot of funds or a demand-led mechanism that pays for services (for GGRs, that service could be £/tonne of CO2 abated). If delivered through a contracting mechanism, subsidies have the benefit of offering certainty and stability over revenues to investors, which can reduce the cost of capital.

[37] https://www.gov.uk/guidance/energy-technology-list#enhanced-capital-allowance-eca-scheme
[38] https://www.gov.uk/government/collections/common-agricultural-policy-reform

- Size and scope: The size and duration of the funding provided through subsidies can be determined by government or a public body, providing a high level of control.
- Technology neutral or technology specific: Individual technologies can be offered subsidies at differential rates, allowing the ability to incentivise different options.
- Flexibility over who pays: While subsidies are sourced from a funding pot managed by government or a public body, the funds can be raised through a levy on business or consumers, or a mix.

Enabling and integrating policies

- Links with enabling policies
  - ◊ Innovation: subsidies for GGR deployment would rely on innovation policies that ensure technological readiness of GGR options
  - ◊ Infrastructure: policies to support large scale infrastructure, such as for BECCS and DACCS, would likely be required to enable
- Links with integrating policies
  - ◊ Subsidies for land-based GGR would require careful coordination with broader land use policies due to competition for land.
- GGR for which relevant
  - ◊ Subsidies are most applicable to GGRs that face deployment and/or financing barriers. GGRs with medium or high deployment barriers are biochar, BECCS, enhanced weathering, CCU, DACCS and low-carbon concrete.

8.5.1 Tax credits for a range of GGRs

Tax credits provide reductions in the tax liability of a tax payer for fulfilling defined criteria. Credits can be provided for carbon abatement but also for capital investment. An example of this is the US federal 45Q tax credit, which provides a credit to power plants and industrial facilities that capture and store CO_2 that would otherwise be emitted into the atmosphere.[39]

Policy detail

- *Scope*: Tax credits on both carbon abatement and capital investments in CCS
- *Tax credit rates*: The tax credit on carbon abatement would be set high enough to support opex, which is to close the cost gap between the cost of capturing, compressing, and transporting CO_2 and the price of delivered CO_2.[40] The tax credits are banded to reflect the costs of different technologies.[41]Whereas the tax credit on capital investments would be targeted at supporting capex.

[39] CO_2 used for saline storage would receive $50 per tonne of CO_2 stored while utilisation in products, including EOR, would receive only $35 per tonne of CO_2. Saline storage earns a higher $/tonne CO_2 storage credit than utilisation. https://www.catf.us/wp-content/uploads/2017/12/CATF_FactSheet_45QCarbonCaptureIncentives.pdf
[40] Recent report from the US government suggests a range of $23-38/Mt. More details https://www.energy.gov/sites/prod/files/2017/01/f34/Workshop%20Report--Siting%20and%20Regulating%20Carbon%20Capture%2C%20Utilization%20and%20Storage%20Infrastructure.pdf
[41] For example, carbon storage in saline reservoirs are more expensive than in EORs, thus require a higher tax credit to incentivize its adoption.

- *Accounting*: tax credits would be tied to CO2 certificates, issued according to the amount of carbon stored.
- *Implementation timeline*: the tax credit can be phased in once the supporting infrastructure is in place, most critically a network of CO_2 pipelines and a mature system of CCS facilities

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Under the assumption of a sufficiently high tax credit rate for carbon abatement and capital investment in CCS facilities, tax credits can be effective in providing incentives. For large capital cost options (BECCS and DACCS) a very large tax bill is needed for the tax offset to be meaningful; this may restrict the number of companies to which the tax offset can be effective.
	Addressable risk		Tax credits create policy risks as they can be easily retracted.
	Positive track record		In the US, the 45Q tax credit for carbon storage is expected to support investments in CCS after its latest revision. In a broader context, tax credits have also been effective in stimulating private investment.
Efficiency	Efficient deployment of GGRs		Efficient across technologies within the same band of tax credit as market players have incentives to sequester carbon in the most efficient way possible. However, there is no optimisation in allocating resources to different GGR methods.
	Moral hazard to emission reduction		Does not reduce the incentives to cut emissions.
Feasibility	Progressive distribution of costs		The costs on government funds are ultimately distributed progressively across the tax base.
	Public acceptability		Publicly acceptable as tax credits do not have carry the stigma of explicit subsidy mechanisms.
	Tractability of accounting		CO_2 certificates would be tied directly to CO_2 stored, which is relatively measurable given a policy focus on BECCS and DACCS.
Strategic fit	Complementarity with enabling policy		Can complement broader industrial strategy to encourage the development and deployment of CCS infrastructure.
	Complementarity with integrating policy		Issuance of certificates could be tied to rules on responsible land use, environmental standards etc.
	Flexibility		Relative to explicit subsidies, the level of tax credits can be adjusted with relatively less public scrutiny.

