Clearing the air?

Advice for principles and policy for governing carbon dioxide removal

Advisory report

WKR The Netherlands Scientific Climate Council

Content

Foreword

In the first advice of the Netherlands Scientific Climate Council (WKR), entitled “All aboard for the transitions”, we recommended gaining experience with removing CO_2 from the atmosphere as soon as possible and at a meaningful scale (WKR, 2023). Net carbon dioxide removal (CDR) from the atmosphere is necessary to become climate neutral and, in the long term, potentially limit the temperature rise. The second advisory report of the Council presented here addresses this: we outline principles and risks of CDR and set out how the Netherlands can govern its development.

The title of this report is “Clearing the air?”. The question mark has been put there for a reason: while it is critical to remove CO_2 from the atmosphere, it is far from certain whether the required CDR capacity will materialise and whether the disadvantages can be averted. The first policy priority should continue to be the reduction of emissions. For this advisory report, we considered how CDR policies could be designed in conjunction with emission reduction policies. It is in the interest of the Netherlands to have a good CDR policy in place at the European and national level. With this advisory report, the Netherlands Scientific Climate Council aims to help the Dutch government and industry to make haste with the development of CDR.

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Summary

Deep, rapid and sustained reductions in emissions of greenhouse gases (GHGs) are essential to avoid the most severe climate impacts. But carbon dioxide removal (CDR) is required too.

The effects of climate change caused by human emissions of GHGs are becoming increasingly noticeable and severe. In the 2015 Paris Agreement, all countries agreed to limit global warming to well below 2°C, and to aim for 1.5°C. These temperature limits require rich countries, such as the member states of the European Union (including the Netherlands), to achieve net zero GHG emissions by 2050 at the latest. To this end, the parties to the European Climate Law have agreed to become 'climate neutral' by 2050, meaning they emit no more GHGs than are removed from the atmosphere. The Netherlands adopted this target in the 2019 Dutch Climate Act, which also states that the Netherlands will achieve 'negative emissions' after 2050 (in other words, that it will remove more GHGs from the air than it emits). CO_2 is the only GHG that can currently be removed from the atmosphere. This means that the Netherlands can only achieve its targets in the Climate Act with the help of CDR. This advice suggests principles and policies the Dutch government can adopt to steer the development of CDR.

Removing CO_2 from the atmosphere serves two purposes: it limits and reduces temperature overshoot, and it counterbalances residual emissions. GHG emissions can be brought to zero for many, but not all activities. Moreover, global emissions are not expected to fall fast enough to limit the rise in average global temperature to 1.5°C. It is therefore necessary to remove GHGs from the atmosphere, in addition to reducing emissions, for the following reasons:

- To lower the concentration of CO_2 in the atmosphere so that temperatures rise less rapidly or so that this rise could even be reversed. This could limit an overshoot of the 1.5°C target, and return the average global temperature rise to below 1.5°C by the end of the century.
- To achieve climate neutrality by offsetting GHG emissions that cannot be prevented, i.e. counterbalancing residual emissions.

CDR involves deliberate activities to remove net CO_2 from the atmosphere and store it for an extended period of time. Examples of CDR methods include planting new forests, using wood as a building material, biomass conversion combined with CO_2 capture and storage in deep geological formations, direct capture of CO_2 from the air combined with geological storage, mineralisation (where CO_2 reacts with minerals to form rock or building materials), and agricultural practices that increase soil carbon content. We consider methods where the CO_2 is stored for at least a few centuries permanent CDR. These include geological storage in deep geological formations and mineralisation of CO_2. Methods such as afforestation, sequestration of CO_2 in agricultural soils or the use of biomaterials in construction capture CO_2 temporarily, probably only for decades, and come with the risk that the CO_2 will be released even earlier due to events such as forest fires or drought. This is considered temporary CDR. Carbon dioxide capture and storage (CCS) and carbon dioxide capture and utilisation (CCU) of fossil CO_2 emissions only reduce emissions, and so are not CDR methods.

CDR has limitations and risks, both for the individual technologies and for the climate system as a whole. Practically all existing CDR methods either use a lot of (renewable) energy, land, or both. As a result, many methods have only a limited potential. Some methods have unwanted side effects, such

as a negative impact on nature, which could reduce public support for CDR. Methods for permanent CDR are not yet applied at the required scale, because they are not yet fully fledged, because they are too expensive, or for other reasons. This makes it uncertain whether CDR can be applied on a sufficiently large scale in practice.

If emitters rely too much on CDR and it fails to meet the expectations, future generations will be faced with even more climate change. Given the uncertainties and risks, there is a risk that CDR will not achieve the required capacity. Moreover, there is a real risk that emitters will delay reducing their emissions because they are counting on the CO_2 being removed from the atmosphere at a later stage, even if this CDR is still uncertain. This could mean that future generations will be confronted with even more extreme climate change. And even if these uncertainties and risks can be avoided, implementing CDR too late could lead to irreversible consequences for the climate system if temperatures continue to rise.

Avoiding emissions is more effective and reduces climate risks with more certainty than CDR. However, both are necessary, so we must be cautious not to trade one off against the other. Any GHG emissions that will have been avoided, will not contribute to climate change. Most emission reduction measures, such as energy conservation or solar power, have fewer negative side effects than most CDR methods. A balance will have to be struck between the rapid scale-up of new or existing CDR methods and continuing emission reductions. CDR policies should not detract from efforts to reduce emissions, or in any case as little as possible.

Recommendation
The Council recommends making maximum efforts to reduce emissions. This will limit the dependence on CDR to achieve climate neutrality. The Council also recommends that CDR be deployed primarily to limit and reduce a potential temperature overshoot.

Government intervention is needed to deploy CDR methods at the required scale. CDR is a public good: everyone benefits from it, and not just the party who carries it out. Companies are currently unable to monetise the benefits of CDR, leading to a lack of investment in the development and scaling up of permanent CDR methods. Government policy is needed to ensure demand for CDR is created so that it can be scaled up in time. Subsequently, national and European policy is required to ensure that CDR is widely and responsibly implemented.

Recommendation
The Council advises the Dutch government to pursue CDR policy, in conjunction with European policy.

To ensure that emissions are reduced as much as possible, it is prudent to limit the amount of CDR that can be used to counterbalance residual emissions. CDR should be deployed as little as possible to counterbalance residual emissions. Over-commitment to CDR could result in emitters failing to reduce avoidable emissions. To maintain the incentive for emissions reductions, it will help to establish the amount of allowable residual emissions in 2050. This will also determine the maximum amount of CDR that can be deployed for counterbalancing emissions. Such limits could be imposed at the European, national and sectoral levels. The limit could be reviewed on a regular basis and revised (if necessary) based on new developments, for instance if new societal or technological opportunities for emission reductions emerge.

Recommendation
The Council recommends setting limits to the use of CDR for counterbalancing residual emissions at the European, national and sectoral levels.

Only permanent CDR is suitable for offsetting fossil CO_2 and other GHGs that remain in the atmosphere for a long time. The global carbon cycle can be divided into a short cycle, for example plants absorbing CO_2 and indirectly re-emitting it, and a long cycle, such as carbon in fossil fuels that was sequestered millions of years ago. Human activities, such as the use of fossil fuels or the felling of old-growth forests, mix carbon from the long cycle with that of the short cycle. This CO_2 then stays in the atmosphere for a long time, causing global warming. Preventing the mixing of carbon from the short and long cycles therefore helps to mitigate climate risks. In addition, a very long storage duration is important for some other greenhouse gases, such as nitrous oxide or fluorinated compounds, which remain in the atmosphere for centuries or even millennia. Offsetting these greenhouse gases requires a proportional amount of permanent CO_2 removal.

Recommendation
The Council recommends deploying only permanent CDR to offset fossil GHG emissions and emissions of GHGs that remain in the atmosphere for a long time.

Policies are required to scale up permanent CDR methods in particular and develop a market for them. Unlike temporary CDR methods, permanent CDR is not yet widely applied. This is why policies are necessary to scale up permanent CDR and develop the market for these methods.

Recommendation
The Council recommends focusing Dutch CDR policy on permanent methods.

Despite its limited contribution to the climate targets, there are good reasons to stimulate temporary CDR as part of other policies, such as those directed at nature restoration or sustainable forestry and agriculture. Methods for temporary CDR (such as afforestation, reforestation and sequestration of CO_2 in agricultural soils) are often more developed and cheaper than permanent methods. However, temporary methods have only a limited potential in the Netherlands. Policies that promote temporary CDR in agriculture and forestry could have negative impacts on other policy areas, such as food production, biodiversity and land use. Policies aimed at sustainable construction, sustainable agriculture, nature restoration and the prevention of soil subsidence could on the other hand have positive side effects.

SUMMARY

Recommendation
The Council recommends encouraging temporary CDR in the Netherlands, but only as part of other policies.

There are various policy instruments that could be deployed to implement and scale up permanent CDR. There is a voluntary carbon market where CDR certificates are traded. However, the current voluntary market will not be able to achieve the required scale and quality of CDR. First, it is not sufficiently clear whether the voluntary market will lead to long-term, sustainable and truly additional CDR. The voluntary market is geared towards offsetting fossil emissions with relatively cheap, temporary CDR. Second, the voluntary market is likely to remain small, because the incentives for companies to invest in CDR are limited and fragile. There are various other ways in which the government can stimulate the demand for CDR, for example by procuring CDR certificates, obliging emitters to carry out CDR, or including CDR in an emissions trading scheme. A key prerequisite for the deployment of these instruments is a reliable certification system for CDR. European certification policy to this end is already at an advanced stage.

It is in the Netherlands' interest to ensure that sustainable methods for permanent CDR become widely available as soon as possible. As a rich country with both high current and historical per capita emissions, the Netherlands must contribute to reducing a temperature overshoot. The Netherlands also has an interest in counterbalancing what will likely be 'hard-to-abate' residual emissions, for example from some parts of the agriculture sector, the industry and aviation. The Dutch government should therefore adopt targeted policies to stimulate the implementation of various methods of permanent CDR. To meet the climate targets, this would need to be well underway before 2035. An obligation that would only apply to Dutch emitters would create an uneven European playing field. Targeted procurement of CDR certificates is currently a suitable instrument, as it can be introduced relatively quickly, does not come at the expense of emission reductions, and does not disadvantage Dutch emitters.

Recommendation
The Council recommends launching a Dutch government-led procurement programme for permanent CDR to gain experience with various methods of CDR in the Netherlands in the runup to 2035.

It is important that, in addition to Dutch policies, European CDR policies also get off the ground quickly. As a member state with a relatively large need for permanent CDR, it is important for the Netherlands that European CDR policies are implemented. With European-level policies, more CDR options will become available, which will reduce the costs. Such policies can also prevent carbon leakage and create a level playing field for emitters. It is therefore in the Netherlands' interest for Europe to quickly reach sound agreements. The Netherlands can influence this by leading the way in the development of a European strategy for creating demand for CDR.

SUMMARY

Recommendation
The Council advises the Dutch government to initiate cooperation with other member states to explore possible European policy instruments for creating demand for CDR and encourage their introduction.

Any potential inclusion of CDR in Europe's Emissions Trading Scheme (ETS) should be subject to stringent conditions. Delaying the moment of integration will reduce the risks of trade-offs between CDR and emissions reductions. Under the current policy, fossil CO_2 emissions covered by the ETS will need to fall to zero between 2040 and 2045. For some strategic or economically important activities, however, achieving zero CO_2 emissions will be almost impossible in that timeframe. The remaining emissions would require offsetting within the ETS to reach net zero. However, including CDR in the ETS too early could reduce the incentive for emissions reductions. To prevent this from happening, CDR should only be deployed in the ETS under strict conditions: only if it concerns permanent CDR (because the emissions regulated by the ETS consist entirely of fossil emissions), and only if there really is no other means, for example because the ETS no longer functions properly because there are only limited opportunities for emission reductions. Moreover, if CDR certificates are introduced in the ETS by the government, the European Union will have more opportunities to regulate the deployment of CDR in the ETS.

Recommendation
The Council recommends to exclude CDR from the ETS as long as possible, to maintain the incentive for emission reductions for as long as possible. The Council further recommends that, should CDR become part of the ETS, only the government be authorised to introduce CDR certificates in the market.

To avoid shifting the costs of CDR to future generations, it is reasonable to ask current emitters to help pay for future CDR. Permanent CDR that is achieved today, and is not used to offset emissions, will help to limit temperature overshoot. However, there is currently little permanent CDR capacity available. It is therefore not possible to oblige current emitters to remove all their remaining CO_2 emissions from the atmosphere. Most of the costs of CDR therefore risk to be shifted to future generations, who are not themselves responsible for the emissions. To avoid the situation where future generations bear a disproportionate burden of CDR, provisions should be taken today to ensure that current emitters contribute to future CDR. There are several ways to do this, such as a CDR fund or extra investments to reduce emissions. More research is needed to determine the best route.

