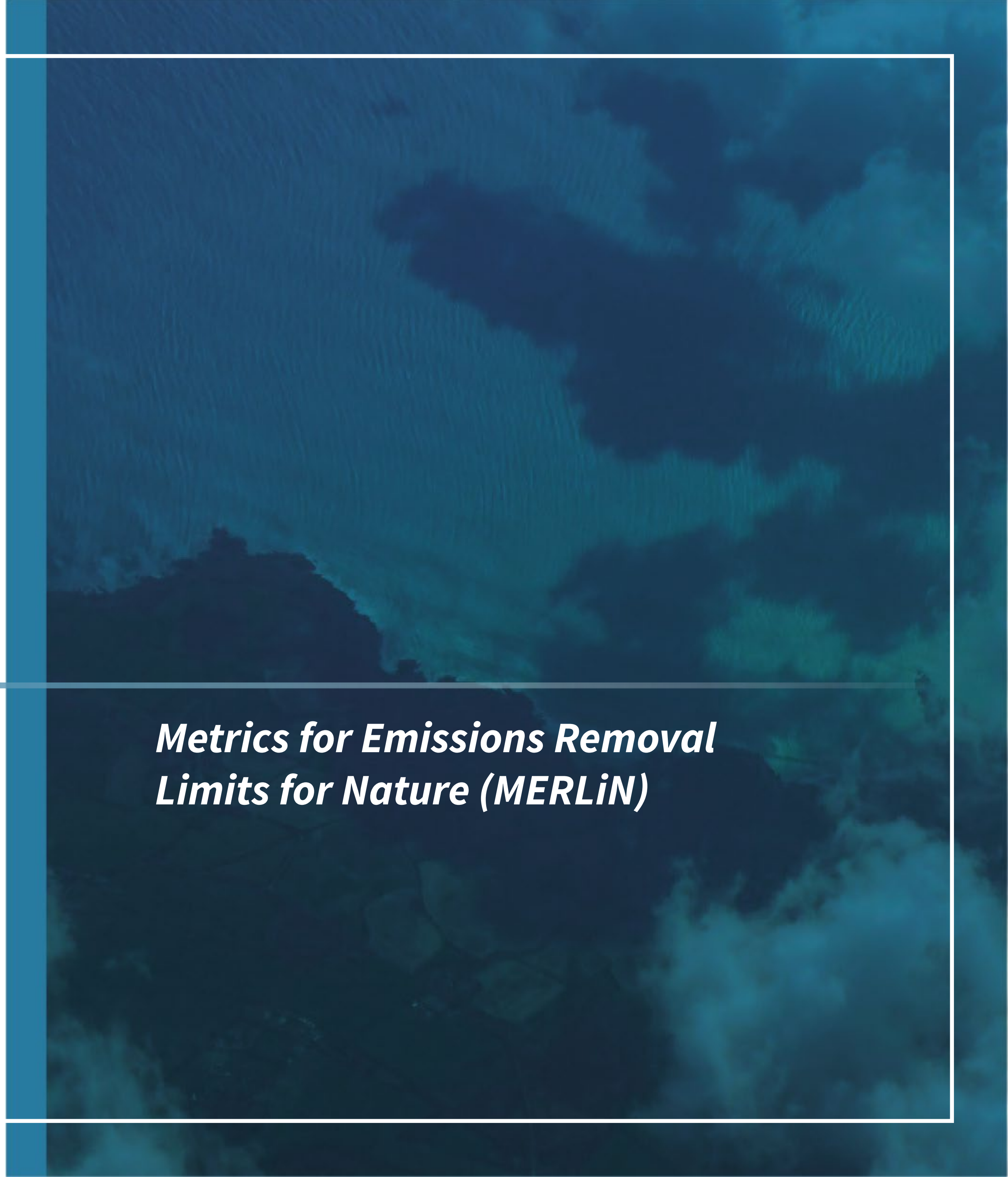
GREENHOUSE GAS REMOVAL
RESEARCH PROGRAMME

UK GGR Research Programme
Policy Brief



Metrics for Emissions Removal Limits for Nature (MERLiN)

Summary

The removal of greenhouse gases from the atmosphere (‘GGR’) after their emission is an integral part of climate change mitigation pathways, but not all aspects of GGR have been incorporated meaningfully into policy action.

If we exceed levels of CO_2 that correspond to meeting international targets and then later recapture CO_2 there will be a different climate impact compared to the situation where the carbon budget was achieved without the need for any recapture. The difference between the impacts of the two pathways sets limits on how much, if at all, society can exceed its emissions budget. These limits must be part of any decision about deployment of GGR.