8.5.2 Payment for services for land-based GGR

Payment schemes for GGR have been used widely for afforestation schemes, such as in the Emissions Reductions Fund in Australia. The size of the scheme would be on a similar scale as the Common Agricultural Policy, but payments would be tied to agricultural practices as opposed to land size so as to provide incentives. Complementary policies to account for and verify emissions reductions are essential.

Policy detail

- *Scope*: subsidies to land-owners based on the scale of the GGR projects, covering forestation, habitat restoration, soil carbon sequestration, biochar and enhanced weathering
- *Contracting mechanism*: landowners register with the government and submit proposals to bid for contracts.
- *Accounting*: A monitoring mechanism would be in place to verify the projects and its outcomes
- *Implementation timeline*: the payment scheme can be enacted immediately, starting with projects featuring relatively established GGR methods such as forestation, and expand to biochar and enhanced weathering once they are deemed commercially mature

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Assuming an appropriate payment structure, the scheme would provide strong incentives to undertake GGR.
	Addressable risk		The policy does not create additional risks if the payments to landowners are based on appropriate contracts.
	Positive track record		Payment schemes for afforestation are well established internationally. However, past experience suggests that a well-defined land strategy is required.
Efficiency	Efficient deployment of GGRs		Competitive bidding for contracts ensures cost effectiveness deployment of GGRs. However, there is no optimisation in allocating resources to different GGR methods.
	Moral hazard to emission reduction		Does not reduce the incentives to cut emissions.
Feasibility	Progressive distribution of costs		The costs on government funds are ultimately distributed progressively across the tax base.
	Public acceptability		The idea of paying for public goods is generally well received by the public, although some in the agricultural sector may be concerned about future returns. The issue would however be more contentious in the forestry sector where landowners could be concerned about effects on land value.
	Tractability of accounting		The burden of proof falls on project developers. No costly inspections are required.
Strategic fit	Complementarity with enabling policy		Would require enabling policies to support innovation on biochar and enhanced weathering.
	Complementarity with integrating policy		This payment could be introduced in the Agricultural Bill currently passing through the UK Parliament, which includes provisions for payment for public goods which include services that GGR provides, such as improved soil quality and biodiversity (Defra, 2018b).
	Flexibility		Due to the competition for public funds, adjusting the level of payments could be a divisive issue. This limits policy flexibility.

8.6 Cap and Trade: general design notes

A cap and trade scheme limit total emissions across several sectors/activities, which typically include power, steel, cement and refining. Under the scheme, emitters must hold tradeable certificates (allowances) equal to the number of tonnes of CO_2 they emit. Emitters can trade these allowances, which creates an incentive to reduce emissions and sell surplus allowances. The price of these certificates is determined through supply and demand in a market for allowances, and thus indirectly by the cap set by government.

Examples of policy internationally

- *EU* Emissions Trading System (EU ETS)[42]: This is largest and most well-established cap and trade scheme in the world. It covers power and heat generation, energy-intensive industries and aviation. Allowances are actioned off, although some free allowances are allocated to limit carbon leakage. The price of allowances currently stands at around £20/tCO_2 and the overall emissions cap is ratcheted down annually.[43] The UK is currently part of the scheme, although future participation is uncertain. Notably, some of the proceeds from allowance auctions have been used to fund innovative low-carbon technologies, such as CCS through NER 300.[44]

- New Zealand Emissions Trading System (NZ ETS): This began operation in 2008 and continues to serve as a principal element of New Zealand's policy response to climate change. It covers the forestry, stationary energy (electricity and heat), transport, industrial processes, synthetic GHGs and waste sectors. Biological emissions from agriculture (animal production and nitrogen fertilizers) carry reporting obligations only. For fishing and forestry, the government provided one-off free allocations to compensate for the loss of asset value resulting from the NZ ETS for fishing and forestry. Some participants in the NZ ETS are given units for greenhouse gas removals. Participants must surrender units for every tonne of CO_2 emitted or can buy an additional NZU from the government.[45]

Key design features

- *Scope*: The sectors included within the ETS. To provide support to land-based GGR options, agriculture and forestry would have to be included.

