Background report

Responsible use of temporary carbon dioxide removal

WKR The Netherlands Scientific Climate Council

Summary

On 10 July 2024, the Netherlands Scientific Climate Council (WKR) issued the advisory report '*Clearing the air*'). In the report, the WKR made policy recommendations about the use of *temporary* carbon dioxide removal (CDR) from the atmosphere . Two recommendations are primarily relevant for temporary CDR. Firstly, the WKR recommends compensating fossil and long-lived greenhouse gas (GHG) emissions exclusively with permanent CDR. Secondly, the WKR recommends to "encourage temporary CDR in the Netherlands, but only as part of other policies" – in other words, not as part of CDR policy.

Following the publication of the advisory report, the Interdepartmental Working Group on Carbon Removal asked the WKR to take a more in-depth look at how temporary CDR can responsibly contribute to achieving climate goals. In response, the WKR has drawn up this background report. The key question addressed in this report is: ***For which climate goals of the Paris Agreement and under which conditions can temporary CDR be used responsibly?*** That question is answered below by way of the following subsidiary questions:

What contribution can temporary CDR make to the climate goals of the Paris Agreement?

Temporary CDR can only make a small contribution to limiting global warming, because the CO_2 stored is subsequently released again. As a 'deferred emission', temporary removal does not contribute to limiting cumulative CO_2 emissions in the long term, which is what will be decisive for the level global temperature eventually reaches.

However, under certain (climatic) conditions, it is possible to increase the carbon stock[1] in the long term, for example by means of sustainable forestry. If such carbon sequestration is maintained for a very long time, this form of storage takes on a 'pseudo-permanent' character, and as such can be of value for achieving temperature goals. However, it is difficult to guarantee long term storage in advance.

In theory, temporary CDR could also be used to limit peak global warming. However, in scientific terms this approach is highly speculative, due *inter alia* to the significant uncertainties that exist with regard to the time and duration of peak global warming. The expected climate gains could even prove negative for future generations if temporarily removed carbon is released at an unfavourable point in time.

Under certain conditions, however, temporary CDR can compensate for residual emissions and can then make a contribution to achieving climate neutrality and thus stopping global warming.

Which emissions are eligible for compensation with temporary CDR?

Emissions which are technically difficult to avoid, or are generated by an activity that is deemed desirable for compelling economic or societal reasons are 'hard to abate'. Only hard-to-abate emissions are eligible for compensation. Compensation must take place in accordance with the like-for-like principle. In concrete terms, this means that only emissions originating from the short carbon cycle may be compensated with temporary CDR. Emissions from the long carbon cycle must be compensated by removing and storing it in permanent carbon reservoirs. Based on these conditions, we can determine whether and how each specific emission is eligible for compensation. The result is shown in the form of a decision tree; see Figure 1.

[1] The total quantity of sequestered carbon in a forest or in the soil, for example.

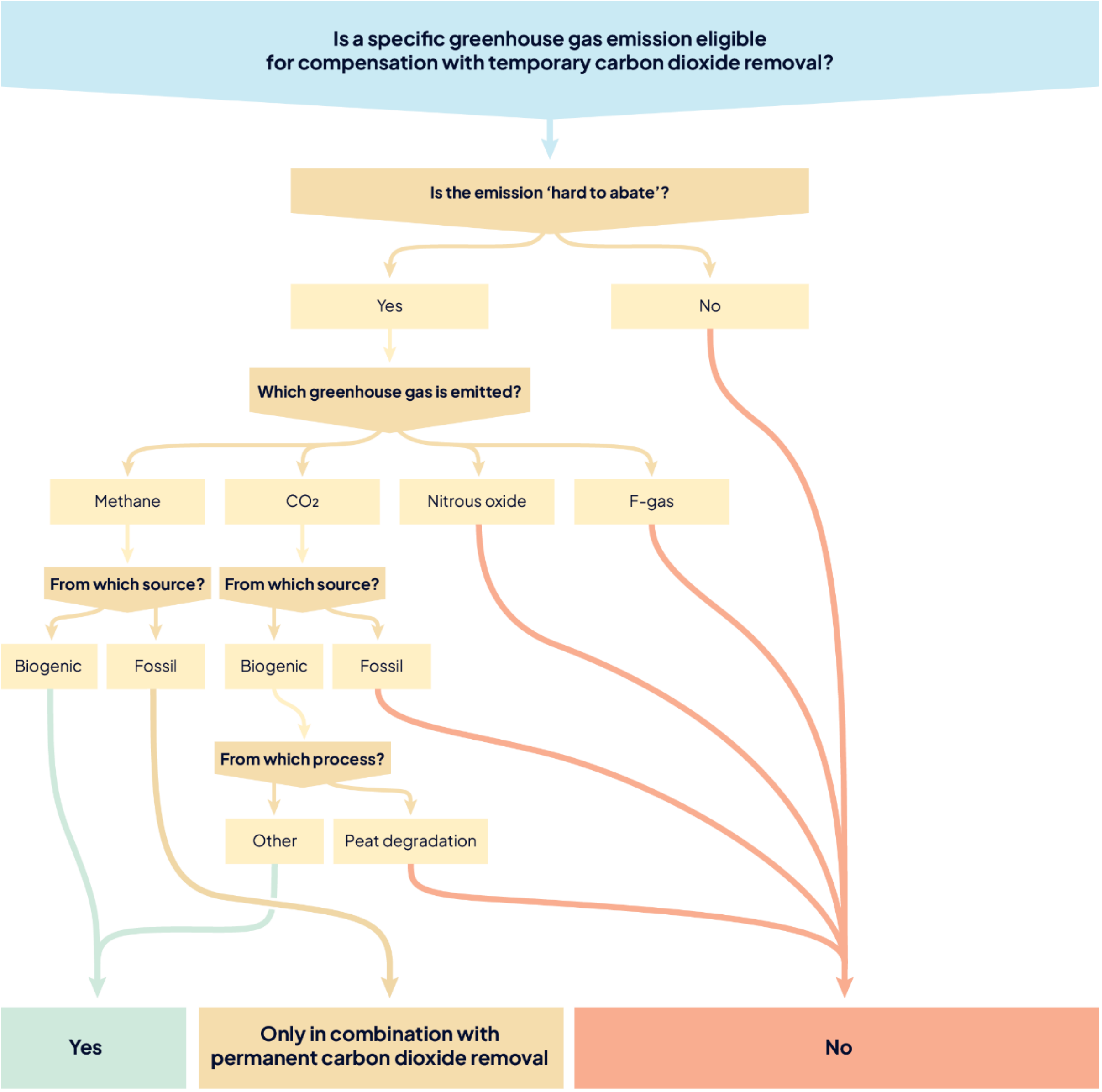

Figure 1. *The decision tree is a visualisation of the answer to the question: "Is a specific greenhouse gas emission eligible for compensation with temporary carbon dioxide removal?", based on a limited number of basic questions.*

From a climate perspective, the conclusion is that only biogenic CO_2 emissions or biogenic methane emissions qualify for compensation with temporary CDR. There are two exceptions to this. Firstly, if the biogenic CO_2 emission or biogenic methane emission originates from peat degradation, it must be compensated with permanent CDR. This is because peat degradation represents an irreversible deterioration of a biogenic carbon reservoir that has a long sequestration timescale. Secondly, temporary CDR can compensate for the temporary warming effect of fossil methane, provided it is accompanied by simultaneous permanent CDR to compensate for the long-term warming effect. A condition is that the combined temporary and permanent CDR cancel out the warming effect of methane at all times.