Through modelling the climate impact of an overshoot followed by CO_2 removal, MERLiN researchers have demonstrated that emissions affect the climate immediately and that recapturing the same amount of CO_2 later will not return us to the pre-overshoot climate. Keeping global average temperature within safe boundaries could be possible if enough CO_2 is removed, but there are predicted to be other climate impacts, particularly in sea level, that will take longer to rectify.

Appropriate carbon accounting is needed to incorporate these limits into GGR. MERLiN researchers have identified current challenges to GGR accounting and proposed the use of an approach that works systemically and incorporates indirect – as well as direct – impacts from GGR. The project adds to the growing evidence that current carbon accounting approaches may not be fit-for-purpose to assess GGR. Changing these approaches will be challenging but, based on research, a shift will be needed to ensure GGR is effective.

Overshoot and non-overshoot scenarios

To assess how to meet the temperature goals of the Paris agreement, models explore different pathways of future emissions. Many of these pathways rely on a combination of overshooting targets and negative emissions. In the overshoot pathway, there are relatively high emissions at the start of the century that lead to a temperature overshoot, which is corrected using large-scale deployment of GGR during the second half of the century to take global temperatures back below the targets. In the non-overshoot pathways, emission reductions are more immediate and temperatures stay below the global temperature goals throughout the century.

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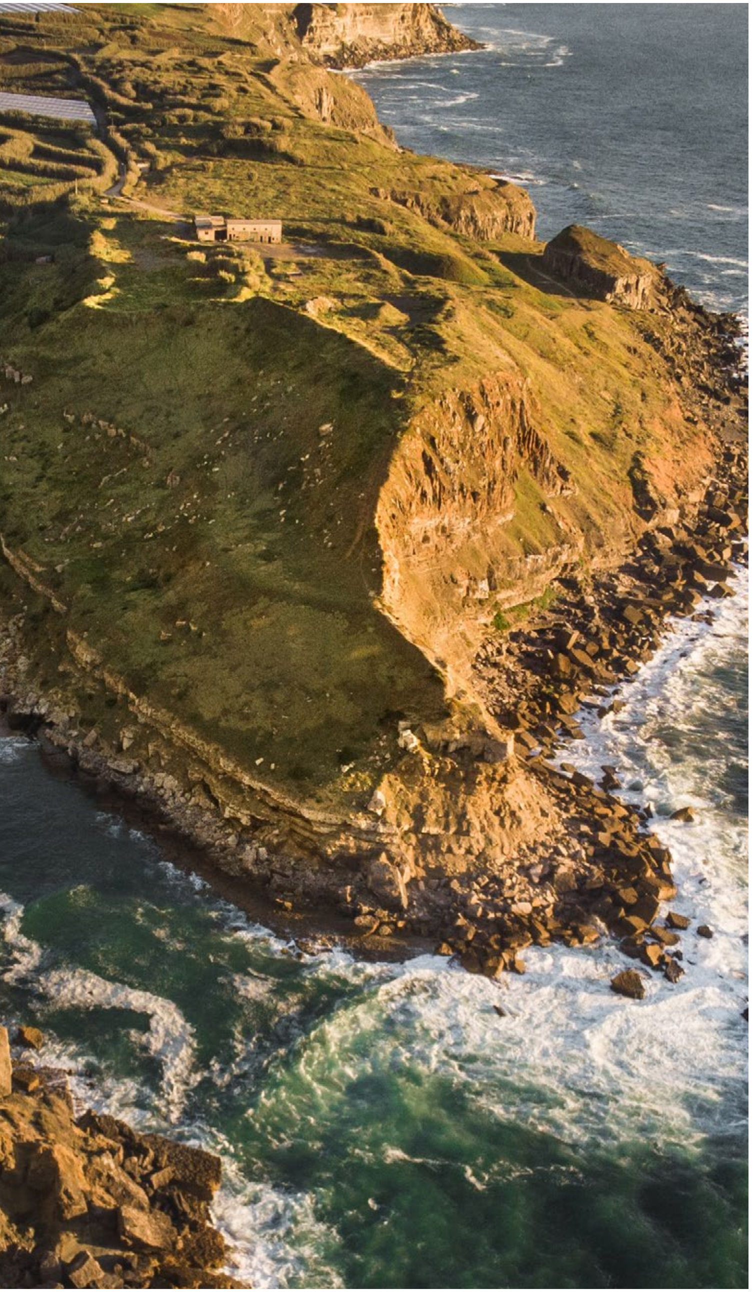

Recommendations

The impacts of GGR approaches are not constrained to where (and when) they are deployed. Modelling and accounting should be done at a planetary and systemic level and in ways that consider the timing of both emissions and removals of GGR.