- *Accounting*: 'Negative emission certificates' or similar would need to be created, with an established conversion factor to standard allowances.

- *Revenue recycling (optional)*: The proceeds of allowance auctions can be used to support the development of low-carbon technologies as is done with the NER 300. A similar scheme could be setup to support GGR development.

- *Allowance allocation*: A key question with an ETS is the allocation of free allowances (if any). This is a tool to alleviate competitive impacts and reduce the costs on a sector but can distort the price of certificates significantly.

Enabling and integrating policies

- *Links with enabling policies*

  - ◊ Similar to obligations, cap and trade policies are more effective with incentivising take-up of the cheapest available GGR. Complementary innovation policy will be necessary to allow immature GGRs to be phased into the scheme.

[42] More information available from: https://ec.europa.eu/clima/policies/ets_en
[43] See https://sandbag.org.uk/carbon-price-viewer/
[44] More information on NER 300 available from: https://ec.europa.eu/clima/policies/lowcarbon/ner300_en
[45] See http://www.mfe.govt.nz/climate-change/new-zealand-emissions-trading-scheme/about-nz-ets

- *Links with integrating policies*
  - There is a clear potential for further integration with other ETS to capture efficiency gains, although this would face substantial technical difficulty.
- *GGR for which relevant*
  - A wide range of GGRs are compatible with the policy, as long as units of carbon can be accounted accurately.

8.6.1 Inclusion of GGR in ETS

Negative emissions could be included into the EU ETS (or UK equivalent). This can be achieved by creating negative emission certificates which can be exchanged against allowances. The activities which qualify for negative emissions can be defined broadly to support a wide range of GGRs. Alternatively, a narrower range of GGRs may be included by only making negative emission certificates available to, for example, BECCS or forestry. A challenge of including negative emissions in an ETS is that the permanence of emissions reductions from GGR options may be different to other abatement options, so there is no scientific equivalence between 1 tonne abated from GGRs and 1 tonne abated, for example, in the power sector.

Box 10 BECCS and DACCS in an ETS

1. Rigorous accounting methods can likely be established for BECCS and DACCS. Both are calculable at point of storage and involve the power and industry sectors, which are used to detailed MRV processes for their existing emissions. As discussed in Section 5.1.1, the permanence of storage is likely the greatest challenge.
2. Based on EU ETS price projections, the EU ETS – together with current UK Government price incentives - is a price mechanism in the right range to support BECCS. An inclusion of BECCS and DACCS into today's ETS would provide a long term signal to the market that government is serious about providing a price for sequestered carbon.
3. Inclusion of BECCS and DACCS in the ETS could provide a base for more advanced policy support options, as discussed in Section 4.2.

Policy details

- *Scope:* A wide range of GGRs would be included into the scheme as they become mature. Sectoral coverage could be a contentious issue, but for this assessment we assume coverage of forestry, agriculture, industry and power sector.
- *Certificates*: The obligation can be met through CO2 certificates of carbon stored. The CO2 certificates would be equal value between different GGRs. Some simplifying assumptions around GGR permanence would need to be made. Note, for the assessment we assume equal value of certificates, but certificates could be banded to support specific GGRs.
- *Implementation timeline*: The policy could be enacted immediately once a certification system is in place.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Carbon prices in the near term (£20/tCO_2) are far too low to provide sufficient incentives for GGR deployment. Only from 2030 onwards, as carbon prices are expected reach £100/tCO_2, incentives would become more relevant.
	Addressable risk		Fluctuation in carbon prices would be limited given substantial market liquidity for ETS.
	Positive track record		Past experience suggests that integrating forest carbon while maintaining price stability is difficult.
Efficiency	Efficient deployment of GGRs		The broad scope of the ETS ensures negative emissions and emission reductions are undertaken where they are least-cost. Assuming new GGRs are included within the ETS once they reach maturity, resources should be allocated efficiently.
	Moral hazard to emission reduction		To avoid a reduction in incentives to reduce emissions, the ETS cap has to be adjusted to reflect the inclusion of negative emission certificates. This would be difficult in practice.
Feasibility	Progressive distribution of costs		Inclusion of GGR options within the ETS could be achieved without imposing significant costs on any party. The distribution of costs can also be managed effectively through the allocation of allowances.
	Public acceptability		The policy design would involve some contentious issues, such as sectoral coverage and the setting of the overall cap.
	Tractability of accounting	For land-based GGR	The scheme would require rigorous accounting to enable trade of certificates. Uncertainty over the actual amount of carbon abated through land-based GGR could erode trust in the certificates, damaging the ETS system.[46]
Strategic fit	Complementarity with enabling policy		The price of certificates can only cover opex and thus require additional innovation policies to encourage high capex projects. Reliable accounting mechanisms need to be in place for actual implementation.
	Complementarity with integrating policy		Integration with international mechanisms (i.e. other ETS) is possible although technical difficulties exist.
	Flexibility		The cap of the ETS can be adjusted periodically in response to changes in policy ambition. However, there would be technical challenges in trying to include more sectors and more GGR types.