Recommendation
The Council advises the government to ensure that emitters start contributing from now on to the future costs of limiting and reducing a temperature overshoot, and to design and implement instruments to this end.

1 Introduction

1.1 Background

In the Paris Agreement, almost all countries in the world agreed to limit global warming to well below 2°C, and to pursue efforts to limit it to 1.5°C. Today, the Earth is already 1.2°C warmer than in the pre-industrial period (defined as the period between 1850-1900). Climate science tells us that every bit of additional warming exacerbates the global impacts, risks, loss and damage from climate change.[1] If every country were to rapidly reduce their emissions of greenhouse gases (GHGs), it would be possible to limit warming to 1.5°C by the end of the century.[2] This is also important for the Netherlands: the likelihood of issues such as water scarcity, extreme summer heat, and heavy rainfall increases with further climate change, and particularly in a high warming scenario.[3] Sea level rise inhibits the drainage of the Netherland's rivers and also increases the risk of flooding in the densely populated delta, particularly when combined with heavier rainfall.

There is a real likelihood that the 1.5°C target will be exceeded. There is an almost direct relationship between total historical CO_2 emissions and global warming. Scientists use that relationship to estimate how much CO_2 can be released if we are to limit global warming to 1.5°C by the end of this century. This is called the carbon budget. According to the latest report by the Intergovernmental Panel on Climate Change (IPCC), the world has a remaining budget of 250 $GtCO_2$[4] emissions to still have a 50% chance of limiting global warming to 1.5°C by the end of the century. This is only six times the current annual global CO_2 emissions, and these emissions are still not falling. As the remaining carbon budget to stay below 1.5°C is so small, there is a real risk that the 1.5°C target will be temporarily exceeded sometime this century.[5] This is called a 'temperature overshoot': a situation where the average global temperature is more than 1.5°C higher than pre-industrial levels.[6] The additional consequences, risks, damage and suffering caused by overshooting the 1.5°C target can be reduced by limiting the degree and duration of a temperature overshoot. This is why all IPCC scenarios that limit global warming to 1.5°C or 2°C by the end of this century require rapid emission reductions, but also the removal of CO_2 from the atmosphere. This is called carbon dioxide removal, or CDR. In fact, a temperature overshoot can only be reduced with the help of CDR in combination with maximum GHG reductions.

CDR involves a range of activities that remove net CO_2 from the atmosphere and store it durably for an extended time period.[7] An example of such an activity is planting and restoring forests. Plants and trees sequester CO_2 from the air as they grow and can thus lower CO_2 concentrations in the atmosphere. There are also certain minerals that remove CO_2 from the atmosphere as they weather, such as olivine and basalt, and CO_2 can be co-mineralised during cement production. There are farming practises that increase the sequestration of organic matter in the soil, which also remove CO_2 from the air. Furthermore, CO_2 can be directly filtered from the atmosphere by blowing air over a material that binds the CO_2 in that airstream. The filtered CO_2 can then be stored, for example in underground natural gas fields (direct air carbon dioxide capture and storage, DACCS). Finally, CO_2 can be removed from the atmosphere using biomass in combination with carbon dioxide capture and storage (bioCCS). Box 1 provides the definition of CDR that we use in this report.

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Box 1: Definition of Carbon Dioxide Removal (CDR)
The IPCC defines CDR[8] as "anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products".[9] 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 GHG emissions in the CDR supply chain.[10]

As GHGs remain in the atmosphere for at least several decades (e.g. methane), centuries (CO_2 and nitrous oxide) or even millennia (fluorinated gases), CO_2 must be stored for extended periods of time in order to combat climate change. We therefore distinguish between temporary CDR, which leads to storage for at least a few decades and involves the risk that CO_2 will be released earlier than planned, and permanent CDR, which involves a storage period of at least a few centuries and with a very low probability of early release of the stored CO_2.

CDR is necessary for two purposes: to limit the degree and duration of a temperature overshoot, and to counterbalance residual GHG emissions. First, the European Union (EU) and the Netherlands want to achieve net zero GHG emissions (also referred to as climate neutrality) by 2050. This means that GHG emissions and removals on European territory must balance. As not all emissions can be reduced to zero, a small part of the emissions in 2050 (the residual emissions) must be compensated with CDR.[11] Second, the Dutch climate act and European climate law require that 'negative emissions' be achieved after 2050: this means that on EU territory, more CO_2 must be removed than GHGs are emitted. In this situation, the Netherlands and the EU start removing a part of their historical CO_2 emissions and help to ensure a shorter period during which the target of maximum 1.5 °C global warming is exceeded. Figure 1 illustrates the different roles of CDR.

1 INTRODUCTION

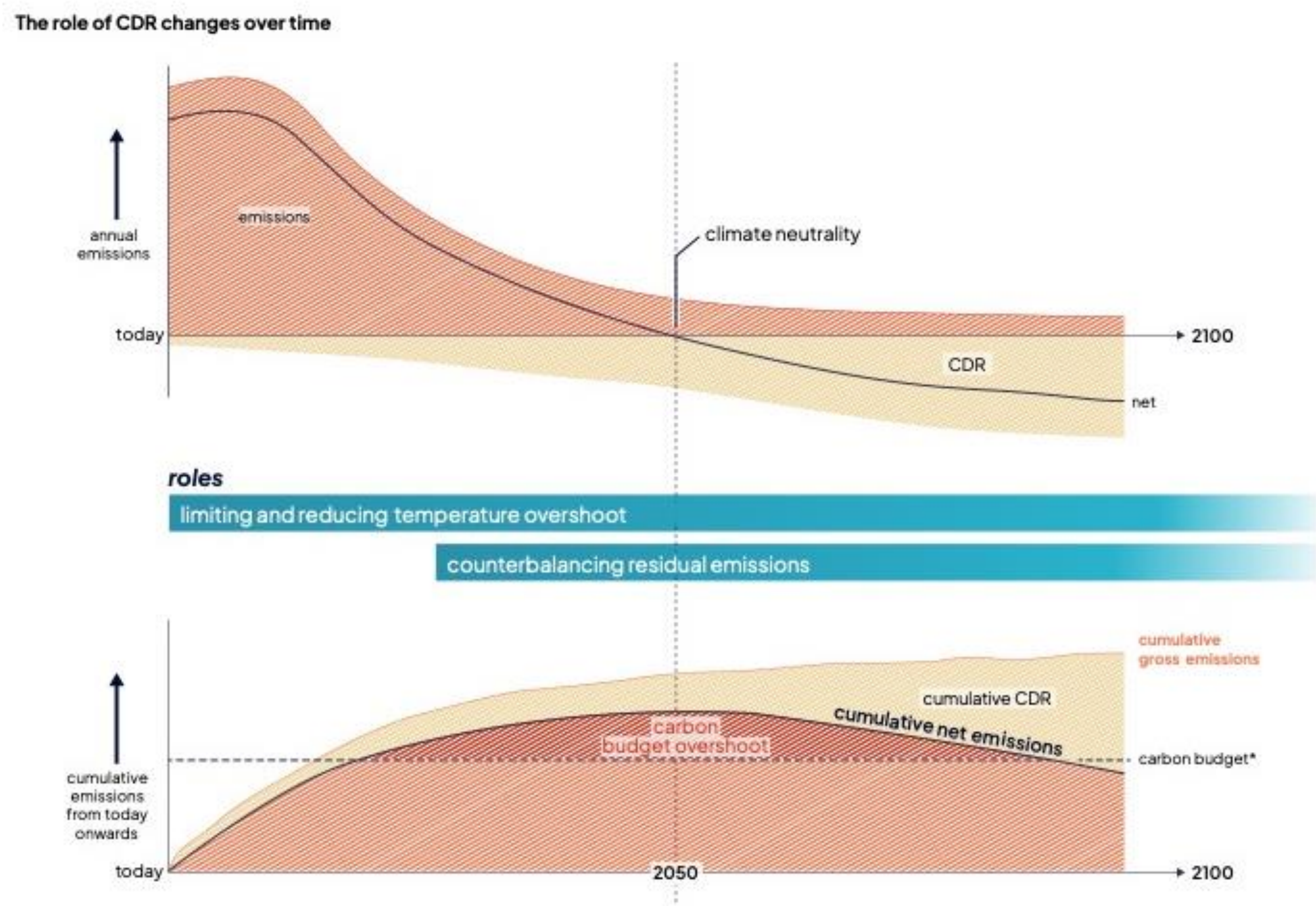

Figure 1: The role of CDR changes over time
Illustration of the roles of CDR in mitigating climate change. CDR is needed to limit and reduce a temperature overshoot, and to counterbalance the small proportion of residual emissions to achieve climate neutrality. The red shaded area shows the annual (top graph) and cumulative (bottom graph) GHG emissions. The yellow area shows the annual (top graph) and cumulative (bottom graph) amount of CO_2 removed from the atmosphere. The black lines show the net emissions, i.e. GHG emissions minus the CO_2 removed. Global warming is reduced as soon as CDR starts (upper blue bar). When it becomes very hard or expensive to continue reducing emissions, CDR can also be deployed to counterbalance the residual emissions (lower blue bar). In the bottom figure, the area between the dotted line and the solid line depicting an overshoot of the carbon budget is illustrative.

1 INTRODUCTION

Temporary CDR is already taking place, but the scale is limited. Methods that permanently remove CO_2 are scarcely available. Afforestation and reforestation currently make the largest contribution to CDR worldwide. However, due to the scarcity of available land, the maximum CDR by these means is expected to be reached around the middle of this century.[12] Moreover, forests are under pressure from human activity worldwide, forests can burn down, and trees can be vulnerable to disease. In these situations, the CO_2 stored by the trees is released again.[13] Weather extremes such as heat and drought are exacerbated by climate change, further increasing this risk. To achieve the expected amount of CDR necessary, new methods for the permanent storage of CO_2 are needed. However, the current applications of these relatively new methods are still limited. By 2020, they made only a very limited contribution globally: 0.0025 $GtCO_2$/yr, significantly less than the 3 $GtCO_2$/yr currently stored through forest management (Figure 2).[14] Achieving the two CDR aims will require a major scale-up of the methods for permanent CDR.

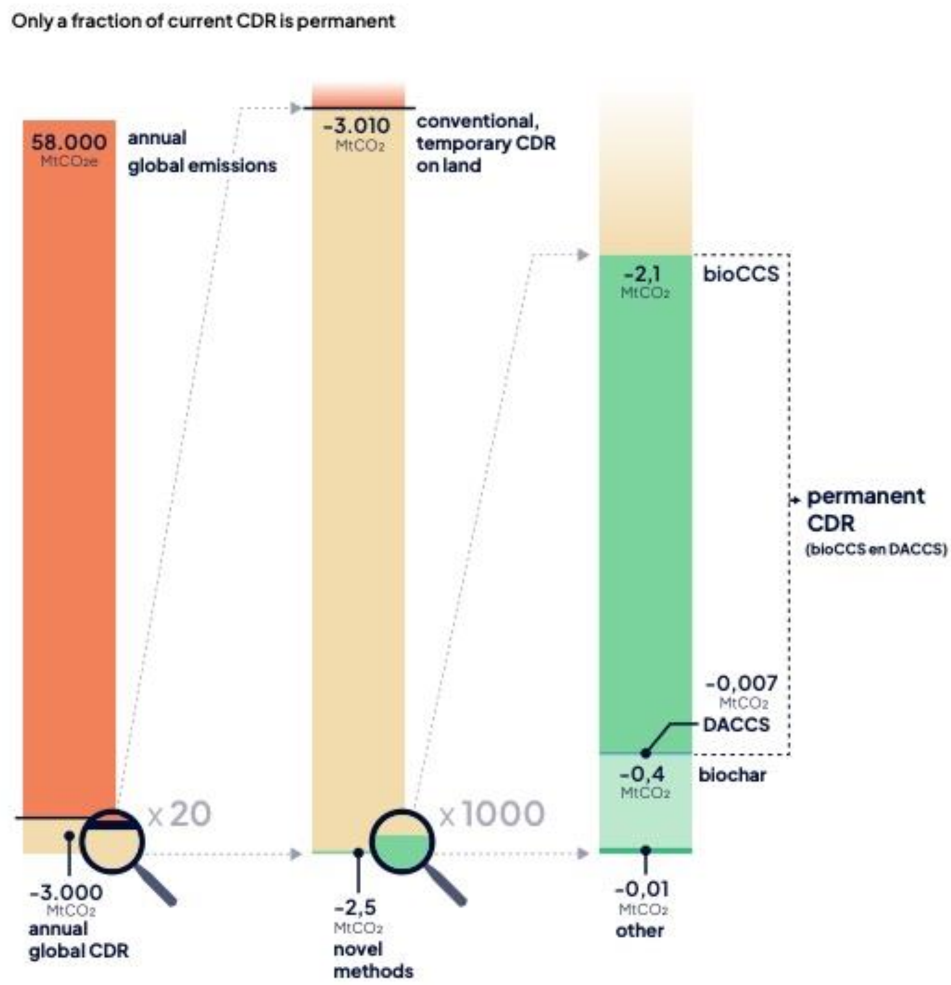

Figure 2: Only a fraction of current CDR is permanent
Worldwide, substantially more carbon dioxide equivalents (CO_2e) are emitted annually than removed (left). The current amount of CDR is 99.9% temporary CDR, mainly in the form of CO_2 sequestration through forest management (centre). Only a tiny fraction is permanent CDR (right). This figure is based on Lamb et al. (2024b).