The CO_2 that we are currently emitting is impacting our climate now, not only in terms of the surface temperature but other aspects of climate. To assess the efficacy of GGR and to set appropriate incentives, the 'reality principle' (which proposes counting emissions and removals where and when they occur) offers a partial solution but, alongside this, incentives should also be guided by consequential accounting methods which consider the global environmental benefits and burdens.

Consequential methods have the potential to paint a fuller picture of the environmental impacts of GGR, as they include indirect market and price effects. Attributional methods have a narrower focus and assess only those impacts that are directly associated with the GGR approach in question.

Currently, national inventories of emissions use an attributional approach and are an embedded feature of the UNFCCC architecture. To overcome reluctance to use consequential methods there may need to be top-down policy direction, such as guidance from the Intergovernmental Panel on Climate Change.

There is variation in the permanence of carbon storage in GGR technologies and in the certainty of this permanence. Rather than being a reason to delay decision-making, the level of uncertainty and associated risk need to be measured and incorporated into decision processes about different types of GGR. If there is relatively high certainty in the amount and permanence of a GGR approach this should inform decision-making around its deployment. For example, it could be better to have reliable but potentially smaller amounts of CO_2 removal compared to larger but highly variable levels of removal.

1. Integration into policy

Despite the assumption by most modelled emission scenarios that GGR will play a role in climate change mitigation there is an absence of detail in policy on how and by whom large scale GGR might be delivered (Geden et al., 2018, 2019).

There is a need for clearer definition of the limitations of GGR that are caused by the possible negative impacts of CO_2 removal at scale. These limitations must be translated into metrics to effectively integrate GGR into policy and deliver more reliable accounting practice.

2. What is known about the impact of CO_2 removal?

GGR incorporates a range of techniques at different stages of maturity, from enhancing natural carbon sinks to the engineered removal and subsequent storage of CO_2. Currently, GGR methods are yet to be tested at scale, so current knowledge of their impacts on the carbon cycle has been extrapolated from research on natural examples, modelling or laboratory investigations. This highlights the need to advance research and the importance of recent initiatives to put in place demonstrators for these technologies to assess their impact in real life (Keller et al., 2018a).

2. 1 Natural carbon fluxes and carbon dioxide removal (CDR)

The CO_2 that has been added to the atmosphere does not remain there; a large amount is redistributed to the land and the ocean (Le Quéré et al., 2015) .

Earth system models have shown that deliberate removal of CO_2 at a large scale will produce an immediate reduction in atmospheric CO_2 but carbon will then be gradually released by the ocean and land. One study has estimated that if 100 Gt of CO_2 is removed then after 100 years the atmospheric CO_2 will only be 25 Gt lower because carbon will have been released by the land and sea (Keller et al., 2018a). These so called ‘backfluxes’ of CO_2 can be viewed as a ‘carbon debt’ that should be paid back if effective large scale GGR is to be deployed.

2. 2 Timescales, feedbacks and permanence

Different factors are instrumental in the response of different parts of the earth system to CO_2 movement. This builds variation and uncertainty into the timescales of the response to changes in carbon. The ocean takes longer to respond (decades to millennia) whilst the timescale of the land's response is in years to decades.

GGR can trigger feedbacks in the climate-carbon cycle that can affect the overall impact on climate change. For example, changes in the amount or type of vegetation from GGR approaches such as Bioenergy with Carbon Capture and Storage (BECCS) can alter the albedo (reflectivity of the earth's surface) and change natural or existing methods of climate cooling.

For many of the land-based GGR approaches such as afforestation and soil carbon enhancement there are issues around storage, requiring careful management to ensure that sinks do not release too much of their carbon. The natural carbon stores in forestry and soil are much less secure than geochemical or geological stores.

3. Impacts of overshooting targets and climate reversibility

To understand the limits and efficacy of GGR, models must integrate interactions between atmosphere, ocean and land and consider the possible effects of feedback, timescales and permanence. For a given level of expected global average surface temperature change, there is a budget for cumulative CO_2 emissions and if this budget is exceeded there will be an overshoot of the target temperature. To understand the effectiveness of GGR, any modelling must be done within the context of this overshoot and at a planetary scale.

The FAMOUS model (see box 1) is an Earth system model that integrates interactions between the atmosphere, ocean and land to estimate the state of the climate under different conditions. MERLiN researchers used this model to predict the consequences of CO_2 overshoot and subsequent GGR. This was done by modelling the impact of large pulses of CO_2 added to the atmosphere, followed by a matched amount of CO_2 removal at a later stage.