Emissions of all other GHGs, i.e. fossil CO_2, nitrous oxide and F-gases, must be compensated with permanent CDR.

When is compensation of emissions by CDR responsible?

If a GHG emission qualifies for compensation with temporary CDR, it can be responsibly compensated if two criteria are met:

1. The quantity and duration of the compensation of an emission of a particular GHG must cancel out the warming effect (the so-called effective radiative forcing) of the emission at all times, with all the effects of the chosen CDR method being included in the calculation (including energy consumption, land use and physical effects). This is part of the like-for-like principle.
2. The compensation must take place by means of high-quality CDR projects. This means that the removals are additional, are not double counted, do not result in impacts being passed on to other sustainability areas and future generations, and that the risks of premature release of CO_2 have been minimised and covered. Moreover, the project results must be verifiable, based on transparent measurements and accompanying reports.

These criteria apply to permanent and temporary CDR projects alike. Due to the relatively high risk of the premature release of CO_2 associated with temporary CDR (a risk which is increasing with climate change), the projects call for specific forms of risk management, and appropriate liability mechanisms must be in place. This is to prevent future generations having to bear the consequences of premature release.

To what extent does emissions accounting comply with the requirements of equivalent compensation?

Most CDR methods can already be included in emission inventories. This is not yet true for CO_2 sequestration in biomaterials made from non-woody crops.

The manner in which compensation with temporary CDR is currently treated in the inventory has various shortcomings, for example:

1. The like-for-like principle is not applied in the existing accounting system. This means that temporary CDR can be used to compensate for fossil emissions, which can cause additional warming in the long term.
2. The existing accounting system underestimates the short-term warming effect of emissions of short-lived GHGs. If these emissions are compensated with (temporary) CDR, for accounting purposes this can make it appear that the entire warming effect has been compensated, yet there can still be a warming effect in the short term.
3. Because natural carbon sequestration and temporary anthropogenic CDR are not properly distinguished from one another in the emission inventory the climate gains of removal may be double counted and therefore overestimated.

The Netherlands and the European union do not impose any further requirements as regards the type of CDR (temporary or permanent) that may be used to achieve the climate goals. Achieving those goals therefore does not guarantee that the compensation takes place in accordance with the like-for-like principle.

In upcoming decisions on the further development of European climate policy (for example, the creation of an emissions trading system for the agriculture sector), there will be opportunities to ensure that temporary CDR is not used to compensate for fossil emissions or long-lived GHGs.

Contents

1 Introduction

On 10 July 2024, the Netherlands Scientific Climate Council (WKR) issued its advisory report 'Clearing the air'.[2] In it, the WKR argues that immediate and active government intervention is needed to achieve carbon dioxide removal (CDR) from the atmosphere (see Text Box 1 for the definition of CDR). At the same time, the primary focus must continue to be maximising efforts to reduce greenhouse gas (GHG) emissions. The advisory report contains a number of concrete recommendations about principles and policy for removing CO_2 from the atmosphere. In brief, they are:

1. Make maximum efforts to reduce emissions.
2. Focus Dutch CDR policy on permanent methods.
3. Deploy only permanent CDR for compensating fossil GHG emissions and emissions of GHGs that remain in the atmosphere for a long time.
4. Encourage temporary CDR in the Netherlands, but only as part of other policies.
5. Pursue Dutch CDR policy, in conjunction with European policy.
6. Set limits to the use of CDR for counterbalancing residual emissions at European, national and sectoral levels.
7. Initiate cooperation with other member states of the European Union to explore possible European policy instruments for creating a demand for CDR.
8. Exclude CDR from the European emissions trading system for as long as possible, to maintain the incentive for emission reduction for as long as possible.
9. Launch a Dutch government-led procurement programme for permanent CDR.
10. Ensure that emitters start contributing from now on to the future costs of limiting and reducing a temperature overshoot.

Tekstbox 1. Definition of CDR

CDR comprises anthropogenic activities that remove CO_2 from the atmosphere and capture it for long-term storage in the soil, in deep geological reservoirs, in ocean sediments or in products. It is important that there is *net* removal of CO_2: the total amount of CO_2 removed from the atmosphere must be greater than the total amount of GHG emissions from the activity subject to the CDR process.[3]

CDR can have a permanent or temporary character. CO_2 that is stored for at least several centuries is regarded as permanent CDR. This includes geological storage deep underground and mineralisation of CO_2. Sequestration of CO_2 in forests, agricultural soils or in biomaterials captures CO_2 temporarily, probably only for decades.

Following the publication of the advisory report, the Interdepartmental Working Group on Carbon Removal – a group of policy makers from various ministries – asked the WKR to look in more depth at how temporary CDR can responsibly contribute to achieving the climate goals, in the context of the Climate Plan for 2025-2035 and the Carbon Removal Roadmap (*Routekaart Koolstofverwijdering*), both of which will be published in 2025 and will address the approach to temporary CDR. Research in this area has been announced in the draft Climate Plan.[4]

In response, the WKR decided to draw up this background report. The key question addressed in this report is:

[2] WKR (2024b).

[3] IPCC (2021, p. 2221).

[4] From the draft Climate Plan 2025-2035 (Ministry of Climate Policy and Green Growth, 2024): "We are investigating whether temporary CDR can be used in a responsible manner to compensate for long-lived GHGs and, if so, what additional guarantees are called for, in line with the Sustainability Framework for Bio-Based Raw Materials" and "Research still needs to establish whether it is possible to guarantee that using temporary CDR for the compensation of long-lived GHGs can actually contribute to the climate goals and, if so, how."

For which climate goals set out in the Paris Agreement and under which conditions can temporary CDR be used responsibly?

An important factor in the WKR recommendations on temporary CDR, as expressed in the advisory report 'Clearing the air?', is that the lion's share of the Netherlands GHG emissions comes from fossil sources. In accordance with the advisory report, these need to be compensated using permanent methods, not temporary ones. Another reason for the recommendation not to include temporary CDR as part of CDR policy is the limited potential for temporarily sequestering CO_2 in Dutch forests and soils: the Netherlands simply has too little space.