Government intervention is needed because market incentives for developing and scaling up permanent CDR methods are lacking. While there is a voluntary CDR market, it is unsuited to achieving the required scale and quality of CDR. The vast majority of the supply in this market consists of low-cost temporary CDR solutions, while there is also a need for permanent CDR. Permanent CDR comes with high costs that cannot currently be recouped, even though it benefits society. This makes CDR a public good. As a result, high-quality, permanent CDR solutions will not be developed without some form of incentive. Government intervention is therefore required to develop and implement permanent CDR on a sufficient scale.

CDR has limitations and risks, both in terms of the individual technologies and in terms of the climate system as a whole. It is therefore important to pay careful attention to the design of CDR policy. Practically all existing CDR methods either use a lot of energy, a lot of land, or both. As a result, many of these methods have only limited applicability. Technologies for permanent CDR cannot yet be applied at the required scale, because they are not yet fully fledged, because they are too expensive, or for other reasons. Also, the creation of national and European institutions for CDR (in the sense of decision-making rules, laws, regulations, and the like), achieving public support, and the timely completion of the required infrastructure will not happen as a matter of course. This makes it uncertain whether CDR will get off the ground in good time to be applied on a sufficiently large scale. Despite all these risks, constraints and uncertainties involved in CDR, there is a real risk that emitters will delay reducing their own emissions, because they count on the removal of this CO_2 from the atmosphere at a later stage. Policymakers need to take this risk into account too. On top of that, even if durable and large-scale CDR is eventually implemented, there could be irreversible consequences for the climate system if temperatures continue to rise before this happens.

1.2 This advisory report

1.2.1 Request for advice
This advice by the Netherlands Scientific Climate Council (WKR) aims to contribute to the development of CDR policy by the Dutch government. The advice focuses on the following central research question:

What principles and policies can the Dutch government adopt to govern the development of CDR?

1.2.2 Scope
- **Focus:** The focus of this advisory report is government CDR policy. This policy needs to be further developed and implemented at both the national and the European scale. The advisory report focuses on the following policy components: principles for responsible incentives for CDR, and instruments for creating demand for permanent CDR.
- **Applicable period:** This advisory report applies to the period up until climate neutrality has been achieved as well as to the period thereafter, when the goal is net negative emissions. This policy advice focuses on plans that can be implemented with immediate effect.
- **Policy context:** The advice is limited to the Dutch and European policy context. According to the European Climate Law, climate neutrality must be achieved on European territory.
- **Generic instruments:** The instruments for creating demand for CDR that we recommend in this advisory report have a broad scope and are not focused on specific CDR methods. If desired, the government can also pursue policies that target specific CDR methods (for example methods with fewer unwanted side effects). Such specific polices are not discussed in this advisory report.

- **Innovation policy:** Innovation policy is beyond the scope of this advisory report, because the report focuses on principles and instruments for scaling up CDR. Nevertheless, an exploratory study of the Dutch innovation system for CDR needs to be carried out to establish the position of the Netherlands in the global CDR arena.[15] Policy instruments that stimulate demand for CDR can also indirectly promote innovation, both inside and outside the Netherlands.

1.2.3 Target group
This advisory report primarily addresses the Dutch government and parliament and aims to support the government's thinking and policymaking on CDR. In particular, the advisory report provides input for the upcoming Dutch Climate Plan for 2025-2035 and the Carbon Removal Roadmap (*Routekaart Koolstofverwijdering*). The advisory report also aims to support the ideation of Dutch contributions to the CDR policy theme in the EU. In addition, the Council hopes that this advisory report will support the academic community, civil society organisations, and the industry in the development of ideas and solutions for CDR.

1.2.4 Working method
This advisory report is based on a literature review, two international expert meetings organised by the Council, exchanges of information with the European Scientific Advisory Board on Climate Change, policymakers of the Ministry of Economic Affairs and Climate Policy, and the Ministry of Agriculture, Nature and Food Quality and the Ministry of Infrastructure and Water Management, the European Commission (EC), and commentary provided by a group of experts.
CDR is a rapidly developing research field on which new insights, ideas, analyses and overviews are published regularly. In that sense, this advisory report forms a snapshot in time in terms of the scientific state-of-the-art.

1.2.5 Reading guide
Chapter 2 provides a brief overview of various CDR methods. Chapters 3 and 4 contain the Council's advice and jointly answer the central research question. Chapter 3 discusses the key principles of CDR policy and highlights the importance of government in creating demand for permanent CDR. Chapter 4 provides a brief overview of the key components of CDR policy and then focuses on the limits that need to be established for residual emissions and instruments for creating demand for permanent CDR.

Notes

1 IPCC (2022b, pp. 15-23).
2 UNEP (2023).
3 KNMI (2023).
4 This involves a large uncertainty range of -200 to 830 $GtCO_2$ (17-83% confidence interval). There are many uncertainties, because we are still finding out precisely how sensitive the climate system is to our emissions, and the mitigation potential of GHGs such as methane and nitrous oxide is unclear.
5 Moreover, the remaining global carbon budget must be shared by all the countries in the world. There is no international consensus as to how this should be done, and what grounds of feasibility and distributive justice should apply. See also Box 8 and Lamboll et al. (2023).
6 This concerns a lasting overshoot of the 1.5°C target, and not only for one or a few years.
7 A useful overview can be found in Smith et al. (2024).
8 In line with the IPCC, we use the term carbon dioxide removal (CDR) in this advisory report. This is synonymous with the term 'carbon removal'. We use the term 'negative emissions' in this advisory report only when there is a case of net CDR at the country or global level. In that case, more CO_2 is removed than GHG emissions take place.
9 IPCC (2021b, p. 2221).
10 See the criteria of Tanzer & Ramírez (2019).
11 PBL (2024b).
12 Lamb et al. (2024a).
13 Das et al. (2023); Gatti et al. (2021); Wu et al. (2023).
14 Lamb et al. (2024b).
15 For example, the US and Canada have the most patents related to DACCS and BECCS (Smith et al., 2024).

2 CDR methods: characteristics and areas of concern

This chapter briefly discusses the main characteristics and areas of concern of the different CDR methods. A more detailed explanation is provided in the background report.[1]

2.1 Temporary and permanent CDR methods

Methods for temporary CDR involve sequestering CO_2 in forests, soils or products. We distinguish between CDR methods based on the duration of storage: temporary CDR involves storage for a period of at least a few decades, permanent CDR is for a number of centuries or longer (see Box 1 and Section 3.2). Afforestation and reforestation are examples of temporary CDR, where the trees sequester CO_2 as they grow. Globally, the vast majority of current CDR achieved by human intervention consists of planting and restoring forests (some 3 $GtCO_2$/yr).[2] Other methods for temporary CDR include adapted soil management practices to increase soil organic matter content (for example in agriculture), and restoring peatlands. 'Biochar' (a form of carbonised biomass that can also be produced from waste streams) is another option for temporarily sequestering CO_2 in soils (and simultaneously improving the soil properties).[3] Improved management of coastal areas sequesters carbon in salt marshes and in sea grasses and seaweeds ('blue carbon management'). Finally, CO_2 can be temporarily sequestered in products and materials. Examples are the use of wood as an alternative building material and the use of biomass to manufacture plastics for long-lasting products.

There are three main permanent CDR methods: bioCCS, DACCS and mineralisation. BioCCS[4] is an umbrella term for various techniques and systems for geologically storing CO_2 using biomass as a carbon source. Depending on the technology, availability and quality of the biomass, it is converted into electricity, heat, biofuel or a bio-based raw material. In each of these techniques, the CO_2 released in the process is captured and stored underground. A number of bioCCS methods are explained in more detail in Box 2. DACCS combines direct capture of CO_2 from the air with underground storage. In this method, CO_2 is filtered directly from the air. This is done using large fans to blow air past a chemical that binds CO_2. The chemical can then be treated (e.g. heated) to release the CO_2, and the pure CO_2 can be injected into the deep underground (geological storage). Finally, CO_2 can be mineralised, i.e. converted into carbonate minerals, the main component of rock. Various CDR methods fall under mineralisation. For instance, certain minerals such as basalt and olivine mineralise CO_2 during the process of weathering, thus removing it from the atmosphere. This natural process of mineralisation is very slow, but it can be significantly accelerated by grinding and scattering the material, for example on land or in water. The term 'enhanced weathering' is also used in this context. Another example involves adding the mineral to seawater, which absorbs the CO_2 dissolved in the water. This is also a way to reduce acidification[13] and is also known as 'ocean alkalinity enhancement'. CO_2 can also be added to the cement production process. The CO_2 mineralises with the cement and is therefore permanently stored in the building material.

Box 2: BioCCS methods in the Netherlands
There are various bioCCS methods. One often mentioned method is to burn biomass (usually wood pellets) in a biomass power plant, or co-fire it in a coal-fired power plant and then capture and store the CO_2 from the flue gases. This method is at an advanced development stage[5], and a company in the Netherlands has presented plans to convert two coal-fired power plants into bioCCS plants.[6] However, scenario studies by Netbeheer Nederland[7], TNO[8] and the Netherlands Environmental Assessment Agency (PBL)[9] all conclude that bioCCS will play only a minor role, if any, in electricity generation or heat production as part of the Dutch energy system of the future (or at most it will only be used as a temporary solution). Moreover, it is the intention to phase out the use of biomass for electricity generation and heat production in the coming years[10]. The Hoofdlijnenakkoord (the Dutch coalition's outline agreement) specifically states that "bioenergy combined with CCS" will not be stimulated[11].

In PBL's scenarios, bioCCS is mainly used in the production of advanced biofuels and additionally (but to a much lesser extent) in waste treatment. In other words, biomass does not necessarily have to be incinerated to capture CO_2. CCS in waste incinerators removes CO_2 if the waste is at least partly biogenic. This method is at an advanced development stage.[12] Currently, little, if any, CO_2 is captured during the production of biofuels, biochemicals and bioethanol in the Netherlands. However, the CO_2 released by biorefineries can be captured relatively energy- and cost-efficiently thanks to the high CO_2 concentration in the flue gases, and there is already a biorefinery in the United States that does this. This does only apply to CO_2 that is released during refining or other processing. The amount of carbon removed from the processed biomass depends partly on the end-products. In fuel production, for example for aviation, most of the carbon is released during its use, which means no CDR takes place. When used for plastics, the emissions are delayed, and there may be temporary CDR.

A sharp distinction must be made between CDR on the one hand and fossil carbon dioxide capture and storage (CCS) and carbon dioxide capture and utilisation (CCU) on the other. As CCS also plays a role in applications other than CDR, and this can cause confusion, Box 3 discusses CCS and CCU in more detail. Figure 3 illustrates the differences in a diagram.

Box 3: When is carbon dioxide capture also CDR?
Carbon dioxide capture and storage (CCS) involves capturing CO_2 released during an industrial process and storing it underground. This could be the CO_2 released when fossil fuels are processed or burned in industry. If the CO_2 is not stored, but used as raw material for a new application, we call this carbon dioxide capture and utilisation (CCU). Possible applications of this CO_2 include the fertilisation of greenhouses and as a raw material for plastics and synthetic fuels.