Results indicate that, if CO_2 emissions are reduced to zero, the use of GGR could reach desired targets around temperature and atmospheric CO_2 but there will be climate damage that will either be irreparable or take centuries to overcome, particularly in sea level. Moreover,

The FAMOUS (FAst Met Office/UK Universities Simulator) is derived from a version of the Hadley Centre model (v 3) and has approximately half the spatial resolution of HadCM3, allowing it to run complex projections over long timescales (in order of a millennia) but relatively quickly. The quicker speed brings a compromise in resolution. Other Earth system models exist and the CO_2 removal model intercomparison project (CDRMIP) is assessing and comparing the different models (Keller et al., 2018b).

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BOX 1

Key results from FAMOUS modelling

- When CO_2 is added, atmospheric CO_2 rises very quickly and most of this carbon remains in the atmosphere, indicating that any greenhouse gases that we emit now are impacting the climate immediately.
- Some of the added CO_2 is taken up by the ocean but in lesser amounts than taken up by the atmosphere. The rate of take-up of CO_2 by the ocean slows over time. Warming from the excess atmospheric CO_2 results in sea-level rise that increases linearly with the length of overshoot time.
- Land takes up less carbon than the ocean but the amounts still need consideration.
- The impact of CO_2 removal from the atmosphere on temperature was much less in the case where emissions continue at current levels compared to the case of zero emissions.
- The impact of CO_2 removal on sea level was much slower than the impact on temperature taking about 400 years to return to the situation before emissions overshoot.

damage from emissions is underway as soon as those emissions are within the atmosphere. There is no impact-free period or delay to provide some breathing space for action and this must be considered in assessment methods and policy choices around GGR.

These results are corroborated by similar studies using other models, including the CO_2 removal model intercomparison project which contributed results to Chapter 4 of the 2021 IPCC Working Group 1 report (Keller et al., 2018b).

4. Comprehensive accounting for GGR

The limits identified by the FAMOUS modelling highlight the need for appropriate accounting to help allocate responsibility to undertake GGR and incentivise deployment correctly. MERLiN researchers have reviewed the literature on carbon accounting and identified five distinct challenges to accounting for negative emission technologies that need to be addressed (see box 2) (Brander et al., 2021).

BOX 2

Accounting issues related to negative emission technologies

- Estimating total system-wide change in emissions/removals
- Non permanence
- No equivalence of ‘no overshoot’ and ‘overshoot and removal’
- Accounting for incentives for negative emission technologies
- Temporal distribution of emissions/removals

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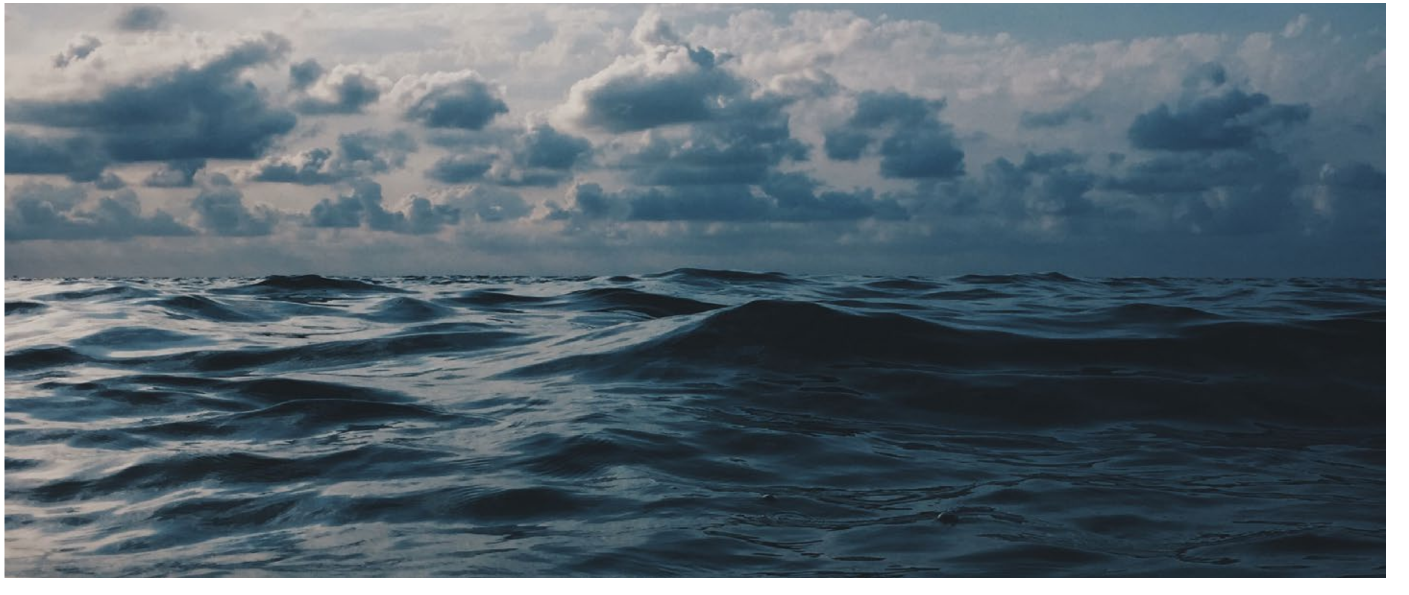