This background report does not contain any recommendations. Its purpose is to examine the subject matter covered in the advisory report 'Clearing the air?' in more depth. It should be read in conjunction with the advisory report and the accompanying 'Background report on carbon dioxide removal'.[5]

In order to answer the central question, academic and grey literature has been studied and interviews have been held with several experts (see References and the 'Experts consulted' appendix).

This report is structured around four subsidiary questions. Chapter 2 asks what contribution temporary CDR can make to the climate goals set out in the Paris Agreement. Chapter 3 then considers which emissions are eligible for compensation with temporary CDR. If an emission is eligible for compensation, the next question is how that can take place in a responsible manner. This is addressed in Chapter 4. Finally, Chapter 5 asks to what extent the emission inventories comply with the requirements for compensation and identifies several points to be considered with regard to the inclusion of temporary CDR in climate policy.

[5] WKR (2024a).

2 What contribution can temporary CDR make to the climate goals of the Paris Agreement?

In this chapter, we show how temporary CDR can contribute to achieving the climate goals set out in the Paris Agreement. Those goals are to limit global warming to well below 2°C and to strive for a maximum increase of 1.5°C. Climate science tells us that the following will be required to that end: 1) limiting total GHG emissions up to the point of climate neutrality, which will determine the extent of global warming, and 2) achieving net zero GHG emissions ('climate neutrality'), which will stop global warming.[6] Because global emissions are not expected to fall fast enough to limit the rise in average global temperature to 1.5°C, achieving this goal will require net removal of CO_2 from the atmosphere.

Here we discuss the role temporary CDR can play in limiting (section 2.1) and stopping (section 2.2) global warming.

2.1 Contribution of temporary CDR to limiting warming

In order to achieve the climate goals set out in the Paris Agreement, net CO_2 emissions need to be reduced to zero. This is because in the long term, global warming is primarily dependent on cumulative emissions of CO_2 (see Figure 2).[7] In combination with an effective emissions reduction policy, CDR can achieve both stabilisation and reduction of cumulative CO_2 emissions.

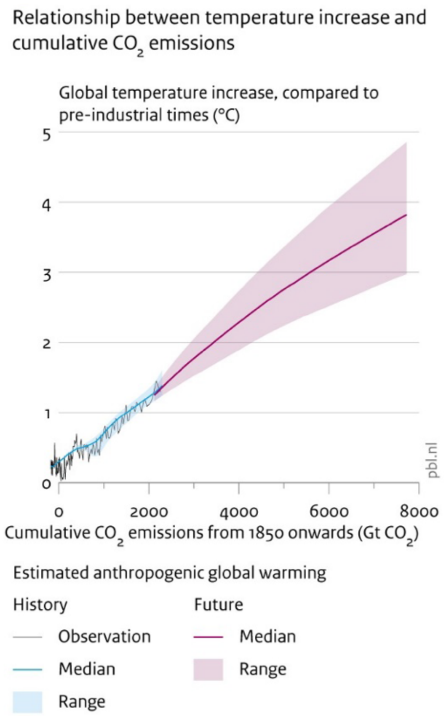

Figure 2. *Despite the complexity of the Earth system, there remains a linear relationship between cumulative CO_2 emissions and global temperature rise compared to the pre-industrial situation. Source: Netherlands Environmental Assessment Agency (PBL) (2024).*

A tonne of temporary CDR should be regarded as a tonne of deferred emissions. In other words, it does not result in a lasting reduction in cumulative CO_2 and therefore does not limit warming in the long term. This contrasts with permanent CDR, which is expected to permanently reduce cumulative emissions, and therefore results in less warming in the long term.

[6] IPCC (2018).

[7] Allen et al. (2009).

There are two ways in which temporary CDR could (in theory) contribute to reducing global warming:

1. **By giving temporary CDR a 'pseudo-permanent' character.**

This means that a stock of stored CO_2 (for example, in a forest) is increased and protected for an extended period of time. While a single individual tree will probably be cut down or die after decades or centuries, sustainably managed forests can continue to exist much longer, with a fairly stable quantity of stored carbon. Recent modelling shows that, given an optimistic estimate of the global potential for afforestation and forest restoration, plus an increased carbon stock in soils, peak warming[8] can be reduced by several tenths of a degree in the second half of this century: by up to 0.1°C by 2055 in 1.5°C scenarios and by up to 0.3°C by 2085 in 2°C scenarios.[9] The limited reduction reflects the short timespan that remains to achieve sufficient temporary CDR. Scenarios which also take account of the climate effects of afforestation not caused by CO_2, such as changes to albedo values and evaporation, show a near halving of the contribution to the reduction in global warming.[10]

Forest that is sufficiently diverse and is properly protected and managed can contribute to the maintenance and recovery of biodiversity. The WKR therefore argues for encouraging temporary CDR in the Netherlands as part of other policies. This is partly informed by the significant challenge of storing carbon by means of sustainable forestry: in many countries of the European Union, carbon capture is currently falling due to climate change and timber harvesting.[11] Even a country like Finland currently has no net uptake in its land use sector, despite its huge forestry sector.[12]

Due to the necessity of long-term management, temporary CDR with a 'pseudo-permanent' character is not suitable for compensating emissions from individual businesses. It would make more sense for countries to arrange for long-term sustainable management, for example as part of their forest or biodiversity strategies.

2. **By timing the temporary CDR so as to reduce peak warming.**

This involves a speculative use of temporary CDR to reduce peak warming (known as 'peak shaving').[13] For this purpose, CO_2 must remain out of the atmosphere long enough to enable the global temperature to stabilise or fall before the CO_2 is released. The point in time when the temperature will stabilise is very uncertain and is linked to the moment of global CO_2 neutrality: the temperature can only peak once cumulative CO_2 emissions have stopped increasing. In global scenarios with a good chance of limiting warming to well below 2°C, CO_2 neutrality is achieved around 2050 (between 2035 and 2060).[14] In the 'real' world, it is still too early to make any pronouncements about this: the faster emissions fall, the sooner clarity will emerge. It will probably take several more decades after achieving CO_2 neutrality before global warming stops. Whether the temperature peaks rapidly or slowly depends on various factors, such as the total quantity of historically emitted CO_2 up to that point, the size of the total natural and anthropogenic CO_2 removal capacity, and developments in the emissions of methane, nitrous oxide, and air pollution (aerosols).[15]

Due to the uncertainties involved, in order to actually achieve a reduction in the temperature peak, the CO_2 sequestration period would probably need to be very long, possibly more than a century.[16] It would be prudent to choose the storage duration conservatively. In the worst case, if the CO_2 removed is released at an

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[8] Peak warming is the maximum average global temperature reached.

[9] Girardin et al. (2021).