CCS and CCU are counted as CDR if three conditions are met (see also Box 1): 1) the CO_2 is atmospheric, 2) the CO_2 is sequestered for at least a few decades (underground in the case of CCS, or in a product in the case of CCU), and 3) net sequestration must be higher than the amount of CO_2 emitted throughout the CDR supply chain. If CO_2 is captured from flue gases, for example in fossil fuel refining, this is therefore not counted as CDR, because that CO_2 is not atmospheric. This changes if the CO_2 is captured from biomass or directly from the air (direct air capture). If this CO_2 is captured with CCS and stored underground (i.e., permanently), it qualifies as CDR in the form of bioCCS and DACCS respectively. Under the second condition, CCU applications such as CO_2 fertilisation in greenhouses and CO_2 as a raw material for fuels do not qualify as CDR. This is because this CO_2 is released again within hours to weeks.[14] An example of an application that does qualify as CDR is the use of CO_2 from biomass to produce carbonates, which are then incorporated into building materials such as concrete.[15]

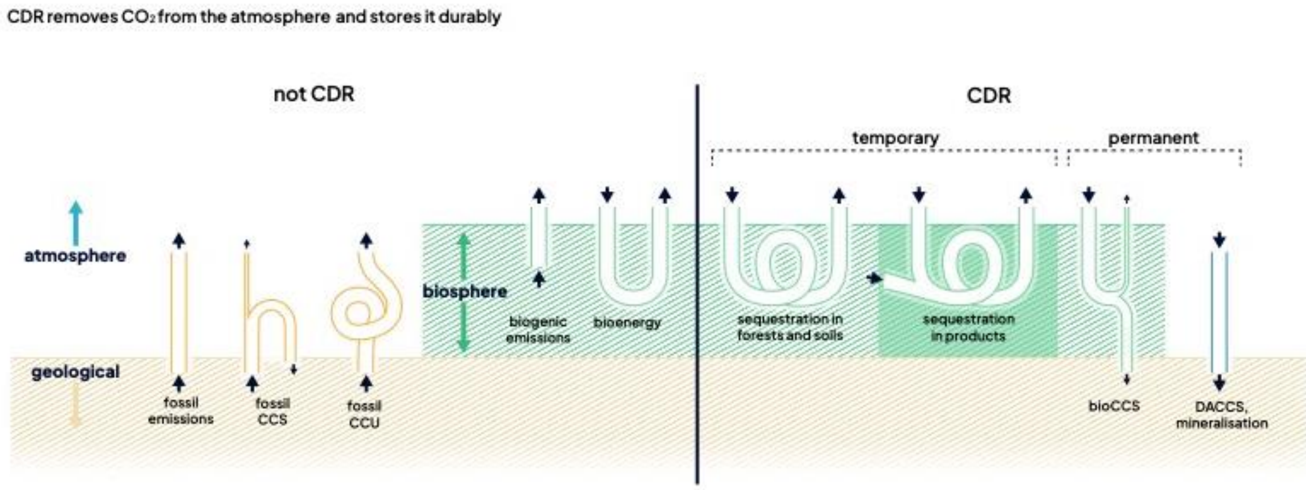

Figure 3: CDR removes CO_2 from the atmosphere and stores it durably
CDR removes CO_2 from the atmosphere and stores it durably. It is therefore important to consider both the origin and the destination of the CO_2. Sequestration in forests, soils and products (the 'biosphere') is generally temporary, while storage in the deep underground (geological) or in rock (mineralisation) removes CO_2 permanently from the atmosphere. Fossil CCS or CCU reduces or postpones emissions, but this CO_2 is not atmospheric and therefore does not qualify as CDR (see Box 3). In the figure, looped arrows indicate that carbon circulates in this process for longer, thus delaying emissions. The two arrows entering at 'sequestration in products' indicate that the carbon was either captured from biomass (arrow coming from the biosphere), or via direct air capture (DAC, arrow coming from the atmosphere). The amount of CO_2 released during bioCCS depends on the capturing technology. This figure does not include indirect emissions upstream or downstream in the CDR supply chain. Nor does it show that some of the temporarily stored CO_2 could become permanently stored, for example by burning end-of-life wood from timber structures in a waste incinerator with CCS.

2.2 Characteristics of CDR methods

CDR methods differ in terms of the storage duration and medium, their development stage, and their potential and costs. A number of methods for permanent CDR have already been implemented at scale, notably bioCCS (Box 2). However, the other methods are not at a sufficiently advanced development stage to be applied at scale and/or they involve high costs. DACCS and most forms of mineralisation also involve high energy consumption.[16] Methods of temporary CDR are relatively well-developed and often involve low costs. They are already widely used in forest management. It is essential, but also difficult, to monitor the current stock of temporarily stored CO_2. This is not the case, or to a much lesser extent, for permanent storage methods. The potential for storage in Dutch forests and soils is estimated to be small (Table 1 and Section 3.2).

2 CDR METHODS

CDR synergies, negative side effects and risks depend on the method. BioCCS, afforestation and reforestation, and biomass-based materials and products require relatively large amounts of land and, in the case of irrigation, also water. This could lead to competition with food production and thus to higher food prices. Planting diverse, native species of trees and crops can help to increase biodiversity. Conversely, however, there is a risk that planting monocultures or non-native species (for example to maximise the amount of CO_2 removed per hectare) could actually decrease biodiversity or stress the natural soil and water system. Opportunities for synergy include adaptation: the restoration of peatlands by rewetting can lead to more CO_2 sequestration, as well as help to prevent soil subsidence and prevent desiccation.[17] Unlike DACCS, bioCCS methods provide products and services with an economic value, such as energy, biofuels and bio-based raw materials, in addition to the CDR itself.

Table 1 provides an overview of some of the characteristics of CDR methods. The background report provides a more comprehensive overview of the CDR methods and their characteristics.[18]

Table 1: Overview of the most important CDR methods for the Netherlands and their characteristics, based on data from CE Delft (2023). ‘Potential NL’ gives the realistic potential for the Netherlands in 2050, the ‘Costs’ describe the expected costs in 2050. The development stage is based on the technology readiness level (TRL): low (TRL of 1 to 5; exploratory/development), average (TRL of 6 or 7; prototype at scale/demonstration) or high (TRL of 8 or 9; operational/commercial).

Method	Storage period	Potential NL *$MtCO_2$/yr*	Development stage	Costs *€/tCO_2 removed*	Main synergies	Main negative side effects
Afforestation and reforestation	Temporary	0.7	High	50-1000	+ Biodiversity	- Spatial footprint and potential competition with food production - Risk of unsustainable forest management
Carbon sequestration in the soil	Temporary	0.5-0.9	High	0-50	+ Improved soil quality and water management	- Risk of methane emissions in peatlands
Blue carbon management	Temporary	Unknown	Low-Average	9[19]	+ Biodiversity + Coastal protection	- Risk of large spatial footprint and possible competition with food production - Risk of use of non-sustainable biomass
Biochar	Temporary	0.05	Low-Average	200-1500	+ Improved soil quality	
Timber construction	Temporary	3.9[20]	High	Unknown[21]	+ Lower emissions than conventional building materials	
Bioplastics	Temporary	Unknown[22]	Low-High	60-80	+ By-products of economic value	
BioCCS	Permanent[23]	22.2[24]	Average-High	0-110	+ Energy production + Potential source of carbon[25]	
DACCS	Permanent	Unknown[26]	Low-High	85-540	+ Potential source of synthetic carbon[27]	- High energy consumption
Mineralisation	Permanent	5.4	Low-High	50-70	+ Economic value (e.g. as fill sand or in building materials) + Reduced soil erosion	- High energy consumption (due to grinding and transport)

2.3 Limits to sustainable potential

Underground storage is an important prerequisite for permanent CDR, but the Dutch potential is limited and is also necessary for fossil CCS. The Netherlands has an estimated 1,700 Mt of capacity for underground CO_2 storage in depleted gas fields under the North Sea.[28] In addition, there may be more than 1,300 MtCO_2 storage capacity in aquifers under the North Sea, but this estimate is highly uncertain.[29] There is also capacity in depleted gas fields and aquifers under land (onshore), but current policy does not allow geological storage under land.[30] When this storage capacity for the Netherlands will be exhausted, depends on the amount of CO_2 the Netherlands adds to the underground reservoirs each year, whether the country also makes use of geological storage capacity available abroad, and whether other countries like Belgium and Germany also use this storage capacity. In scenarios where the Netherlands also stores CO_2 from Belgium and Germany, this could amount to a total of 50 MtCO_2/yr from the chemicals and refining sectors by 2035.[31] The potential of depleted gas fields under the North Sea would then be exhausted within a few decades. If that storage capacity is used only by the Netherlands (and the Netherlands does not store CO_2 abroad), in the best case scenario, the Netherlands could continue to store CO_2 under the Dutch part of the North Sea until the end of this century.[32] There is more potential for underground CO_2 storage in other European countries (such as Norway and Denmark), but scaling up capacity for transport and injection may be a limiting factor in these countries.

The sustainable potential of CDR methods is significantly lower than the technical or economic potential. The IPCC estimates the global technical potential for bioCCS to be maximum 11.3 GtCO_2/yr.[33] Achieving that maximum would require about 18 million km^2 of land, some 13% of the current area of arable land in the world, or four times the area of the European Union. If the environmental and socio-economic risks are factored in, for example for food production, biodiversity, and the availability of water, biomass, energy and land, the remaining 'sustainable' bioCCS potential is only 0.7-2.8 GtCO_2/yr.[34] This amount depends on what is considered to be sustainable biomass, what risks are considered acceptable, and what the expected production is per hectare. See also Box 4 regarding the availability of sustainable biomass. The sustainable potential is further limited by institutional, political and social barriers, such as lack of public support or slow decision-making. As a result, the actual global potential for bioCCS is expected to be much lower than the estimated sustainable potential. Some of these limitations will also apply to the estimated potential in the Netherlands.

Box 4: Availability of sustainable biomass for CDR is limited and uncertain for various reasons
Biomass is needed for the transition to a sustainable energy system, a circular economy, and for achieving CDR, but it is also scarce. The Netherlands already produces insufficient biomass to meet domestic demand, so it imports it.[35] If fossil fuels are partly replaced by biomass, these imports will have to increase sharply. In this respect, the sustainability of biomass is an essential prerequisite. This involves both an ecological dimension (such as the impact on water availability, biodiversity and soil quality) and a socio-economic dimension (which depends on the undesirable effects that may occur in the supply chain).[36] The long-term availability of sustainable biomass for import is very uncertain, because the aforementioned transitions create a growing demand for sustainable biomass, leading to increasing competition for it internationally.

Because sustainable biomass is scarce, Dutch policy is to use biomass as little as possible, and as much as possible in high-grade applications.[37] This also means that less biomass is used for direct energy applications such as heat and electricity. Instead, priority is given to using biomass for applications for which longer-term alternatives are lacking, insufficiently available or too expensive. Examples include marine and aviation fuels and raw materials for chemicals.

To scale up CDR, reduce the risks and hedge the negative effects, there are advantages to implementing a diverse portfolio of CDR methods.[38] Employing a variety of methods will lead to a higher total CDR potential.[39] There is currently no single method that can meet the expected need for CDR, both globally[40] and for the Netherlands alone[41]. A portfolio approach reduces dependency on specific methods, and therefore lowers the risk that certain methods will not be available, affordable and socially accepted in time and/or at the required scale. By deploying different methods simultaneously, the negative side effects can potentially be hedged and distributed, both by category (such as land use, energy use or environmental effects)[42] and by region[43]. The composition of the portfolio depends on policy and other preferences, future developments, and the specific local context and opportunities. The portfolios can therefore be managed at different levels (e.g. both at the European and the country level), and may be different depending on the level of government.[44]

Notes

1 WKR (2024). In addition, a report by CE Delft (2023) elaborates further on the need for and potential of CDR in the Netherlands.
2 Lamb et al. (2024a).
3 Carbon storage in biochar is more stable than traditional methods for increasing soil carbon sequestration, but there is uncertainty about its long-term stability (NEGEM, 2024). Incorporating biochar in concrete or other building materials could increase its stability and potentially enable permanent CDR.
4 In this advisory report, we use the term bioCCS (biomass with carbon dioxide capture and storage) to make it clear that we refer to all forms of biomass conversion combined with CCS. Therefore, it does not only involve combustion in biomass plants, which is often associated with the term BECCS (bioenergy with carbon dioxide capture and storage). A similar term is BiCRS (biomass carbon dioxide removal and storage), which has been introduced to describe CDR methods that use biomass but do not use CCS, and emphasises carbon dioxide removal rather than bioenergy production (Sandalow et al., 2020).
5 CE Delft (2023).
6 RWE (2022).
7 Netbeheer Nederland (2023).
8 TNO (2022).
9 PBL (2024b).
10 Minister for Climate and Energy Policy & State Secretary for Infrastructure and Water Management (2022).
11 PVV, VVD, NSC & BBB (2024).
12 CE Delft (2023).
13 Oceans absorb about 30% of the CO_2 emitted by humans. In the process, ocean water acidifies, with adverse effects on marine life such as coral.
14 Fertilisation using CO_2 from biomass can reduce fossil fuel use in greenhouse horticulture, for example when it replaces the use of fossil fuels in a gas boiler.
15 de Kleijne et al. (2022).
16 It should be noted here that DAC plants are very flexible systems, and therefore could be a solution for capturing CO_2 from low-grade (residual) heat.
17 Van der Brugge & de Winter (2024).
18 WKR (2024).
19 NEGEM (2022). The costs may be higher, or even much higher, in the Dutch context, see Hoefsloot et al. (2020).
20 This is the potential if all new buildings in the Netherlands are constructed of timber.
21 Estimates of the additional costs (compared to conventional building materials) range from +100% to -20% (CE Delft, 2023).
22 CE Delft (2023) applies a realistic potential of zero here, because the policy target is for the Dutch economy to be fully circular by 2050, and no increase in green carbon is to be expected in the economy from then onwards. However, because this very much depends on whether this target is met, and how the removal is allocated and to what measure, we qualify it here as unknown.
23 Only the part that is captured when the biomass is processed into a raw material or fuel results in permanent CDR; the rest ends up in products (temporary CDR) or fuel (no CDR).