There are some solutions to these issues but others need more work. GGR impacts are not confined to boundaries and will have indirect environmental impacts in other parts of the system in which they operate (see box 3). System-wide change can be accounted for using consequential carbon accounting methods, such as consequential life cycle assessment (LCA) – this is different from the predominant LCA approach which is attributional and assesses only those emissions that are directly produced from a GGR approach or technology. Consequential methods quantify the total system-wide change, including emissions that occur indirectly as a consequence of deploying a GGR approach.

GGR approaches vary in their storage security or permanence - forestry may suffer carbon release from wildfires or disease, whilst CO_2 captured from BECCS or Direct Air Carbon Capture and Carbon Storage (DACCS) and stored in geological formations could be vulnerable to leakage. Some approaches have used 'temporary credits' to represent non-permanence but its consideration in accounting remains a challenge.

The FAMOUS modelling demonstrates that a tonne of CO_2 removed at a later date does not provide the equivalent reversal effect as a tonne of CO_2 removed or mitigated some time before due to the immediate effect of emissions in the atmosphere. Discount factors on the cost per tonne of removed CO_2 have been used to correct for differences, but this may not ensure equivalence for other impacts such as sea-level rise. The problem is inherent in the use of single metrics to represent climate impact and more sophisticated metrics may be needed.

Consequential methods quantify the total system-wide change, including emissions that occur indirectly as a consequence of deploying a GGR approach.

For an accounting method to work it must create appropriate incentives. Existing approaches can be misaligned with desired outcomes, for example incentivising the use of biomass in BECCS when the country exporting the biomass is not incentivised to manage its land sustainably and its own emission targets do not include emissions from its land sector. One partial solution is to use a 'reality principle' which proposes that emissions and removals should be counted when and where they actually occur (see box 4).

The timing of delivery of negative emissions by GGR differs according to GGR technology (see figure 1 for comparison of BECCS and DACCS)

BOX 3

Example of limits of attributional LCA – BECCS

For BECCS an attributional LCA will include all processes directly used in the life cycle of a technology such as biomass harvesting, and the energy used in capturing, transporting and injecting CO_2. However, it does not account for indirect or market-mediated effects such as indirect land-use change caused by increased prices for biomass . In the case where BECCS is used for enhanced oil recovery (EOR), attributional LCA does not account for a possible decrease in oil prices resulting in an increase in oil consumption. Although there may be large uncertainties around indirect effects – for example the unknown impact of EOR on oil prices – this is not a reason to ignore these effects. The level of uncertainty is decision-relevant information and should be incorporated into plans around BECCS (Tanzer and Ramírez, 2019).