[10] Matthews et al. (2022).This does not include the effects of clouds, which in turn can have a cooling effect. For this reason, the authors expect that a smaller share of the reduction in warming will be cancelled out.

[11] Winkler et al. (2023).

[12] ICOS (2025).

[13] See, for example Matthews et al. (2023) and Cullenward (2023).

[14] Schleussner et al. (2022).

[15] See A2.2 in IPCC (2018).

[16] Cullenward (2023).

unfavourable moment, the intended reduction in peak warming could actually prove to be an increase in peak warming. Moreover, a whole series of other conditions will need to have been met. For instance, multiple countries would have to commit to reducing peak warming on a large scale and in a coordinated manner to make a noticeable contribution to temperature reduction.

2.2 Contribution of temporary CDR to stopping global warming

Climate models show that after achieving CO_2 neutrality, the temperature will stabilise within several decades, on the condition that emissions of other GHGs such as methane and nitrous oxide are also cut substantially. The European and Dutch climate acts therefore opt for GHG neutrality: a balance between emissions and removal of *all* GHGs on the territory of the European Union. In order to make a meaningful contribution to stopping global warming, this balance would need to be maintained for an extended period.[17]

Under certain conditions, temporary CDR can compensate for the emissions of some GHGs originating from specific sources. Chapter 3 shows which emissions might be eligible for compensation with temporary CDR from a climate perspective.

[17] Schleussner et al. (2024).

3 Which emissions are eligible for compensation with temporary CDR?

In this chapter, we explain in which situations emissions of a particular GHG are eligible for compensation with temporary CDR. In Chapter 2, we showed that compensation with temporary CDR can only contribute to achieving climate neutrality. However, if a specific emission is to be eligible for compensation, it must meet a series of requirements. We base those requirements on the principles recommended in our advisory report,[18] which are briefly summarised in section 3.1. Section 3.2 then comprises a decision tree based on those principles. This decision tree clarifies whether a specific type of emission may be compensated with temporary CDR. The decision tree can be anchored in policy and in legislation and regulations.

Here we use the word 'compensation' both for companies which are able to purchase CDR certificates to make compensation claims and for countries that include CDR in their emissions inventories and so use it to help achieve their climate goals.

Although there is scientific consensus about the need for CDR, there is still debate about how temporary CDR can compensate for emissions of GHGs other than CO_2. The principles set out in section 3.1 are broadly accepted, but their precise interpretation is specifically a matter for this background report. Experts have been consulted to assist in this interpretation.[19]

3.1 Relevant principles for compensation

3.1.1 Aim for maximum reduction of emissions

The first principle is that the aim should be to limit emissions as far as possible, and that CDR should substitute for emissions reduction as little as possible. This translates to an initial requirement: only emissions which are 'hard to abate' are eligible for compensation with CDR. Emissions are deemed to be hard to abate if they are technically difficult or impossible to avoid, given the available resources and technology, and those emissions are generated by an activity which is desirable based on compelling economic or social reasons.[20]

We note that no unambiguous criteria exist to determine which emissions are 'hard to abate'. Future technical innovations or lifestyle changes may facilitate more far-reaching reductions in emissions which were previously regarded as hard to abate (as we have already seen in new sustainable alternatives for steel production). This is one of the reasons why, in its advisory report, the WKR proposes setting limits for the compensation of residual emissions from different sectors and regularly reviewing them.[21]

Moreover, it is for politicians to decide which activities are of such value to society as to justify the use of the scarce quantity of CDR available. After all, emissions are rarely entirely 'unavoidable', because ceasing the activity (in whole or in part) – such as livestock farming or aviation – is nearly always an option for preventing the associated emissions.

3.1.2 Equivalent compensation

The like-for-like principle imposes requirements for the CDR which can be used to compensate for a particular emission on an equivalent basis.[22] Like-for-like compensation involves first compensating for the

[18] WKR (2024b).

[19] See the 'Experts consulted' appendix.

[20] This formulation is partly based on the *Oxford Principles for Net Zero Aligned Carbon Offsetting* (Axelsson et al., 2024). In those principles, residual emissions are defined as follows: "*Greenhouse gas emissions that remain after taking all possible actions to implement emissions reductions given current resources and technology.*" We have therefore added the social and economic dimensions in our formulation.

[21] See p. 34 in WKR (2024b).

[22] United Nations (2022).

warming effect of the emissions and second arranging for CO_2 sequestration in a reservoir which is comparable in terms of storage duration and permanence to the reservoir that was the source of the original carbon.

The first requirement – compensating for the warming effect – means that efforts are made to cancel out the warming effect of the emissions at every point in time. A measure for the warming effect is radiative forcing, which expresses what the warming effect of a GHG is at a particular moment after emission. CDR has a negative radiative forcing: there is a net cooling effect due to a relative reduction in the greenhouse effect. By choosing the right type and quantity of CDR, the negative radiative forcing of the CDR cancels out the positive radiative forcing of the emission at every point in time. On balance, this results in a zero or even negative warming (i.e. a cooling) effect.

A commonly used measure for determining the required amount of CDR for compensation is GWP100.[23] However, this only accounts for the total effect for a period of 100 years. It does not guarantee that the compensation will cancel out all radiative forcing at every point in time. For instance, methane is a relatively short-lived GHG and therefore has a relatively short-term but potent warming effect. Compensation with CDR based on GWP100 underestimates that effect, resulting in a net warming effect in the short term after all.[24]

The second requirement – that CDR must take place in a reservoir that corresponds with the source of that carbon – means that carbon originating from the long carbon cycle must be returned to the long carbon cycle.[25] Fossil emissions originate from a geological reservoir of the long carbon cycle. Those emissions must therefore be compensated with permanent CDR, which returns the carbon to a geological reservoir of this long cycle. For the same reason, the CO_2 released from the breakdown of fossil methane must always be compensated with permanent CDR. The like-for-like principle also means that emissions from the short (biogenic) carbon cycle can be compensated with temporary CDR. Section 3.2 covers this in more detail.

3.2 Decision tree: Which emissions are eligible for compensation with temporary CDR?

Based on the conditions set out in section 3.1, we can determine whether and how each specific emission is eligible for compensation. The result is shown in the form of a decision tree (see Figure 3), which is followed by a more detailed explanation.

[23] The GWP (Global Warming Potential) is a relative measure that indicates the global warming potential of a GHG compared with that of CO_2. GWP100 represents the warming potential of 1 kg of a GHG compared to the potential of 1 kg CO_2 over a period of 100 years. However, other periods, such as 20 years and 500 years, can also be used.

[24] We make no pronouncements here about the precise conditions for the compensation for methane (or other non-CO_2 GHGs) with CDR, because the question cannot be answered in purely scientific terms. This is because methane and CO_2 are two very different GHGs, with different impacts on the climate. As such, the choice of a particular compensation method depends on exactly which impact we want to compensate, with what degree of certainty, and which interests are given primacy (for example, those of the emitter or future generations).