24 This is the sum of the potential for CCS from biogas plants, high-temperature heat, waste incineration plants and biofuel production. It does not take account of conversion of coal-fired plants into biomass plants, nor the use of biomass in steel production. The realistic potential for the bioCCS systems combined depends heavily on assumptions about the supply of various sustainable biomass streams.
25 If the captured CO_2 is used for fuels (bioCCU), for example, this does not qualify as CDR.
26 CE Delft (2023) applies a realistic potential of zero here, reasoning that the price for DACCS will remain high relative to the CO_2 price for a long time to come (due to the high costs of both technology and energy). DAC(CS) does play a limited role in various scenarios for a climate-neutral Netherlands and Europe, see for example Scheepers (2024) (approx. 3 $MtCO_2$ by 2050 in the ADAPT scenario) and European Commission (2024b).
27 If the captured CO_2 is used for fuels (DACCU), for example, this does not qualify as CDR.
28 TNO & EBN (2018).
29 CE Delft (2023).
30 Akerboom et al. (2021).
31 Koop et al. (2021).
32 PBL (2024b).
33 IPCC (2022a, p. 776).
34 Deprez et al. (2024).
35 PBL (2024b).
36 These requirements are laid down in the European REDII and the Dutch Sustainability Framework for Bio-Based Raw Materials (State Secretary for Infrastructure and Water Management and Minister for Climate and Energy Policy, 2023).
37 State Secretary for Infrastructure and Water Management and Minister of Economic Affairs and Climate Policy (2020).
38 See C.3.4 in IPCC (2018).
39 Nemet et al. (2018).
40 See figure 7a in Rueda et al. (2021).
41 CE Delft (2023).
42 Werner et al. (2023).
43 Strefler et al. (2021).
44 Strefler et al. (2021).

3 CDR policy: principles and necessity

In this chapter, we answer part of the central research question: What principles can the Dutch government adopt to govern the development of CDR? We suggest a number of principles for CDR policies, and provide the rationale for these. We then substantiate why a government policy aimed at permanent CDR is necessary. This leads to five recommendations.

3.1 Constraints and uncertainties of CDR highlight the necessity of rapid emission reductions

It is important to give priority to rapidly and substantially reducing emissions for several reasons, including to reduce the burden on future generations. First, emissions need to be reduced to a level that can actually be offset by CDR.[1] Next, the scarce CDR capacity needs to be deployed for multiple purposes: to limit and reduce a temperature overshoot and also to achieve climate neutrality (offsetting remaining emissions). Emissions reductions lead to lower cumulative emissions and less residual emissions at the time of climate neutrality. This has two advantages: the temperature overshoot is limited, and less CDR capacity is required. Another factor is that certain CDR methods become less effective under the influence of heat and drought, extremes that increase with climate change. This makes it more difficult to retain sequestered CO_2 and remove it in the future.[2] All in all, prioritising deep, rapid and sustained emission reductions lowers the burden on future generations.

Some effects of climate change are irreversible, even if emissions are offset at a later date. For example, sea level rise and ocean acidification cannot be reversed on timescales of centuries to millennia, even if atmospheric CO_2 concentrations start falling again.[3] Plant and animal species that go extinct in the meantime will never return.[4] With (temporary) higher global warming, deadly weather extremes like heatwaves become more frequent. A temporarily higher global temperature also increases the risk that the climate system will be pushed over a tipping point. After this point, it will become much more difficult, if not impossible, to return the planet to a safer degree of warming.[5]

Prioritising deep, rapid and sustained emission reductions is in line with existing legal frameworks and national and international agreements. Relying heavily on future and uncertain CDR methods is at odds with the precautionary principle and national, European and international climate agreements (or their spirit). Moreover, the importance of gross emission reductions follows from the principles of intergenerational justice, as well as the 'no harm' principle that requires countries to prevent environmental harm to other countries.[6] The Paris Agreement further states that a country's climate goals should reflect "the highest possible ambition".[7] That European laws and regulations give priority to emission reductions is evidenced by, amongst other things, the recent legal obligation for major emitters to establish a climate transition plan to align their operations with the 1.5°C target.[8] Once climate neutrality has been achieved, only the residual emissions after a 90-95% gross emissions reduction may be counterbalanced with CDR.[9]

1. Recommendation
The Council recommends making maximum efforts to reduce emissions. This will limit the dependence on CDR to achieve climate neutrality. The Council also recommends that CDR be deployed primarily to limit and reduce a potential temperature overshoot.

If maximum efforts are made to limit emissions, gross emissions will decrease significantly. This will leave only a small amount of residual emissions. In this way the reliance on CO_2 removal to achieve climate neutrality is minimized, and the sustainability impacts and the burden on future generations is limited. This is illustrated in Figure 4.

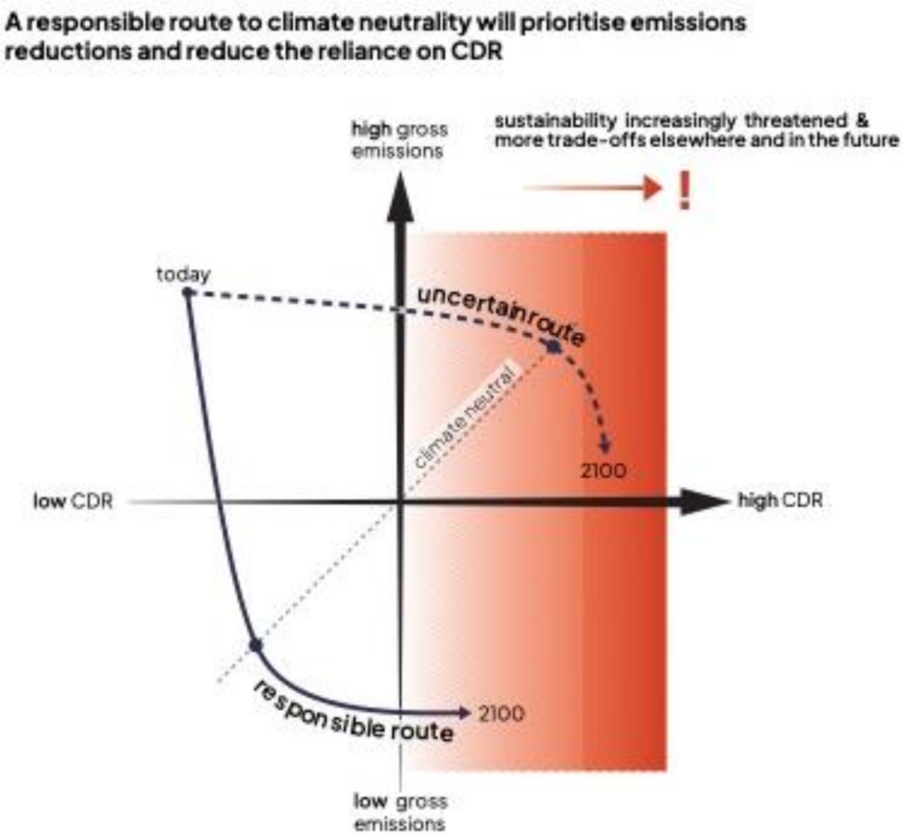

Figure 4: A responsible route to climate neutrality will prioritise emissions reductions and reduce the reliance on CDR
There are various routes between the current situation (top left, with high emissions and low CDR) and the end of the century (bottom right, with low emissions and high CDR). The figure illustrates two routes. The solid arrow represents the responsible route. Characteristics of this route are rapid emission reductions and so a low reliance on CDR to achieve climate neutrality. Less emission reductions and a heavier reliance on CDR characterise the uncertain route (dotted arrow). The sustainability risks involved in reducing a temperature overshoot are higher with this route than with the responsible route. This route also places a larger burden on sustainability issues and future generations.

3.2 Permanent CDR offers greater security than temporary CDR

Effective policy is needed to get permanent CDR off the ground. Chapter 1 and 2 described how methods for permanent CDR are still applied much less than temporary CDR methods. Permanent CDR methods store CO_2 in the long carbon cycle, which is necessary because the vast majority of Dutch emissions are fossil based.

The Netherlands has only a small potential to temporarily sequester CO_2 in forests and soils. The reasons for this are the small available area of land and the high population density, as well as the presence of a highly productive agriculture sector, the large area of wetlands and peatlands[10], and the small area under forest. Expansion of the area under forest and/or nature will come at the expense of agricultural land and implies political choices regarding the future of the agriculture sector and the use of land. We note that the natural, water and soil systems of the Netherlands are in a poor state.[11] It is already a significant challenge to maintain the existing carbon stock in forests, soils and nature in the face of advancing climate change, let alone increase this stock of carbon sustainably. Partly because of this limited potential (see also Table 1 in Chapter 2), Dutch CDR policy should be focussed on permanent CDR.

2. Recommendation
The Council recommends focusing Dutch CDR policy on permanent methods.

Fossil CO_2 emissions are part of the long carbon cycle and therefore cannot be offset by temporary CDR in the short carbon cycle. Carbon from coal, oil, and gas has spent millions of years underground, remains in the atmosphere as CO_2 for centuries after combustion, and takes many thousands of years to return to stable geological reservoirs. This is called the long carbon cycle. During that period, fossil carbon moves between the atmosphere, the surface waters of oceans, and forests and soils, where it often only remains for some decades. During this period, the fossil carbon forms part of the short carbon cycle. In recent centuries, the combustion of fossil fuels has caused a lot of carbon to move from the long to the short carbon cycle. That process is one of the major contributors to climate change and must be stopped by reducing emissions as much as possible, and offsetting the remainder like-for-like.

For CDR to offset emissions on an equivalent basis, the climate effect and the stability and duration of the storage must match that of the emission.[12] Offsetting fossil CO_2 emissions with carbon sequestration in forests, soils or products moves carbon from the long to the short carbon cycle, and therefore does not achieve an equivalent climate outcome. Permanent CDR on the other hand returns fossil carbon back to the long carbon cycle. Under strict conditions, biogenic CO_2 emissions can be compensated by sequestration in forests and soils, because this CO_2 is already part of the short carbon cycle and is reabsorbed into it. Figure 5 shows the difference between achieving climate neutrality through mixing (B) and separating (C) the short and long carbon cycles.

Emissions of nitrous oxide and fluorinated gases can only be offset equivalently through permanent CDR. Nitrous oxide and the fluorinated gases are very potent GHGs that remain in the atmosphere for a long time; over a hundred years for nitrous oxide, and even thousands of years for the fluorinated gases. As nitrous oxide and fluorinated gases occur in much lower concentrations in the atmosphere than CO_2, it is technically very difficult (or very expensive) to remove these GHGs from the atmosphere. After maximum emission reductions, these gases must be offset with permanent CDR.

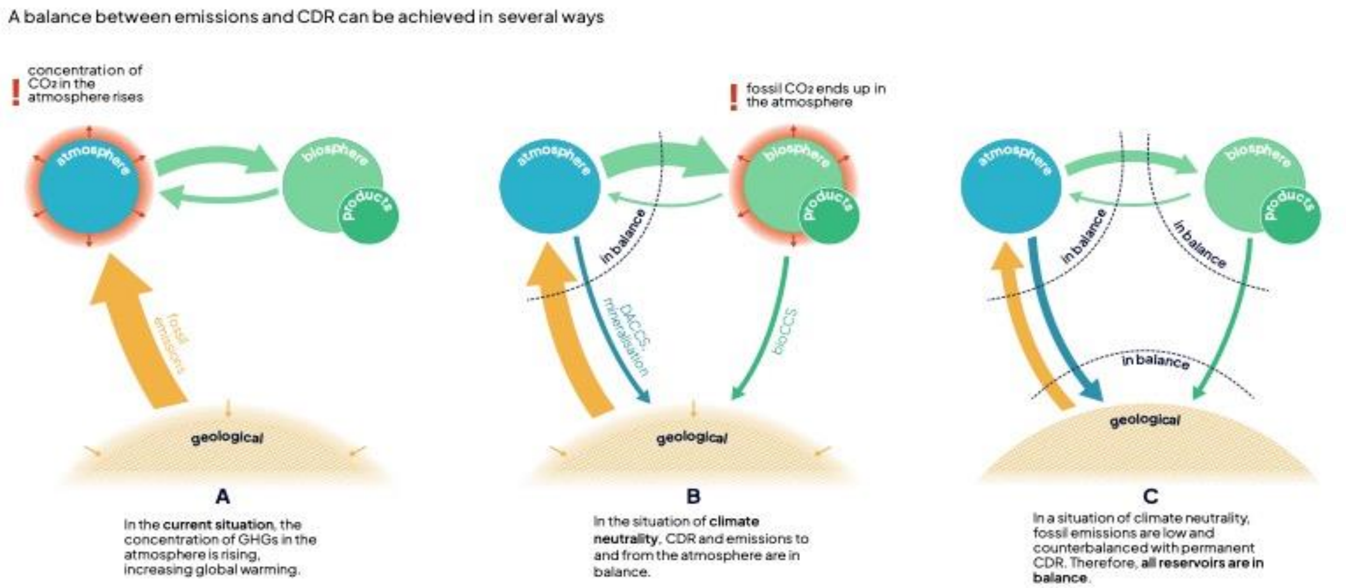

Figure 5: A balance between emissions and CDR can be achieved in several ways
Panel A shows the current situation with high emissions and little temporary or permanent CDR. Panel B illustrates a situation of climate neutrality with high emissions and much CDR, where fossil fuels are offset with temporary CDR. This involves mixing the short and long carbon cycles. Panel C illustrates a situation of climate neutrality with low emissions and with little dependence on CDR. Moreover, the long and short carbon cycles are separated as much as possible by permanently offsetting fossil emissions. This ensures that not only the atmosphere, but also the biosphere and geosphere are in balance. The figure is based on Fankhauser et al. (2022).