Putting the reality principle into practice

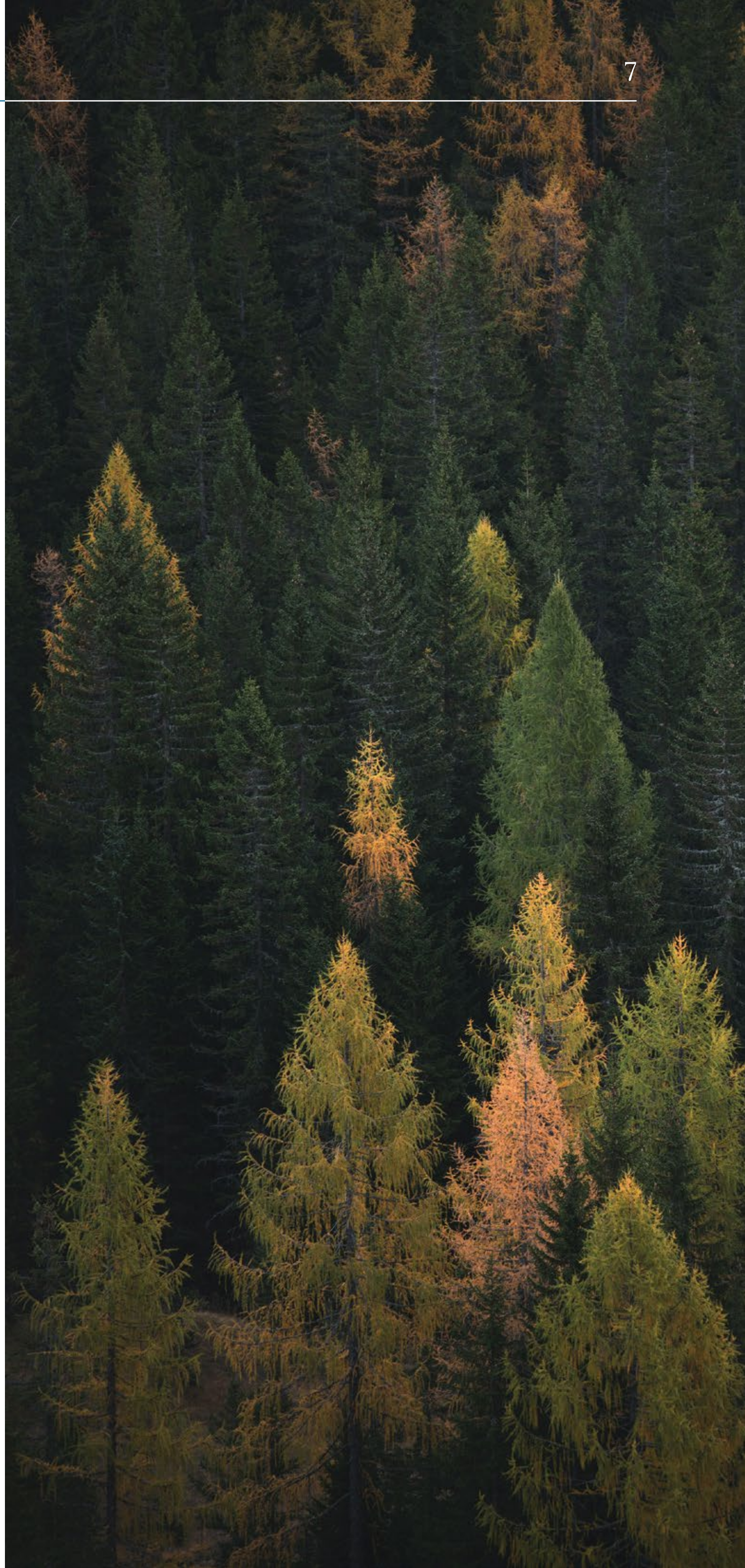
BOX 4

Under current accounting rules if, for example, imported biomass is used in BECCS the changes in carbon stocks from harvesting and growing trees are counted as emissions or removals in the greenhouse gas (GHG) inventory of the exporting country (even though no emission may occur in the exporting country) . When the wood is burned in the importing country, if the emissions are captured and stored then the importing country can report a removal (although no physical removal from the atmosphere occurs within the importing country). One problem with this approach is that if the exporting country has not included the land sector within the scope of its own reduction targets it will not have an incentive to ensure the harvested trees are replanted.

In contrast, following the reality principle, the importing country would count the emissions from the combustion of biomass in its energy sector (as that is when and where the emissions occur), and if the emissions from combustion are captured and stored then there will be no emissions, and the account will correctly report emissions as zero. Similarly, the sequestration that occurs as biomass regrows would be counted in the land sector of the exporting country, at the time that the regrowth occurs (which would also reflect the timing of when removals actually occur with BECCS).