[25] See p. 26-27 in WKR (2024b) for an explanation of carbon cycles.

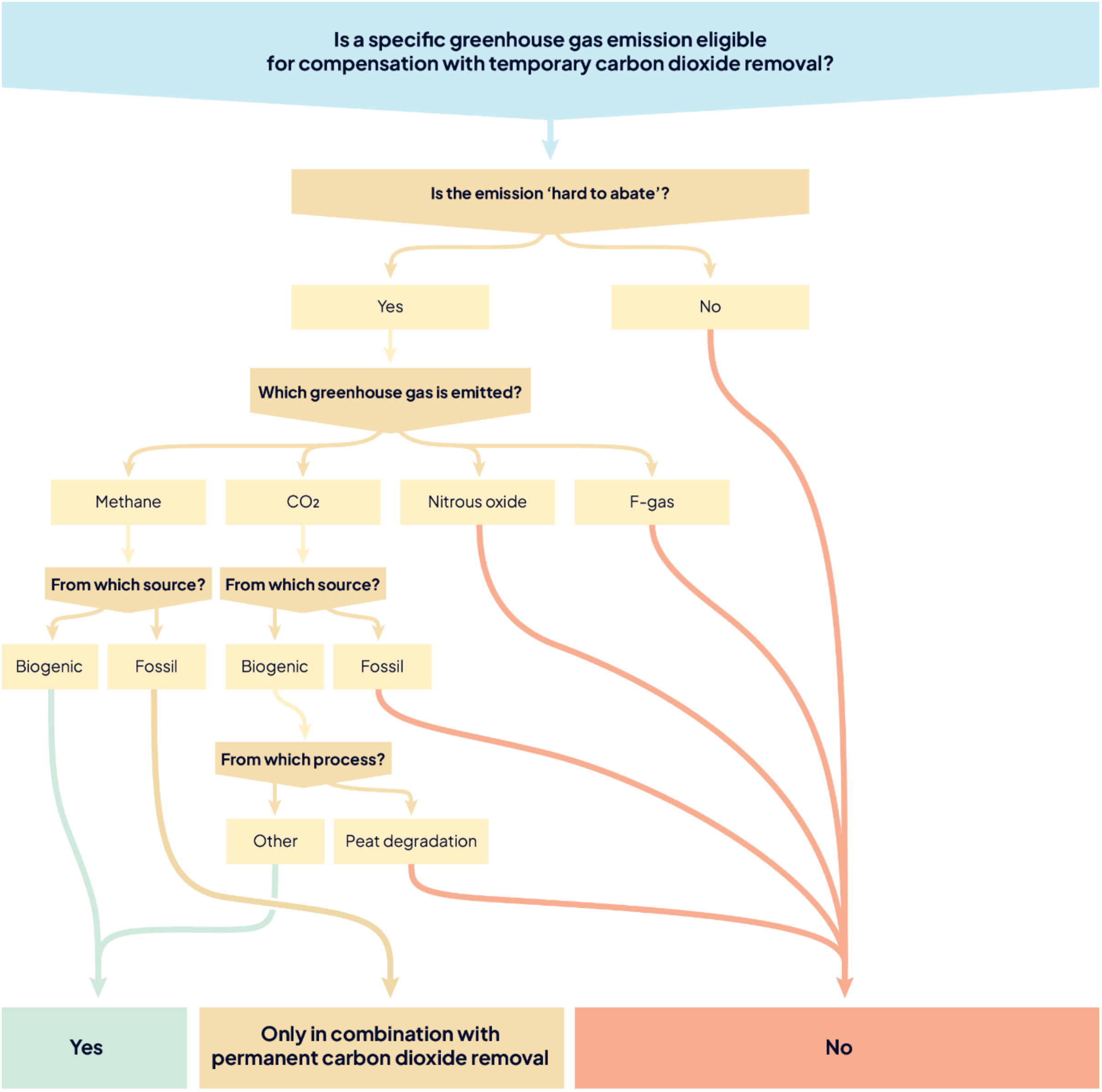

Figure 3. *The decision tree is a visualisation of the answer to the question: "Is a specific greenhouse gas emission eligible for compensation with temporary carbon dioxide removal?", based on a limited number of basic questions.*

We provide more detail on the decisions for the different GHGs, originating from different sources and possibly processes, below:

- **Fossil CO_2:** Under the like-for-like principle, fossil emissions are only eligible for compensation with permanent CDR.
- **Biogenic CO_2:** Under the like-for-like principle, biogenic CO_2 emissions which are part of the short carbon cycle are eligible for compensation with temporary CDR. These are CO_2 emissions caused by land use and changes in land use. However, this does not apply to biogenic CO_2 emissions from peatlands, because those emissions originate from a reservoir which is thousands of years old and it will take thousands of years to restore this carbon stock. The same applies, for similar reasons, to CO_2 emissions from thawing permafrost.
- **Fossil methane (CH_4):** Under the like-for-like principle, fossil emissions are only eligible for compensation with permanent CDR. For this reason, emissions of fossil methane may not be compensated with temporary CDR (alone). Because methane – unlike CO_2 – is a short-lived but potent GHG, it primarily

has a warming effect in the short term. A possible application of temporary CDR is therefore to compensate for the short-term warming effect of methane, combined with simultaneous permanent compensation of the long-term warming effect.[26] A condition is that the combined temporary and permanent CDR cancel out the warming effect of methane at all times.
We note that the vast majority of fossil methane emissions are avoidable with existing technologies and resources, for example by preventing leaks in natural gas pipelines. In that case, the emissions in question do not meet the first requirement in the decision tree and therefore are not eligible for compensation.

- **Biogenic methane (CH_4):** Biogenic methane is eligible for compensation with temporary CDR, because it contains carbon originating from the short carbon cycle and the warming effect of the gas is of a short duration. Analogously with biogenic CO_2 emissions from peatlands, methane emissions from peatlands must be treated in the same manner as fossil methane.
- **Nitrous oxide (N_2O):** Emissions of nitrous oxide are primarily caused by the use of chemical fertilisers, which causes nitrogen compounds to be added to the existing natural nitrogen cycle. As a result, the use of chemical fertilisers directly or indirectly causes emissions of nitrous oxide. Whereas in the case of biogenic CO_2 emissions, CDR returns the carbon to the original reservoir, the same is not true for the nitrogen from nitrous oxide. Because nitrous oxide persists in the atmosphere for a long time, it must therefore be compensated with permanent CDR.
- **F-gases:** These GHGs have a long half-life in the atmosphere and did not exist before humans started producing them; there is therefore no natural cycle. As such, they contribute to global warming in their entirety and that contribution is of a very long duration. For this reason, temporary CDR is not an option for compensation.