[46] This assessment assumes that all GGRs are to be included in the ETS. In the case where land-based GGRs with unreliable accounting standards are ruled out, the policy can become more feasible.

8.7 Standards: general design notes

Standards require a minimum performance level to be achieved. This could be in the form of safety or quality standards on products, buildings standards, emissions or efficiency standards for engines, or environmental standards on, for example, water and soil quality. Standards are typically put in place to ensure a level playing field in a market, as competitors cannot undercut each other by dropping below the standard.

Examples of policy in the UK

- Emissions performance standard (EPS)[47]: This sets a maximum emissions level (450g/kWh) for all new-build power plants in the UK.
- EU mandatory emission reduction targets[48]: These set maximum emissions level for the gCO_2/km for the fleet average produced by a manufacturer.
- Soil protection standards[49]: These set requirements on farming practices to minimise soil erosion etc. with financial penalties if inspectors report non-compliance

Key design features

- *Penalty level*: The penalty associated with a standard is key to determining its impact. If a fine, its level effectively acts as a carbon price in the case of GGR, which if low, may mean market actors elect to pay the fine rather than meet the standard. Other options include market exclusion through, for example, refused permits.
- *Phase-in period*: Imposing a stringent standard can be a significant shock to a market. Consequently, standards are typically phased in gradually to allow the market to adapt.

Enabling and integrating policies

- Links with enabling policies
  - ◊ Innovation: standards to deploy GGR are ineffective in promoting technological innovation. Additional innovation policy is necessary to enable immature technologies to develop.
  - ◊ Infrastructure: standards are only feasible if widespread infrastructure is in place to support GGR deployment. Standards requirements should avoid GGRs that lack existing infrastructure, e.g. in BECCS and DACCS, which would be too costly for businesses to adopt.
- Links with integrating policies
  - ◊ Standards should be embedded in broader legislation around land use, agriculture and forestry to ensure policy alignment.
- GGR for which relevant
  - ◊ Standards are most applicable on GGRs that are relatively straightforward for businesses to adopt, i.e. not capital intensive. These would focus on building with biomass and a range of soil protection techniques.

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[47] More detail available here: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48375/5350-emr-annex-d--update-on-the-emissions-performance-s.pdf
[48] More detail available here: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en
[49] More details available here: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/397046/CCSoilPS_2015_v1_WEB.pdf

8.7.1 Building standards incorporate timber content requirements

Note: the below could equivalently be applied to the use of low-carbon concrete

Akin to existing energy efficiency requirements for buildings, minimum standards can be set defining the amount of biomass/timber that must be used within new builds.