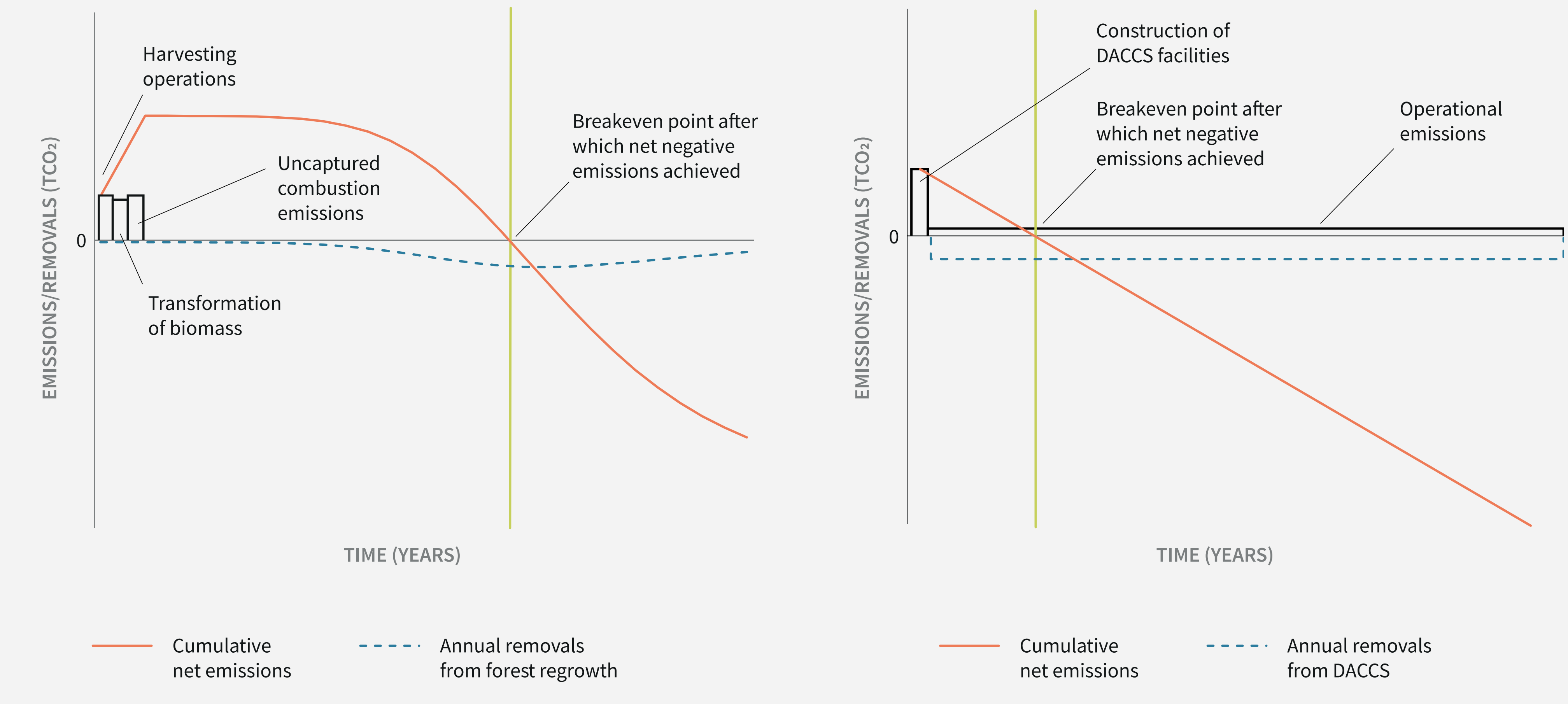
To appropriately incentivise negative emissions technology (NET) the reality principle can be coupled with tradable credits, such as the Internationally Transferred Mitigation Outcomes (ITMOs) under the Paris Agreement (UNFCCC, 2015, Article. 6.2). With the accounting structured according to the reality principle the 'credit' for negative emissions from BECCS would accrue to the exporting country, as it would report net removals from the regrowth of the biomass. In order to incentivise BECCS, one option would be for the importing country to buy the removal ITMO credit as well as the biomass. In this way, all the parties involved would have an incentive to undertake the NET activities.

With the current accounting approach there would be no incentive for the importing country to make a payment for removals to the exporting country as the accounting approach already allows the importing country to claim a net removal. As a result, the exporting country does not have an incentive to replant forest.



and there is a need for accounting to incorporate this time-related aspect into its assessment. Currently, both forms of LCAs (attributional and consequential) tend not to provide temporal information.

FIGURE 1: **Illustration of temporal distribution of emissions with BECCS (left) and DACCS (right). The chart for BECCS shows a single instance of harvesting, combustion, capture, storage and regrowth (rather than overlaying ongoing instances of these activities), while the chart for DACCS shows ongoing removals and operational emissions over the lifetime of a DACCS facility.**
The red line represents cumulative emissions and the breakeven point is achieved when the negative emissions bring the cumulative value down to zero.



Next steps

Modelling shows that the carbon we use today has an immediate impact and removal of the same amount at a later date cannot equivalently negate that impact. This is important to consider in decisions about GGR that might delay mitigation.

Carbon accounting will need to shift its approach to effectively assess the impact of GGR with a focus on consequential LCA, applying the reality principle and the consideration of permanence and timescales. If possible, this accounting approach should be developed and applied in the next generation of projects attempting to evaluate the effectiveness of GGR.