[26] Methane oxidises in the atmosphere into long-lived CO_2, so the warming effect of that CO_2 molecule must in any event be compensated with permanent CDR.

4 When is compensation of emissions by temporary CDR responsible?

If going through the decision tree in Figure 3 results in a decision to compensate, the compensation must meet a number of criteria (section 4.1). Most of those criteria apply to all forms of CDR, but the way in which they can be met may differ for permanent and temporary CDR. This applies particularly to risk management, which we discuss specifically in section 4.2. In section 4.3, we show that beyond the individual project level there are also relevant responsibility questions which are characteristic for particular forms of temporary CDR.

4.1 Criteria for responsible compensation

Compensating a GHG emission which is eligible for temporary CDR may be regarded as responsible if it meets the following criteria:

1. **The quantity and duration of compensation are scientifically sound:** This means that compensation is equivalent, as explained in section 3.1. There is as yet no concrete scientific answer to the question of how the duration and quantity of compensation should be determined. CO_2 and other GHGs have differing impacts on the climate. So the question is how the effects of another gas which behaves differently to CO_2 can be cancelled out with CDR. For example, should the CDR be based on the temperature effects, the effective radiative forcing or a particular Global Warming Potential (GWP)? Moreover, the specifics of how to compensate equivalently are not informed by science alone. For instance, the required quantity of compensation differs depending on whether it is based on GWP20 or GWP100, which is a political choice.

   The required duration of compensating may be longer than the duration of a compensation project. In such a case, the actor in question must invest in a new compensation project following completion of the current compensation project and, if necessary, do so again at the end of the new project. In this situation, guarantees for successive projects would need to be provided beforehand.

2. **Compensation takes place by means of high-quality carbon dioxide removal projects:** this means that the projects in which the actual compensation takes place must meet specific criteria. The set of criteria and their details are currently under development. Various organisations are working to develop criteria that 'high-quality' or 'high-integrity' CDR projects in the voluntary carbon market would need to meet – for example, the European Union, the Integrity Council for the Voluntary Carbon Market and Carbon Direct & Microsoft.[27] Companies are increasingly demanding projects that meet these criteria.[28] Broadly speaking, the criteria are as follows:
   a) The projects are demonstrably additional. That is to say that projects go beyond what is legally required at the level of the individual operator and would not take place without the funding or other support for the compensation project.
   b) The projects do not result in impacts being passed on to other sustainability areas and future generations. Indeed, ideally they should contribute to other sustainability goals.
   c) The risks of premature release of CO_2 have been covered. We refer to premature release if stored CO_2 is released before the expected (or claimed) storage duration of a CDR project has been reached. Coverage of risks takes the form of risk minimisation on the one hand and adequate risk management on the other. This is to prevent others (e.g. future generations) having to bear the cost of damage remediation.
   d) Liability mechanisms for the consequences of premature release of CO_2 are in place.
   e) The projects achieve the intended compensation in a measurable and verifiable manner and report transparently on this.

[27] See Regulation (EU) 2024/3012 (2024), ICVCM (2024) and Microsoft & Carbon Direct (2024).

[28] See for example de Wit (2024).

The criteria under point 2 apply to all CDR methods, but they require further elaboration for the individual methods. So, for instance, the European Commission is working, via delegated acts, to tailor the EU carbon removal certification framework to different CDR methods. Only once that work is complete[29] will the precise details of these criteria be known. In any event, it is clear that by comparison with permanent removals, temporary removals are generally associated with a higher risk of premature release. This means that more stringent requirements must be imposed on projects that temporarily remove CO_2 in terms of how risks are dealt with (see also section 4.2).

4.2 Management of risks of premature release of CO_2 from temporary removal projects

Responsible compensation with temporary CDR imposes high requirements on risk management. Firstly, it is necessary to assess and minimise risks as far as possible beforehand; secondly, ongoing risk management is important (e.g. because risks can change if (climate) conditions change); and finally, the operator[30] needs to take measures in advance in case risks actually materialise. The existing voluntary carbon markets primarily make use of buffer pools for this purpose. In a buffer pool, in addition to the intended CDR, a reserve of CDR capacity is built up (e.g. by planting extra trees), which are used to compensate for the damage in the event of premature release of CO_2. However, cases have already occurred in practice where the buffer pools proved insufficient.[31] This represents yet another type of risk that needs to be managed, for example by means of geographical distribution of projects or compensation of the damage by means of other temporary or permanent CDR methods.

The required intensity of risk management varies for the individual methods of temporary CDR because they differ in terms of both risk of premature release of stored CO_2 and expected duration of sequestration.[32] These two dimensions are visualised for the different methods of CDR in Figure 4. It may be observed that the expected storage duration and the risk of premature release are correlated but are not related one-to-one. For instance, it may be that stored CO_2 can be sequestered longer with afforestation and reforestation than with timber construction: a forest can stand for centuries, but centuries-old wooden houses are rare. On the other hand, the risk of premature release of CO_2 stored in a forest is greater, because the forest is also at risk from natural factors such as forest fires and diseases of trees. There are fewer threats of this kind that affect timber construction. From a risk perspective, the preference is for the use of methods with a low risk of premature release.

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[29] This is expected to be the case in 2025; see European Commission (2024) for the timetable.

[30] The operator is the party that implements the CDR project.

[31] Badgley et al. (2022).

[32] See for example Höglund (2022).

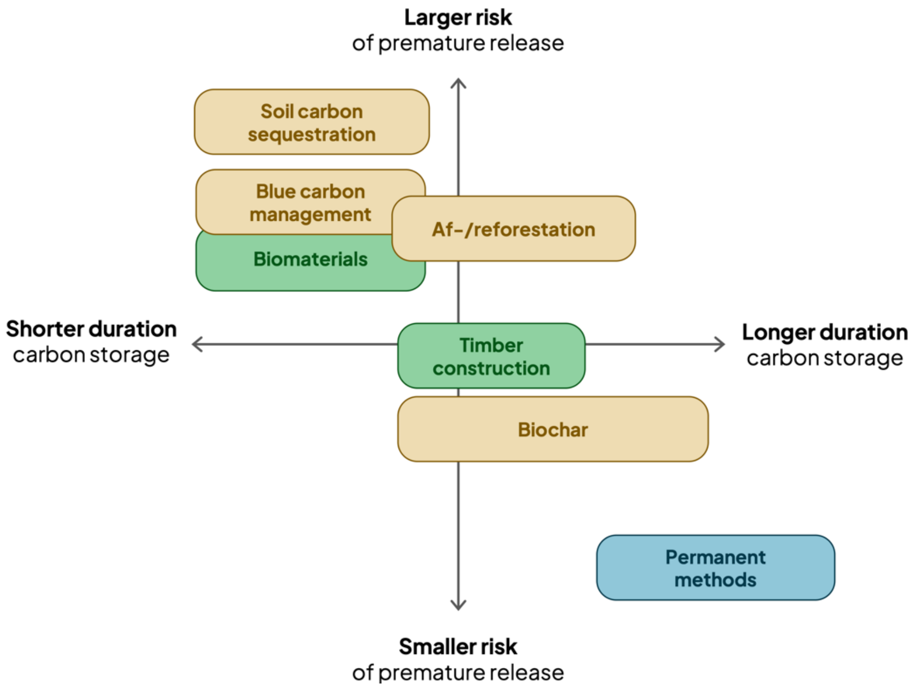

Figure 4. *Classification of CDR methods based on sequestration duration and the risk of premature release. Green stands for temporary sequestration in products and brown for sequestration in soils and crops. The axes are indicative.*