Policy detail

- *Scope*: Requirements on timber content set on all new builds.
- *Penalty level*: Can be either financial or regulatory (i.e. embedded in the license to operate), severe enough to ensure widespread compliance.
- *Implementation timeline*: This scheme could be implemented immediately, gradually ramping up stringency of requirements.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Provided the penalty for violating the standards is high enough, this would provide a strong incentive.
	Addressable risk		The cost of transition to building with more timber has been considered negligible.[50] However, future shortages of wood supply would be a risk if standards are ramped up too quickly.
	Positive track record		Building standards is an established policy tool that has been effective in contexts such as fire safety and energy efficiency.
Efficiency	Efficient deployment of GGRs		The standards do not encourage optimisation across GGRs.
	Moral hazard to emission reduction		Requirements on timber content alone do not affect incentives to reduce emissions. However, care needs to be taken to prevent interference with e.g. "net-zero building standards", such that the use of wood substitutes other low carbon building methods.
Feasibility	Progressive distribution of costs		Smaller construction companies would face relatively greater difficulty to respond to changes in building requirements.
	Public acceptability		There could be some unease amongst the public regarding the fire safety of timber framed buildings.
	Tractability of accounting		Established mechanisms to record the use of timber in construction projects make monitoring relatively easy.
Strategic fit	Complementarity with enabling policy		Establishing the building standards do not require enabling policies because construction with timber is a well-established method.
	Complementarity with integrating policy		There are complementarities with wider afforestation targets. However, the demand for land does create competition with other uses which would create further policy challenges.

[50] Royal Society 2018 report on GGR

	Criteria	Score	Scoring notes
	Flexibility		Timber content requirements can be escalated gradually as the construction sector adapts to the standards. However, shortages in wood would be problematic in the future.

8.7.2 GGR options are incorporated in soil protection standards

Management of, and increases to, the soil carbon content could be integrated into wider soil protection standards. For soil carbon sequestration, biochar and enhanced weathering, standards could be set that enforce implementation, although effective monitoring will be required. For soil carbon sequestration, practices like current checks for erosion management can be implemented. For biochar and enhanced weathering, soil samples may need to be taken.

Policy design details

- *Scope:* landowners face a set of requirements on soil carbon sequestration, biochar and enhanced weathering. The assessment assumes that no financial support is provided to aid this transition.
- Accounting and enforcement: checks on land management practices and soil quality would be conducted, with penalties on landowners who do not meet the standards
- Implementation timeline: the standards will initially cover soil carbon sequestration, and can be ramped up to include biochar and enhanced weathering when the technology matures

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Provided the penalty for violating the standards is high enough, this would provide a strong incentive.
	Addressable risk		This would impose significant costs on farmers.
	Positive track record		There is a wide range of existing standards around land use, with mixed results in their enforcement.
Efficiency	Efficient deployment of GGRs		The standards do not encourage optimisation across GGRs.
	Moral hazard to emission reduction		The standards would not affect existing incentives to reduce emissions.
Feasibility	Progressive distribution of costs		The standards would impose significant costs on farmers.
	Public acceptability		Soil protection is viewed positively amongst the public. However, farmers would likely be resistant to change.
	Tractability of accounting		Enforcement of soil protection standards likely require costly monitoring mechanisms.
Strategic fit	Complementarity with enabling policy		There are significant financial barriers for farmers to deploy GGRs and would require other targeted support to lower the costs of e.g. biochar and enhanced weathering.

	Criteria	Score	Scoring notes
	Complementarity with integrating policy		Potential synergies with the environmental land management scheme
	Flexibility		Soil protection standards can be escalated gradually as GGRs mature.

8.8 Finance provision: general design notes

Investors' lack of information regarding the performance of GGRs in the field, and lack of familiarity with the contracting and policy arrangements that enable these technologies can increase the cost or even prevent the flow of finance. This is particularly the case when GGR options are at a relatively early stage, and over time, as the options become better understood by the private sector, risks reduce, and the private sector becomes able to support these projects. While finance is in limited supply or high-cost, government intervention can help address the finance gap through one of two ways:

Direct provision of finance: This can lower costs as the government can borrow more cheaply than the private sector.

Socialising risk: Risk reduction is possible as the government is well placed to take on greater risks than the private sector due it its comparatively large balance sheet. Options for de-risking are addressed in the following section.

Some measures do achieve both these objectives, as when government invests this can reveal information to private investors that the project is credible and worth investing in, enabling them to provide finance at lower cost.

The division between finance provision and risk-reduction measures is not always clear. For example, by providing a steady stream of revenue, CfDs remove price risk from private actors, but they are also the primary mechanism for delivering projects. Similarly, if equity is provided through a government institution, there is some evidence to suggest that this also de-risks the investment.