Carbon accounting will need to shift its approach to effectively assess the impact of GGR.

Based on the findings from the MERLiN project there are several questions around the functionality of GGR and what it means for policy scenarios and business models that need to be further addressed in the next stage of GGR research and demonstrator projects (see box 5).

Questions for next generation of research projects to address

BOX 5

- How can the consequences and risks of overshoot and recapture be better incorporated into climate mitigation pathway analyses?
- How can more permanent removals be delivered and ensured?
- What practical steps are needed to improve present approaches to accounting around greenhouse gas removals?

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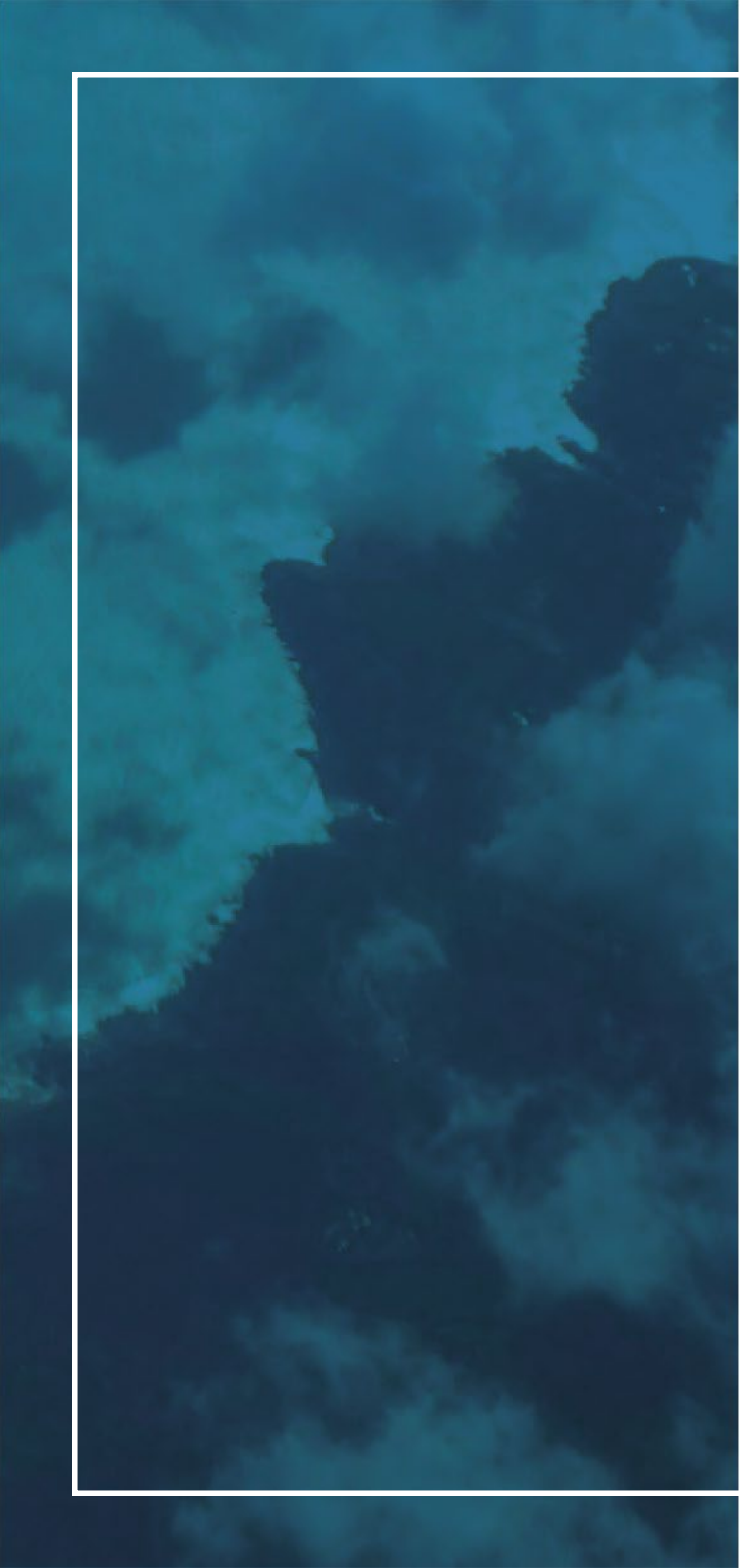

About the programme

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

The MERLiN (Metrics for Emissions Removal Limits for Nature) project is one of the eleven components. This policy brief was created in close collaboration with the project team Professor Simon Tett, Dr Vivian Scott, and Dr Matthew Brander.

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