There is currently no scientific consensus on the best way to offset methane with CDR.[13] Due to the low concentration of methane in the atmosphere, it is technically difficult to remove, and its climate impact will have to be offset with CDR.[14] As a GHG, methane is much more potent than CO_2, but it also stays in the atmosphere for a much shorter time: its atmospheric lifetime is 9.1 years. The warming effect of methane relative to CO_2 therefore depends strongly on the chosen time horizon: over a 20-year period, methane is 81.2 times stronger than CO_2, while over a 100-year period it is still 27.9 times stronger.[15] After methane breaks down in the atmosphere, it is ultimately converted into CO_2. Thus, methane has both a temporary and a permanent impact on the climate.

There is, however, a difference between methane of biogenic origin and methane from fossil sources. CO_2 that originates from the breakdown of fossil methane must be offset with permanent CDR because this carbon is from the long carbon cycle. The purpose of this offsetting is to compensate for the warming effect of methane, to prevent a rise in temperature. Using only permanent CDR to offset methane overestimates the long-term warming impact of methane, while underestimating its short-term warming effects. The latter would cause a temperature rise in the short term. In turn, offsetting with only temporary CDR will not adequately address methane's long-term warming impacts. A possible solution is therefore to offset methane with partly temporary and partly permanent CDR. This could be done based on the warming potential of methane over time, further distinguishing between methane from the short (biogenic) or long (fossil) carbon cycle.

3. Recommendation
The Council recommends deploying only permanent CDR to offset fossil GHG emissions and emissions of GHGs that remain in the atmosphere for a long time.

Temporary CDR can bring climate gains. First, temporary CDR (storage period of at least some decades) can slow down short-term climate warming, allowing more time for climate adaptation. Second, temporary CDR at the time of a temperature overshoot can reduce the amount of overshoot above the 1.5°C target.[16] Finally, some of the temporarily stored CO_2 may yet become permanently stored in the future. For example, construction timber can be incinerated at the end of its lifecycle, after which the captured CO_2 can be stored in the deep underground (bioCCS).

However, temporary CDR also carries risks that have implications for distributive justice. The temporary storage of CO_2 in forests, soils or products involves a risk that the CO_2 may be released earlier than anticipated. For instance, carbon stored in forests and soils can be released due to changes in land use, disease in trees and fire (whilst the occurrence of such events may increase due to climate change). Temporary CDR is often relatively costly and difficult to monitor, including the assessment of additionality[17]. Measurements are difficult to carry out and have a large margin of uncertainty because, depending on the place and time, there is large variation in the amount of CO_2 sequestration. In nature, for example, carbon sequestration fluctuates annually and seasonally. All these risks and uncertainties may have implications for distributive justice between generations. If the captured CO_2 is released early, these are effectively deferred emissions and no longer qualify as CDR. Future generations will be burdened with recapturing that CO_2 or will suffer more climate effects.

Temporary CDR in forests and soils and through land use management already has a place in Dutch and European climate policy. The European Union aims to increase net carbon sequestration in forests, soils and land use between 2026 and 2030 from around 230 $MtCO_2$/yr today to 310 $MtCO_2$/yr.[18] The European Forest Strategy[19], Soil Strategy[20] and Biodiversity Strategy[21] are amongst the instruments that will contribute to that goal. In addition, farmers and landowners are encouraged to take up ‘carbon farming’. This involves adopting improved land management practices that lead to increased carbon sequestration in biomass and soils.[22] Certain forms of carbon farming are already being stimulated as part of the eco-schemes under the European Common Agricultural Policy.[23]

It is uncertain how much policies that stimulate a circular economy and render carbon chains more sustainable can contribute to temporary CDR. More sustainable carbon chains and more circularity can help to achieve temporary CDR. An example of a measure the EU and the Netherlands are considering is to require an increasing percentage of bio-based and otherwise renewable raw materials in plastics, which can temporarily remove CO_2 if those plastics are recycled often enough. However, policies in these areas are still evolving, and the contribution to and opportunities for CDR are still uncertain.

Temporary CDR should not be part of Dutch CDR policy, but can form a valuable addition to other policies. Soil quality, restoring biodiversity and a sustainable economy are central to policies aimed at restoring nature, reducing soil subsidence, or stimulating sustainable agriculture or the circular bio-economy, for example. Temporary CDR then is a co-benefit of such policies, and may be encouraged provided that it supports the main objectives of these policies. This could include offering compensation for such activities. Focusing CDR policies primarily on temporary CO_2 removal could jeopardize other policy goals, like biodiversity, food production, and land use planning. It might also diminish the emphasis on permanent CDR, which needs to be scaled up.

4. Recommendation
The Council recommends encouraging temporary CDR in the Netherlands, but only as part of other policies.

3.3 Government intervention is needed to achieve CDR

A voluntary CDR market will not be able to achieve the required scale and quality. The growth of the voluntary carbon market has led to concerns about the quality of the certificates (see Box 5). The vast majority of these markets involve temporary CDR, as this is generally much cheaper than permanent CDR (see Table 1). Consumers' willingness to pay for CDR is low compared to the cost of permanent CDR. Therefore, there is only a realistic business case for a voluntary market for cheaper, and therefore temporary, CDR. Voluntary markets are an unsuitable instrument for effectively scaling up permanent CDR, because they cannot be adequately coordinated regarding the nature and scale of the CDR and the optimal deployment of scarce, high-quality CDR capacity to counterbalance residual emissions.

Box 5: Voluntary carbon market: concerns about quality of certification and sequestration
The voluntary carbon market has grown rapidly in recent years, as more and more companies have indicated they wish to comply with the Paris Agreement. Two types of certificates are traded in this market: 1) certificates for achieving an additional reduction from a specific emission source and 2) certificates for removing CO_2 from the atmosphere. These certificates allow companies to claim climate improvements and offset their own or their customers' emissions. The market is 'voluntary' because emitters cannot meet their formal obligations with these certificates.

Voluntary certificates are made available through a variety of emissions reduction and CDR projects. The supply of certificates is not capped in principle, which implies that there are no limits to offsetting. This means companies or consumers can almost endlessly postpone emission reductions measures that they think are too complicated or too costly. This is because it is sometimes easier to offset emissions rather than reduce them, because substantial emission reductions often require more drastic changes to a company's operations, such as changes to product lines or behaviour.

The voluntary carbon market is not subject to regulation or regulatory oversight. Although various international verification bodies exist that assess these certificates, this has not prevented several recent certification scandals. There are several concerns with voluntary certificates. The first is the question of what quality they guarantee. Do they really facilitate additional and permanent climate mitigation? It is also possible that some countries are including double counts of offsets.[24] Finally, there are concerns about the effects of offsetting projects on humans and the environment. Recently, a number of EU countries (including the Netherlands) stressed that certification must be reliable and transparent, both in terms of emission reductions and CDR.[25]

Market incentives are needed to ensure the widespread adoption of permanent CDR. The demand for CDR is comparable to that for any other product; the demand is based on the product's benefits to the buyer. But the benefits of CDR are not exclusive to the buyer, as everyone benefits from it. This makes CDR a public good. Without incentives, private parties therefore have insufficient incentive to implement CDR, while society as a whole would benefit from it. It is the government's responsibility to address this. It follows that mitigation policies that only focus on emission reductions are deficient, as the government also has a role to play in CDR.

5. Recommendation
The Council advises the Dutch government to pursue its CDR policy, in conjunction with European policy.

Notes

1 Lamb et al. (2024a); Strefler et al. (2018).
2 Hughes et al. (2019); Terhaar et al. (2022); van der Woude et al. (2023).
3 IPCC (2021a, pp. 775-776).
4 Wudu et al. (2023).
5 Lenton et al. (2023).
6 Günther et al. (2024); Stuart-Smith et al. (2023).
7 Paris Agreement, Art 4.2 and 4.3.
8 European Parliament (2024). Art. 22
9 Regulation (EU) 2023/2772
10 Lesschen (2021).
11 Het Nationaal Dashboard Biodiversiteit (nd); PBL (2023).
12 Allen et al. (2022).
13 See for example Allen et al. (2018); Brazzola et al. (2021); Lauder et al. (2013); Meinshausen & Nicholls (2022).
14 Jackson et al. (2021).
15 IPCC (2021c, p. 1017).
16 The literature also refers to this as 'peak shaving' (Matthews et al., 2023).
17 CDR is additional if the quantity removed is in addition to that removed through standard management practice and existing plans.
18 Regulation (EU) 2023/839. According to the European allowances system, the Netherlands can produce net emissions of 4.5 MtCO_2e/yr from land use in 2030, given the baseline situation with little forest and many peatlands. Based on the current policy, the Netherlands is expected to produce 2.5-3.7 MtCO_2e/yr in 2030, so it will remain below the European target, but will not achieve its own target of a maximum of 1.8 MtCO_2e/yr (PBL, 2024a).
19 European Commission (2021b).
20 European Commission (2021a).
21 European Commission (2020).
22 European Commission (2024a).
23 RVO (2024b).
24 AFM (2023).
25 Ministry of Economic Affairs and Climate Policy (2023).

4 Designing CDR policy

This chapter discusses the policies the Dutch government can implement to achieve CDR. First it provides an overview of what is already being done and what remains to be done. It then discusses measures to minimise residual emissions. Finally, it discusses various policy instruments that can create demand for permanent CDR. This leads to five recommendations.

4.1 What is already being done and what still needs to be done?

Certification that ensures safe and reliable CDR, with minimal trade-offs, is a prerequisite for effective CDR policy. It is important that a reliable system of certification is agreed by governments and subsequently operationalised and monitored by governments. This is a prerequisite should CDR certificates ever be traded on compliance markets.[1] At the EU level, the European Commission has proposed a framework (initially voluntary) for transparent and reliable certification of verifiable and high-quality carbon removals: the Carbon Removal Certification Framework Regulation (CRCF).[2] According to the CRCF, certificates must be based on four criteria: quantification, additionality, sustainability and long-term storage (including monitoring requirements and liability in case of early release of CO_2).

Governments will need to take initiatives in several areas to achieve large-scale CDR. Table 2 provides an overview of such initiatives[3] and the status of European and Dutch policy under development or already implemented. This information is based on various literature sources. This chapter focuses on the first two initiatives in Table 2: providing clarity about the role of CDR in climate policy, and creating demand for (permanent) CDR.

4 DESIGNING CDR POLICY

Table 2: Overview of initiatives that must be implemented to create demand for large-scale, permanent CDR, and the initiatives the European Union and Dutch government have already set in motion.