- *Enabling and integrating policies*
- Links with enabling policies
  - ◊ The provision of government finance towards GGR projects do not help improve the returns on GGR projects. A range of enabling policies in innovation, infrastructure and accounting, must therefore be implemented to support respective GGRs, depending on the maturity of technologies.
- Links with integrating policies
  - ◊ Finance provision for GGRs can be integrated within a wider range of government funding support for low carbon projects, such as the Clean Growth Fund.
- GGR for which relevant
  - ◊ Finance provision is most applicable where credit constraints are relevant, for example in deploying BECCS and DACCS at scale in industries, and altering land use for land-based GGRs.

8.8.1 Targeted grants for farmers and land managers to deploy GGR

Like the One Billion Trees Fund in New Zealand, direct landowner grants could be provided to reduce the barriers to tree planting, enhanced weathering and biochar. Grants could be differentiated according to the type and application of GGR and whether it achieves other objectives (e.g. the One Billion Trees Fund has different rates for indigenous species and introduced species). This policy is different to the grants measures discussed under "innovation" in that it is targeted at overcoming deployment and financing barriers, rather than innovation barriers.

Policy design details

- *Scope*: grants and loans are offered to projects for afforestation, enhanced weathering and biochar.
- *Allocation:* a stringent criterion is applied to assess projects such that the grants and loans are allocated to a selective group of cost-efficient farmers and land managers, with funding sizes that are just large enough to incentivize the alteration of land use and deployment of GGRs
- *Implementation timeline:* This scheme could be implemented immediately.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		The grants can provide incentives to deploying GGRs to the extent that they cover some upfront capital costs.
	Addressable risk		The grants would not place any financial burden on businesses.
	Positive track record		Incentives for afforestation in Scotland in the 1980s created unintended consequences on forestry.
Efficiency	Efficient deployment of GGRs		Does not encourage optimisation across GGRs.
	Moral hazard to emission reduction		Does not reduce the incentives to cut emissions.
Feasibility	Progressive distribution of costs		Offering such grants and loans reduces the revenues of the government. The costs are ultimately distributed progressively across the tax base.
	Public acceptability		Grants and loans could be favoured by special interests, increasing their feasibility. However, grants and loans compete with other demands on public finances and could be perceived as a poor use of government resources.
	Tractability of accounting		The burden of proof falls on project developers. No costly inspections are required.
Strategic fit	Complementarity with enabling policy		Does not require significant enabling policy.

	Criteria	Score	Scoring notes
	Complementarity with integrating policy		Grants and loans can sit alongside other deployment measures and are unlikely to cause unintended consequences in their interactions with these policies
	Flexibility		As the provision of grants and loans are associated with the government budget, flexibility in adjusting policy ambition would be limited.

8.8.2 Provision of co-investment equity e.g. BECCS and DACCS

This option is the provision of equity support, with the objective of crowding in further private investment. This approach could be delivered through a public or public-private institution or directly from HMT.

Policy design details

- *Scope:* Co-investment would focus in high capex ventures, or emerging technologies (i.e. high market risk), such as BECCS and DACCS
- *Implementation timeline:* This scheme could be implemented immediately.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Co-investment does not provide any revenue support for deploying GGR projects.
	Addressable risk		Co-investing with the government limits the risks faced by private investors.
	Positive track record		Projects that might otherwise not secure finance, or secure it at high cost, have been shown to proceed due to government equity provision, such as from the Green Investment Bank.
Efficiency	Efficient deployment of GGRs		Co-investment can be very efficient due to its ability to leverage private finance
	Moral hazard to emission reduction		Does not reduce incentive for emission reductions.
Feasibility	Progressive distribution of costs		The costs are borne by the general tax base.
	Public acceptability		Private finance providers can perceive government involvement in financial markets as crowding out their business. The burden on public finances could also be perceived as a poor use of government resources.
	Tractability of accounting		The burden of proof falls on project developers. No costly inspections are required.

	Criteria	Score	Scoring notes
Strategic fit	Complementarity with enabling policy		Does not require significant enabling policy
	Complementarity with integrating policy		Given that the Green Investment Bank (GIB) has recently been privatised there may be little appetite for a new institution; however, there are departmental routes to delivering this finance. There may be the opportunity to use the Green Investment Group (GIG) as a delivery mechanism for these activities.
	Flexibility		As the provision of funds for equity investments are associated with the government budget, flexibility in adjusting policy ambition would be limited.

8.9 De-risking: general design notes

As described above, there are two broad financial interventions: provision of finance and de-risking. From the perspective of government, a de-risking strategy (through CfDs) is likely to be preferable to a finance provision strategy (such as co-investment equity) as the latter requires greater resources. However, for high capex and less mature infrastructure, both de-risking and finance provision may be required to crowd in private finance.