Another dimension is the extent to which the premature release of stored CO_2 is predictable. In the example of the forest, not only is the risk of premature release relatively high, but the moment at which it might happen is difficult to predict. In a hot, dry summer, a large area of forest can suddenly burn down and start emitting CO_2. In the case of timber construction, by contrast, the risk of premature release of stored CO_2 (for example as a result of demolition or fire) is more limited and easier to predict: the development over time is more even.

4.3 Responsible compensation from an overarching perspective

If compensation is responsible at project level, that does not necessarily mean this is also true at the overarching level, for example at the level of a country or the EU. We list a number of examples here.

Under certain circumstances, CO_2 can be released prematurely from multiple temporary CDR projects simultaneously

It is conceivable that (linked) risks of premature release could materialise simultaneously in different CDR projects – for example as a result of fires or plant diseases affecting several afforestation projects at the same time. This also calls for a form of risk management that transcends the individual projects. Examples of strategies for reducing risks of this kind are diversification in the CDR methods used and spatial distribution of projects with similar risk profiles. Moreover, if multiple risks materialise simultaneously, a situation can arise in which although individual projects are insured, insurers are unable to (fully) compensate for the damage because a number of projects have been affected at the same time.[33] For example, this situation could occur in a summer in which many forest fires break out throughout Europe.

[33] That could be financial compensation or compensation in the form of CDR certificates. See for example Kita (2023).

Large-scale temporary CDR can result in carbon leakage

The sum of multiple temporary CDR projects can result in a substantial increase in the agricultural land area (change in land use) elsewhere, assuming constant demand for food, which means the CDR is contributing to carbon leakage.[34] The responsibility for preventing leakage on this scale transcends that of the operator and should be taken at a higher level.

[34] Mitchell-Larson and Allen (2022).

5 To what extent does emissions accounting comply with the requirements of equivalent compensation?

Chapter 3 shows that emissions of a GHG are only eligible for with temporary CDR in a few situations. In the other situations, emissions may only be compensated with permanent CDR. The current system of emissions accounting and climate policy do not yet make any distinction between the origin and nature of a GHG emission and the type of associated CDR, temporary or permanent. This means that the like-for-like principle for compensation described in Chapter 3 is not applied to those emissions and that, as a result, compensation does not always take place on an equivalent basis.

In this chapter, we discuss some specific shortcomings in more detail. Section 5.1 is concerned with shortcomings in emissions accounting. Section 5.2 suggests a series of action points for the design of future European climate policy in order to take account of the requirements for compensation in the use of temporary CDR.

5.1 Temporary CDR in emission inventories

5.1.1 Including temporary CDR in emission inventories

Most temporary CDR methods already have a place in emission inventories within the Land Use, Land Use Change and Forestry (LULUCF) accounting category – specifically, afforestation and reforestation, carbon storage in the soil, management of blue carbon, biochar and timber construction.[35] In principle, biomaterials based on *woody* biomass can be included, in view of the fact that the stock of carbon in 'harvested wood products' is maintained. Not all forms of carbon storage in biomaterials currently fall under that category.[36] Currently, carbon storage in biomaterials based on *non-woody* biomass does not count as CDR. This is because the existing accounting system assumes that when non-woody biomass is harvested, the carbon it contains decays immediately ('instantaneous oxidisation').[37]

Whether temporary CDR is included in the inventory is highly dependent on the chosen method of classification and its level of detail. In many cases, standard emission factors are used to calculate net emissions in an accounting category. As a result, it is possible that an individual CDR project may not be counted. There are proposals to increase the level of detail of the classification by linking data for individual CDR projects to the inventories.[38]

5.1.2 Shortcomings of compensation with temporary CDR in the existing accounting system

The existing accounting system has several shortcomings when it comes to dealing with temporary CDR.[39] The risk is that the climate gains secured on paper with CDR do not exist in reality, or not in full. We highlight three shortcomings:

- **The like-for-like principle is not applied in the existing accounting system.** In the inventories, net greenhouse gas emissions are the sum of recorded greenhouse gas emissions and CDR. This means that emissions of fossil CO_2 or other long-lived GHGs can be compensated with temporary CDR. If this is the case, the like-for-like principle has not been met.

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[35] See Chapter 3 of Jörβ et al. (2022).

[36] The accounting for harvested wood products is based on different pools, each with an estimated half-life for the carbon from those pools. In the Netherlands, the following four pools have been defined: *Sawnwood*, *Wood panels*, *Other industrial round wood*, and *Paper and paperboard* (RIVM, 2024). Timber construction falls into the first three pools, but as yet there is no suitable pool for bioplastics. The IPCC is currently working to improve the guidelines for emissions accounting, and is also including biomaterials under the designation 'durable biomass products' (IPCC, 2024, p. 20).

[37] See p. 23 of Jörβ et al. (2022).

[38] See for example Olesen (2023) and Section 4.1.4 of Fallasch et al. (2024).

[39] As in chapter 3, we use 'compensation' in a broad sense here: it therefore also includes the contribution that CDR can make to net emissions, i.e. what remains 'below the line' in terms of emissions minus removals.