	Initiative	Current situation
1	Provide clarity on the envisaged role of CDR in climate policy in line with the Paris Agreement and national targets, particularly regarding the scale of CDR and how emissions can be offset with CDR.	EU and NL: currently only net targets for the period after 2030. EU: The EC has proposed[4] a net emissions reduction target (90% by 2040 compared to 1990). This would require up to 400 MtCO2 to be removed.
2	Encourage scaling up by creating demand for CDR.	EU: no policy in place yet; EC report on possible integration into EU Emissions Trading Scheme (EU ETS) expected in 2026. NL: funds earmarked for 'negative emissions of BECCS and other techniques (0-3.5 Mt)', including waste incineration, in 2023 Spring Memorandum[5]. It has since been decided not to subsidise BECCS; unclear if this also applies to waste incineration.[6] Initial ideas for creating demand in *Keuzewijzer Klimaat en Energie* (a climate and energy decision-making guide).[7]
3	Encourage innovations to ensure the availability of sufficient new and affordable permanent CDR methods.	EU: innovation funds mainly earmarked for CCS technology.[8] The EC has proposed[9] framework conditions for CCS, CCU, CO_2 removal and CO_2 infrastructure, and funding for research and innovation. NL: CDR is part of generic innovation policy[10]. The roadmap for negative emissions, which was requested[11] by the Parliament, is to describe the R&D incentive policy in more detail.
4	Ensure an effective national and international market for CO_2 transport and storage to guarantee the availability of sufficient capacity.[12]	EU: EC proposal for internal CO_2 market in Europe.[13] NL: nascent market with first provider of offshore underground CO_2 storage and transport via pipelines. International transport also possible using ships.
5	Develop and implement a system for reliable monitoring, reporting and verification (MRV) of CDR as a basis for certification.	EU: further develop the framework for reliable certification of high-quality CDR: the Carbon Removal Certification Framework Regulation (CRCF).
6	Establish frameworks that prevent trade-offs with other sustainable development goals wherever possible, and encourage any positive side effects.	EU: part of CRCF. NL: existing instruments such as environmental impact assessments and environment and planning permits.
7	Develop policies to manage the risks of unintended releases of stored CO_2. This includes liability for risks and rules for long-term safe underground CO_2 storage.[14]	EU: regulated for permanent underground storage in the CCS Directive since 2009.[15] Partly also covered by the CRCF.
8	Attention for public participation and acceptance of 1) CDR policies in general, 2) specific forms of CDR and 3) CDR projects in their specific context.[16]	NL: no active policy in this area yet. However, general participation policy exists for local decision-making (Environment and Planning Act and environmental impact assessments).

4.2 Governing the role and scale of CDR

Both providers of CDR methods and emitters of CO_2 will benefit from clarity about the role and scale of CDR in the future. Providing clarity regarding the expected scale of CDR, both for achieving climate neutrality by counterbalancing residual emissions, and for reducing a temperature overshoot, will offer perspectives to future providers of CDR methods and enable them to achieve the required capacity as it is needed. Providing clarity about the maximum amount of CDR that the government will allow for counterbalancing emissions will also help ensure that emitters do not mistakenly anticipate large-scale offsetting opportunities where these are not available (with the risk of them subsequently doing less to reduce their emissions). This also plays out at the country level, where countries may meet their net emissions targets with CDR rather than emission reductions.

One way to provide clarity is to set limits on the use of CDR for counterbalancing residual emissions. The current emissions targets (European, national and sectoral, including the 2050 climate neutrality target) are *net* targets, which do not specify what share must be provided by emission reductions and what the maximum share of CDR is. Several scientific studies argue for separate emissions reduction targets and limits for CDR.[17] One way to achieve this is to set a cap on CDR in addition to the current net emissions targets.

As sectors have widely varying potentials for emission reduction, separate limits at the sector level should be considered. In some sectors, emissions are relatively easy to reduce to zero; in others, it is more difficult. The emissions footprint available to each sector is a political choice that needs to be clarified at an early stage. Ideally, counterbalancing residual emissions should only be available for activities that offer high value to society, activities that are technically and/or economically difficult to reduce to zero ('hard-to-abate' emissions), or activities where reducing to zero emissions will lead to major undesirable effects and for which no good alternatives are available. The disadvantage of separate sectoral CDR limits is that sectors will not have the same incentives to carry out emission reductions.

6. Recommendation
The Council recommends setting limits to the use of CDR for counterbalancing residual emissions at the European, national and sectoral levels.

There are uncertainties regarding the limits for counterbalancing residual emissions. The limits on CDR for counterbalancing residual emissions and the allocation of these limits to the various sectors should coincide with the realistic CDR capacity, including the limitations of land use and geological storage. The availability of sufficient geological storage capacity depends on the use of this capacity for fossil CCS of domestic and foreign CO_2 (see Section 2.3). Scenario studies can provide information on potential sectoral emission reductions, although these depend heavily on assumptions. For example: Recent Dutch emissions scenarios published by PBL[18] and TNO[19] give residual emissions ranges of 18-37 $MtCO_2e$ and 15-30 $MtCO_2e$ respectively in 2050.[20] These scenarios do not, or only partially, include the potential of behavioural change, so the residual emissions could be lower if policies are implemented to effect this change.

Indicative limits on CDR for counterbalancing residual emissions can be converted into binding limits in the Dutch five-year Climate Plan cycle. Given the earlier described complexities involved in determining suitable limits, it would be wise to first gain national experience with indicative limits. To determine whether the limits are feasible based on the implemented emissions reduction policy, this could be monitored and reported on annually in the Dutch Climate and Energy Outlook (*Klimaat- en Energieverkenning*). The limits can then be reviewed every five years, in parallel with the Climate Plan cycle. Once there is more insight into the actual extent of hard-to-abate emissions and the future CDR capacity, the limits can be made binding.

If sustainability aspects are taken into account, there is no need to restrict the use of CDR to limit and reduce a temperature overshoot. This is because there is no trade-off with emissions reduction here. Any deployment of CDR for this purpose contributes to reducing climate impacts and reduces the burden shifted to future generations. However, any large-scale deployment of CDR must take account of sustainability constraints and risks, such as the social and environmental impacts of energy and land use.

4.3 Policy instruments for creating demand for CDR

The scientific literature describes several policy instruments that could create demand for CDR.[21] First, the government can participate directly as a buyer, second, the government can require companies to participate as buyers, and third, the government can create market incentives to encourage demand for CDR. For these approaches, which are not mutually exclusive, instruments that focus on creating demand for CDR for offsetting emissions can be distinguished from instruments for reducing temperature overshoot. Table 3 shows an overview of the types of instruments discussed in this advisory report. This section addresses demand creation for permanent CDR.

Table 3: Overview of policy instruments to achieve CDR addressed in this advisory report and how they can contribute to the climate targets.

Policy instruments for CDR	Role in achieving climate goals	
	Limiting and reducing temperature overshoot	Counterbalancing residual emissions
Public procurement of CDR	Yes	Yes
Obligation to procure CDR ▶ for emitters ▶ for producers/importers of fossil fuels		Yes
Partial or full integration of CDR in emissions trading scheme		Yes
State provisions for financing CDR in the future	Yes	
From the moment of temperature overshoot onwards: obligation for emitters to take provisions for financing future removal of an equivalent amount of their emitted GHGs	Yes	

4.3.1 CDR requires European policy

Policies for creating demand for CDR can in time be developed and implemented at the European level. Since many climate policies are shaped in the European Union, it is likely that CDR policy will also be shaped at the European level. If member states do not harmonise their CDR policies, an uneven playing field could arise. This could potentially lead to negative effects on the competitiveness of member states, possibly including the Netherlands, and to carbon leakage. Moreover, it is more efficient to have a European market for CDR, as some member states have a surplus potential to remove and/or store CO_2, while others have a deficit.

European policies aimed at creating demand for permanent CDR are still in their infancy. Although there is no European CDR policy as yet, the EU is taking some of the necessary steps towards this, such as developing the framework for certification (see Section 4.1). Decision-making on the design of European CDR policy still largely remains open and implementation is expected to take several years. A European Commission research report on the potential of integrating CDR into the EU ETS is to be published in 2026.

Member states can expedite and influence European policies by cooperating with like-minded countries. This could be achieved, for example, by conducting joint research into policy instruments for creating demand and taking a standpoint. This is a commonly used strategy that the Netherlands also deploys to promote EU policy on sustainable carbon cycles in the chemicals industry, for example.[22]

It is in the interest of the Netherlands to play an active role in shaping European CDR policy. The Dutch economy has a number of sectors which produce hard-to-abate emissions, such as industry, aviation and agriculture.[23] Setting a cap on the total amount of CDR that can be used to offset these emissions would affect the residual emissions that each sector will be able to counterbalance. In addition, the Netherlands has a relatively large potential for underground CO_2 storage, so it is important to continue to influence European regulations on cross-border CO_2 infrastructure.

There are several policy instruments that can be used at the European level to create a demand for CDR. Research into instruments for creating demand will reveal which policy instruments work best for which aims. These instruments could be deployed to scale up CDR capacity, counterbalance residual emissions, and reduce an impending temperature overshoot, for example. All these aims require policies at the country and European level that be implemented today, even for issues that will only come into play later, such as when ETS emissions allowances are reduced to zero.

7. Recommendation
The Council advises the Dutch government to initiate cooperation with other member states to explore possible European policy instruments for creating demand for CDR and encourage their introduction.

4.3.2 Policy instruments for creating demand

The scientific literature describes three types of policy instruments for creating demand to achieve climate neutrality: 1) CDR obligation, 2) integrating CDR in an emissions trading scheme and 3) public procurement of CDR.[24] See Box 6 for a brief description.

Box 6: Policy instruments for creating a demand for CDR.

CDR obligation
The government can require parties to purchase CDR certificates. There are two examples of this in practice:

- *California's Carbon Removal Development Act*: This bill requires emitters in the California ETS to purchase 'negative emissions credits' corresponding to an increasing percentage of their GHG emissions: 1% in 2030, 8% in 2035, 35% in 2040 and 100% in 2045.[25] Emitters can ultimately only meet this obligation by implementing permanent CDR methods or 'negative emissions credits'. It is possible to use two phase negative emission credits which are initially temporary. At a later stage emitters must eventually convert them into permanent CDR.
- *Carbon Take Back Obligation (CTBO)*: The government imposes an obligation on producers and importers who market fossil fuels.[26] They must permanently store a percentage of the CO_2 that would be released from burning these fuels (their 'scope 3 emissions'). This percentage increases over time and must be 100% by the time net zero is reached. Unlike in other policy instruments, fossil CCS is permitted here in addition to CDR. The obligation exists alongside emissions reduction policies.

Partial or full integration of CDR in the ETS
Within the ETS, companies are given the option to partially or fully meet their emission reduction obligations by submitting CDR certificates.[27] Part of the net reduction is then achieved through CDR. Integration into the ETS therefore enables trade-offs between emission reduction and CDR 'by design'. Full integration means that there are no restrictions on the method of CDR and on the amount of CDR that may be used to fulfil ETS requirements. Moreover, ETS participants can purchase certificates directly on a market for CDR certificates. Partial integration does involve restrictions.

Public procurement of CDR
The government can procure CDR certificates by means of calls for tenders, for example. This involves a type of auction where CDR providers bid to deliver a predefined amount of CDR using a given CDR method. This is similar to how tenders for offshore wind are usually organised in the Netherlands.[28] The government can keep the purchased CDR certificates itself, sell them to other countries or to emitters in the future, trade them in an ETS, or sell them on the voluntary market (if such a market is developed). Public procurement of CDR certificates can be organised at either the national or European level. The costs of public procurement can be distributed in various ways. This ultimately determines the distributive justice and efficiency of the instrument.

While obligations can play a role in scaling up CDR and offsetting, the interaction with existing emission reduction policies requires further attention. The obligations described in the literature correspond to increasing percentages of emissions, increasing the cost of a tonne of CO_2 emissions over time. This has a number of implications. First, an obligation leads to additional costs for ETS participants (amongst others): in addition to emission allowances, they have to pay for a proportionate percentage of CDR (or, in the case of a Carbon Take Back Obligation, indirectly for higher fuel costs). Its effects are similar to a European carbon tax on top of the EU ETS price. The ETS price will fall compared to the situation without obligations, because more ETS participants will take their own emission-reducing measures. Further research is needed to determine the exact implications of this, also taking into account the possible banking of allowances and the Market

Stability Reserve. Second, if an obligation is applied, the sum of the price of emissions allowances and the cost of CDR could be higher than the social cost of those emissions, in which case such obligation is neither efficient nor justifiable. This also needs to be further investigated. Third, the introduction of obligations could lead to an uneven playing field and carbon leakage. Some of the above impacts will only come into effect at a later stage under a Carbon Take Back Obligation, as fossil CCS (which is considered emission reduction in the ETS) is expected to be deployed first, before the obligation will lead to CDR.

Alternative policies are needed for sectors with hard-to-abate emissions that do not fall under an ETS. The agriculture sector is a case in point. Currently, the social costs of GHG emissions from agriculture are not included in product prices.[29] The government could choose to pay the cost of CDR required to counterbalance emissions from agriculture from public funds. This does mean that agriculture will not be held fully responsible for its own social costs. Another option, analogous to the Californian bill, is to impose an obligation on businesses to counterbalance their GHG emissions with CDR. This obligation can be imposed on various parties in the supply chain: manufacturers and importers of farm animal feed and synthetic fertilisers, farmers, or the milk and meat processing industry. In this situation, a CDR obligation can be seen as full or partial internalisation of social costs in the price of agricultural products. Again, introducing an obligation could potentially create an uneven playing field.