Examples of policy in the UK

- Green Investment Bank: The GIB was created by the UK Government, its sole shareholder. It provided £3.4m of primarily equity financing from 2012 to 2017, focussed on projects that contributed to the UK Government's environmental and sustainability targets. The GIB, a government body that is now privately owned (the GIG), is a for-profit bank; however, it can provide finance to early stage technologies to a greater degree than the private sector would, and crowd in private finance by signalling its support for technology areas.[51] Sectors the original GIB was particularly active in include offshore wind and waste.

- UK Guarantee scheme: The UKGS supports private investment through a government-backed guarantee to help projects access debt finance. The scheme can issue up to £40 billion of guarantees and is open until (at least) 2026.The scheme has been used for a wide range of projects including the energy sector, transport infrastructure and education.

Enabling and integrating policies

- Links with enabling policies
    - ◊ Although CfDs reduce the risks in deploying GGR, they do not improve the returns on GGR projects. A range of enabling policies in innovation, infrastructure and accounting, must therefore be implemented to support respective GGRs, depending on the maturity of technologies.
- Links with integrating policies

[51] https://www.nic.org.uk/wp-content/uploads/Vivid-Economics-Final-report-Analysis-of-EIB-and-GIB-projects-050718.pdf

- ◊ The contracting mechanism can interact with existing CfD policies in the power sector, and be embedded within broader policies on research and innovation.

- GGR for which relevant
  - ◊ CfDs are more applicable for early stage and high capex options, such as BECCS and DACCS.

8.9.1 Government CfD instrument for BECCS and DACCS

Like the Contracts-for-Difference scheme for renewables in the UK, long-term contracts could be offered to BECCS. The payment would be made for the difference between the electricity price and a 'strike price' (that reflects the cost of delivering BECCS, which would be well above the price of electricity). A similar instrument could be used to support DACCS; the contract price value could be specified based on a clear understanding of the cost and risks of DACCS and its potential value in reducing emissions, both now and in the future. If DACCS was producing a product to be utilised, e.g. synthetic fuels, then a CfD mechanism could apply to the sale of those fuels with a top-up provided to the fuel price.

Policy design details

- *Scope:* CfDs are offered to BECCS and DACCS projects
- *Design of contracts:* issued via competitive auctions, with prices, contract lengths and other characteristics that attract investors
- *Implementation timeline:* This scheme could be implemented immediately.

	Criteria	Score	Scoring notes
Effectiveness	Strength of incentive		Risk-adjusted returns for GGR deployment would be higher with the provision of appropriate CfD instruments. However, CfDs would not be able to provide a strong incentive.
	Addressable risk		Returns are made less uncertain through CfD.
	Positive track record		The CfD scheme for renewables in the UK has been effective in supporting uptake.
Efficiency	Efficient deployment of GGRs		The policy can encourage cost-efficient deployment of BECCS and DACCS respectively as the contracts are issued via competitive auctions. However, there would be no optimization across technologies.
	Moral hazard to emission reduction		Does not reduce incentive for emission reductions.
Feasibility	Progressive distribution of costs		The costs are borne by the general tax base.
	Public acceptability		There may be public objections to 'paying the polluter' if fossil fuel generators invest in BECCS and DACCS. The level of the subsidy could be perceived as unacceptable if it is too high or the case for subsidising is not made clearly or well understood.
	Tractability of accounting		Unlike other incentive policies and standards, the provision of co-investment equity does rely on monitoring mechanisms.

	Criteria	Score	Scoring notes
Strategic fit	Complementarity with enabling policy	Red	Would require a range of supporting policy around innovation and infrastructure to make BECCS and DACCS commercially viable.
	Complementarity with integrating policy	Green	The mechanism is an extension of the existing Electricity Market Reform. Contracts for BECCS and DACCS could extend the innovation policy and of making this technology commercial. The mechanism could interact with the emissions trading scheme in the power sector, and some credits may need to be cancelled to account for the additional abatement.
	Flexibility	Amber	The scheme can be revised periodically in collaboration with the industry. However, the strength of incentives would be limited by the structure of CfDs, making it difficult to adjust for more ambitious policy goals in the future.

Company profile

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