5 To what extent does emissions accounting comply with the requirements of equivalent compensation?

- **The existing accounting system underestimates the warming effect of short-lived GHGs.** In order to compare the warming effects of different GHGs, the Global Warming Potential (GWP) is used. This allows emissions of other GHGs to be converted into CO_2 equivalents. In the accounting system used for the Paris Agreement, this is done by comparing the warming effect of another GHG with that of CO_2 over a time period of 100 years (GWP100).[40] This method underestimates the heating effect of short-lived greenhouse gases such as methane in the short term, but overestimates the effect in the long term. If emissions of short-lived GHGs are compensated with (temporary) CDR, this can make it appear, for accounting purposes, that the entire warming effect has been compensated, yet there can still be a warming effect in the short term.
- **Because natural carbon sequestration and temporary anthropogenic CDR are not easy to distinguish from one another, the climate gains of removal may be double counted and therefore overestimated.** Historically, a large proportion of the emissions caused by humans was absorbed by natural carbon sinks on land and in the sea, as a result of which the climate heated up much less than would otherwise have been the case. Climate models include these natural carbon sinks when calculating how much CO_2 humans can still emit to achieve the Paris goals. The definition of climate neutrality is also based on the idea that forests and oceans continue to absorb CO_2 as a result of natural processes, meaning that net zero GHG emissions as a result of active human intervention is enough to stop global warming. If natural sequestration is counted as well, there is no guarantee that achieving climate neutrality will actually stop global warming.[41]

  Nevertheless, natural sequestration is often included in the emission inventory, because in practice it is difficult to distinguish it from sequestration as a result of human intervention. In order to take this into account, the current system differentiates between 'managed lands' (land under human management or use) and 'unmanaged lands' (lands not under human management or use). Emissions and carbon sequestration in unmanaged lands are not included in the national emissions accounts. However, in the EU, the great majority of land is classified as managed land; indeed, in the Netherlands, *all* land is classified as managed land.[42] This means that all sequestrations in Dutch forests count, even if they are not the result of direct human intervention and therefore do not belong in the emissions accounts. An example is the sequestration that arises as a result of additional CO_2 in forests (CO_2 fertilisation), which is already counted as 'natural sequestration' in the climate models. If this sequestration is also included in the emissions accounts, there is double counting: the same sequestration is included in the climate models and in the accounts.

  For a country like the Netherlands, the effect of this double counting is relatively limited, but in larger countries it can represent a bigger problem. Moreover, to the extent that efforts to increase sustainability become more difficult, an incentive can arise for countries to claim natural sequestration as active removals by humans, in order to more easily meet their climate goals. Such double counting would then suggest progress or a climate-neutral and safe balance, when in fact the warming effect of those emissions is underestimated. That risk increases to the extent that there is more natural sequestration, making it all the more important to properly distinguish between natural and temporary anthropogenic removals in the accounting figures or in policy.

[40] UNFCCC (2019).

[41] Allen et al. (2024).

[42] See table 4.1 in European Union (2023), and van Baren et al. (2024).

5.2 Issues to consider in incorporating temporary CDR in climate policy

5.2.1 Temporary CDR in climate goals

One purpose of emissions accounting is to determine whether efforts to achieve emissions targets – such as climate neutrality by 2050 – are on track. Section 5.1.2 shows that based on the existing accounting system, there is a risk that warming is greater than the accounts suggest, due to the way temporary CDR is counted.

For instance, the Dutch Climate Act states that the Netherlands "will reduce net emissions of GHGs to zero by 2050 at the latest".[43] This could mean that fossil emissions may be compensated with temporary CDR, contrary to the like-for-like principle. In line with our previous recommendations, this could be prevented by adding additional conditions – such as requiring low gross emissions and applying the like-for-like principle.[44]

In practice, there are already examples of setting extra conditions for the achievement of an emissions target. For instance, a maximum of 225 $MtCO_2e$ of CDR may be counted towards the EU emissions reduction target for 2030.[45] Since the goal for the LULUCF sector is to achieve 310 $MtCO_2e$ in CDR by 2030, only a part of that CDR may therefore be used to achieve the 2030 target.

5.2.2 Issues to consider when designing EU climate policy

Within the current architecture of European climate policy, there is limited scope for compensating fossil and long-lived GHGs with temporary CDR. That scope lies in the flexibility mechanism ('LULUCF flexibility'), which allows member states to use removals from the LULUCF sector to achieve their objectives in the Effort Sharing Regulation (ESR) sector. If more CDR is then achieved in the LULUCF sector than needed to fulfil the LULUCF objectives, that CDR can be used to meet the targets for the ESR sector. This can result in temporary CDR from the LULUCF sector compensating fossil emissions or nitrous oxide emissions in the ESR sector, which runs counter to the like-for-like principle and therefore results in non-equivalent compensation. However, because the quantity of temporary CDR that can be added from the LULUCF sector by this mechanism is limited, and because biogenic CO_2 and methane emissions also fall under the ESR sector, the risk of non-equivalent compensation is limited.[46]

In further developing the architecture of European climate policy, there will be opportunities to ensure compensation in accordance with the like-for-like principle. This is needed because, in the following planned or proposed policy sectors, there is a risk of that principle being violated if additional conditions are not imposed:

- **ETS-1 and ETS-2:**[47] Both emissions trading systems relate to fossil emissions. If, under those systems, it becomes possible to obtain emission allowances by deploying CDR, this could be limited to permanent CDR. See recommendation 3 in WKR (2024b).
- **AgETS or AFOLU sector:** [48] There are suggestions to create a European emissions trading system for agriculture (AgETS) or for a sector consisting of the agriculture sector and the LULUCF sector (AFOLU sector). In accordance with the like-for-like principle, emissions from peatlands or emissions of nitrous oxide would not be eligible for compensation with temporary CDR. See section 3.2.

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[43] Klimaatwet (2019).

[44] See recommendations 1 and 3 in WKR (2024b).

[45] Article 4.1 of the European Climate Act (2021).

[46] The total quantity of CDR that can be employed in this way is limited to 262.2 $MtCO_2e$ for the 2021–2030 period, broken down into two shorter periods (2021–2025 and 2026–2030), and further distributed across individual member states in proportion to their agricultural emissions (Fridahl et al., 2023; Regulation 2023/857, 2023).

[47] ETS1: European emissions trading system focused on emissions of CO_2, N_2O (nitrous oxide) and PFCs (perfluorocarbons) from energy-intensive enterprises such as the electricity sector, refining industry, chemicals industry, metals sector.
ETS2: European emissions trading system focused on CO_2 emissions from the built environment, transport and other sectors (primarily small industry that does not fall under EU ETS-1).

[48] AgETS: Emissions Trading System for Agriculture. AFOLU: Agriculture, Forestry and Other Land Use.

Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AgETS	Emissions Trading System for Agriculture
CDR	Carbon Dioxide Removal
CO_2e	Carbon dioxide equivalents
ESR	Effort Sharing Regulation
ETS	Emissions Trading System
ETS-1	European emissions trading system 1, focused on emissions of CO_2, N_2O (nitrous oxide) and PFCs (perfluorocarbons) from energy-intensive enterprises such as the electricity sector, refining industry, chemicals industry, metals sector
ETS-2	European emissions trading system 2, focused on CO_2 emissions from the built environment, transport and other sectors (primarily small industry that does not fall under EU ETS-1)
F-gases	Fluorinated greenhouse gases
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change and Forestry
Mt	megatonne
UNFCCC	United Nations Framework Convention on Climate Change
WKR	The Netherlands Scientific Climate Council

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Appendix: Experts consulted

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Background report: Responsible use of temporary carbon dioxide removal
Accompanying WKR report 002: *Clearing the air? Advice for principles and policy for governing carbon dioxide removal*.

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