Rapid integration into the ETS involves drawbacks and risks. If the price of CDR is competitive in comparison with the price of emission allowances, emitters who do not have hard-to-abate emissions have the possibility to trade off emission reductions against CDR. This would effectively remove the incentive for emission reductions. If the cost of CDR is not competitive in comparison with the price of emissions allowances, the government could choose to subsidise the excess costs. They could do this with 'carbon contracts for difference'. This means that the government would subsidise companies to implement CDR instead of reducing emissions, with all the climate consequences this entails (see Section 3.1).

If integration into the ETS does become part of policy (for example, once only hard-to-abate emissions remain), becoming the sole provider of CDR certificates in the ETS market can give the government additional ways of governing CDR. As sole provider, the government could control such factors as the quantity of tradable CDR certificates, the timings of CDR integration in the ETS market, the method of CDR, and which participants or sectors are allowed to buy certificates.[30] The concept of a European Carbon Central Bank (see Box 7) is based on this idea.

Box 7: European Carbon Central Bank
One proposal that is receiving a lot of attention in the literature[31] is the combination of public procurement with future integration of CDR into the ETS. The idea is that a new European Carbon Central Bank would procure CDR certificates and integrate them into the ETS sometime after 2040 should the CO_2 price rise and excessive price spikes occur. This integration would ensure price stabilisation in the ETS, and can help ensure continued support for the ETS as one of the central elements of climate policy.[32] The establishment of such a carbon central bank is a daunting task. In anticipation of its establishment, member states could already procure CDR certificates today and trade them in the ETS later.

Partial integration into the ETS will need to be carefully timed, based on the right information, and should certainly not be done prematurely. First, the opportunities for emission reductions need to be scarce, so that emissions are only counterbalanced by CDR where there is really no alternative. This scarcity will be reflected in excessively priced emissions allowances. But to anticipate the advent of this situation, independent information regarding the reduction potential of the various sectors is necessary. Second, if emission reduction and CDR are to be traded off, the price for CDR must also internalise external social costs (such as the risk of biodiversity loss when using biomass, emissions produced in the supply chain, and additional land and energy use due to DACCS). This requires a properly functioning CRCF certification framework, in addition to the licensing system and the sustainability framework for the deployment of bio-based raw materials for high-grade applications.

8. Recommendation
The Council recommends to exclude CDR from the ETS as long as possible, to maintain the incentive for emission reductions for as long as possible. The Council further recommends that, should CDR become part of the ETS, only the government be authorised to introduce CDR certificates in the market.

Public procurement through calls for tenders is efficient and is very flexible in terms of the type of certificates, distribution of the costs, and the use of certificates. Moreover, this system can be established relatively quickly compared to other instruments such as obligations, which are currently still subject to uncertainties due to their interaction with emission reduction policy. However, to avoid CDR coming at the expense of emission reductions, it is important that the government delays using its CDR certificates for offsetting for now (for instance by selling them to market parties or to other countries).

Unlike EU-level procurement, a national public procurement policy can be implemented in the short term. European policies will take some years to implement, while permanent CDR methods urgently need to be scaled up. National public procurement will play an important role in achieving CDR at a sufficient scale by 2035.

9. Recommendation
The Council recommends launching a Dutch government-led procurement programme for permanent CDR to gain experience with various methods of CDR in the Netherlands in the runup to 2035.

The public procurement of CDR certificates can be implemented in the form of calls for tenders. Preferably, the procured CDR will be realised in the Netherlands (rather than purchasing it from another country).[33] This will allow experience to be gained with the entire CDR supply chain in the Netherlands. It is important to gain experience with all the various aspects of CDR, so not only technical experience, but also institutional and social experience. This is currently also taking place in some other member states (for example, the Swedish government has put out a call for tenders for bioCCS).[34]

A number of additional considerations come into play with bioCCS. Many bioCCS methods are still at a relatively early development stage and require special attention. Therefore, it is important to take into account their embedding in the future energy system (see Box 2) and future industrial carbon requirements. A bioCCS method that may look promising based on the current energy system could yet result in a lock-in in the longer term. It is also important that sustainable biomass is deployed for high-grade applications (see also Box 4), and that its social embedding is procedurally just.

As the development of EU policy progresses, the government can reconsider whether national public procurement needs to be continued. This is also connected to the aim for which the government would like to deploy CDR. The government can use the purchased CDR certificates itself, or sell them to other countries or to emitters in the future. If the government sells the CDR certificates, they could potentially be used for counterbalancing, and thus replace emission reductions. If the EU opts for a route with a type of European Carbon Central Bank (see Box 7), the certificates could potentially also be sold to that bank.

Funding public procurement requires attention to distributive justice. There are several ways the government could fund the procurement of CDR certificates. For example, by using public funds, by applying polluter pays (e.g. charges for GHG emissions or from the proceeds of auctioned emission allowances) or by introducing a surcharge to household energy costs. If the government imposes charges for GHG emissions on ETS participants, this could affect emissions trading in the same way as imposing an obligation would (see above). In addition, the type of funding also needs to take account of the effects of this funding on consumers and a just distribution of the costs.

4.3.3 Policy instruments specifically for reducing a temperature overshoot

The prevention of a temperature overshoot is a joint global responsibility and involves aspects of justice. This responsibility must be shared between countries (see Box 8). As some of the extensive CDR required to limit or reduce a temperature overshoot will have to take place at a later date, future generations risk having to bear the cost.

Box 8: Consequences of overshooting the global carbon budget for the distribution of CDR responsibilities

Under the current levels of emissions, the global carbon budget required to stay below the 1.5°C target will be used up by around 2030.[37] Not only does this highlight the importance of rapid emission reductions, but it also implies that any temperature overshoot will have to be limited or reversed by means of CDR. As temperature overshoot is connected to the carbon budget, the distribution of responsibility for overshooting the carbon budget between countries gives an indication of the effort sharing required to reduce such a temperature overshoot, in other words who should pay for the required CDR.

Various proposals for this implicit sharing of the CDR responsibility have been made in the literature. The effort sharing takes into account what is socially, economically, institutionally and technically feasible, and what is just. In terms of justice, historical responsibility (such as a colonial past), capacity and economic resilience can be a factor. If justice is taken into account, rich and early-industrialised countries like the Netherlands should only emit very little going forward[38] and therefore have to achieve all the more CDR.

Based on the emissions scenarios for the Netherlands, CE Delft has made an informal estimate of a Dutch carbon budget overshoot, based on two ways of allocating the carbon budget: one based on an allowance per capita and one based on the share in CO_2 emissions (CO_2 intensity per inhabitant). This gives a range of required CDR of between 1.6 and 33 $MtCO_2$/yr from 2050 onwards.[39]

Internationally, there is still no consensus as to what entails just effort sharing and what factors should be taken into account in this.[40] However, there is a consensus that rich countries, such as the Netherlands, must take the lead in combating climate change.

The current generation of emitters can make provisions to prevent shifting the entire burden of CDR to future generations. If current emitters do not make provisions for future CDR today, it will amount to a hefty burden for future generations: financially, socially and ecologically. Since the extent of the temperature overshoot depends on the implemented policy and its effectiveness, it is difficult to estimate the cost of such an overshoot. It has been estimated that a temperature rise of 0.1°C can be associated with about 220 $GtCO_2$.[35] The exact cost of CDR in the future is still uncertain, but it is plausible that CDR at that scale will cost future generations trillions of euros.

A relatively new idea in the scientific literature is to require emitters to make financial provisions for future CDR from the moment of a carbon budget overshoot. These financial provisions must ensure proportionate CDR in the future (see Box 9). Here, as with the obligations discussed in Section 4.3.2, it is important to consider interactions with emission reduction policy, and more particularly emissions trading. It is even argued that if such instruments were to be introduced, emissions trading may be abolished.[36] There is also the question of which emitters would have to offset their emissions directly, and which emitters would only have to commit to future CDR. This is because the potential capacity for CDR is scarce, and it has yet to be determined who may use this capacity.

Box 9: Carbon Removal Obligation/Atmospheric CO_2 Removal Deposits
Bednar et al. (2024) propose that emitters should be required to take on a carbon debt that they will have to repay in the future, as soon as the global carbon budget is exceeded. This debt is similar to a financial loan, where risks are also covered.

Linnell et al. (2024) propose that emitters pay a deposit for CDR into a designated investment fund, based on the principle of producer responsibility. The deposit and any associated capital gain will be refunded once the emitter has demonstrated that the required CDR has been carried out.

The government's commitment today will determine whether the future economy can bear the cost of CDR. In a very broad sense, the government can strengthen the economy of today to ensure that the future economy and public finances will be sufficiently robust to assure a bearable burden of CDR for future generations. This could take the form of low public debt, for example, or investment in innovative CDR technologies that will lower the costs for future generations.

It is clear the current generation of emitters must contribute to minimising the cost of future CDR, but how this should be done, other than with rapid emission reductions, remains to be determined. Minimising the likelihood of a future temperature overshoot through emission reduction policies will reduce the dependence on future CDR (see Recommendation 1 in Chapter 3). In addition, the current generation of emitters could contribute to the cost of CDR for future generations. For example, the government could choose to create a fund. There are various examples of funds that have been established to deal with similar intergenerational distributive issues, such as pension funds and funds for radioactive waste management. Public funds could be used to create a CDR fund, for example in the form of earmarked taxes based on current emissions. By the time CDR starts to play a major role, these emitters will mostly have ceased to exist, as emissions will be close to zero. 'Current emitters' should be understood in the broadest sense of the term, and could be consumers or companies, depending on the policy choices, as long as they share in the responsibility for the emissions.

10. Recommendation
The Council advises the government to ensure that emitters start contributing from now on to the future costs of limiting and reducing a temperature overshoot, and to design and implement instruments to this end.

Notes

1 Burke & Schenuit (2023).
2 Regulation (EU) 2022/0394
3 Bellamy (2022); Burke & Schenuit (2023); Honegger et al. (2021).
4 European Commission (2024d).
5 House of Representatives of the Netherlands, session year 2022–2023, 36350, no. 1.
6 Hoofdlijnenakkoord (2024).
7 Formatiewerkgroep Klimaat en Energie (2024).
8 Carbon Gap (2023a), (2023b).
9 Regulation 2023/0081
10 Based on CETPartnership (n.d.); RVO (2024a), (2024c).
11 House of Representatives of the Netherlands, session year 2022–2023, 32 813, no. 1243.
12 See also Mulder (2024), who remarks that certain parties hold significant market power in the current Dutch situation. He recommends in any case introducing temporary market and price regulation until such time that a nationally and internationally competitive market for CO_2 transport infrastructure and storage is developed. The Minister of Economic Affairs and Climate Policy has adopted this recommendation (see: House of Representatives of the Netherlands, session year 2023–2024, 32 813, no. 1375).
13 European Commission (2024c).
14 Burke & Schenuit (2023).
15 Directive (EU) 2009/31
16 See for example Bellamy (2022).
17 Rickels et al. (2024).
18 PBL (2024b).
19 TNO (2024).
20 This corresponds to emission reductions of 92-84% and 93-87% respectively compared to 1990. For these figures it is assumed that sufficient CO_2 storage capacity will be available in the Netherlands for the CO_2 to be removed and that there are no barriers to policy implementation.
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30 Meyer-Ohlendorf (2023).
31 Rickels et al. (2022); Rickels & Rothenstein (2022).
32 Burke & Schenuit (2023).
33 Biomass may be imported, as the Netherlands cannot produce enough itself.
34 Lundberg & Fridahl (2022).
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37 Climate Change Tracker (2024).
38 CE Delft (2023); PBL (2024c).
39 CE Delft (2023).
40 PBL (2024c).

Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
BECCS	Bioenergy with Carbon Dioxide Capture and Storage
bioCCS	Biomass with Carbon Dioxide Capture and Storage
GHG	Greenhouse Gas
CCS	Carbon Dioxide Capture and Storage
CCU	Carbon Dioxide Capture and Utilisation
CDR	Carbon Dioxide Removal
CO_2e	Carbon Dioxide Equivalent
CRCF	Carbon Removal Certification Framework
CTBO	Carbon Take Back Obligation
DAC	Direct Air Capture
DACCS	Direct Air Carbon Dioxide Capture and Storage
ETS	Emissions Trading System
EU-ETS	European Union Emissions Trading System
Gt	Gigatonne
IPCC	Intergovernmental Panel on Climate Change
kt	Kilotonne
LULUCF	Land Use, Land-Use Change and Forestry
MRV	Monitoring, Reporting and Verification
Mt	Megatonne
NDC	Nationally Determined Contribution
RD&D	Research, Development and Demonstration
t	Tonne
TRL	Technology Readiness Level
UNFCCC	United Nations Framework Convention on Climate Change

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Colophon

"Clearing the air? *Advice for principles and policy for governing carbon dioxide removal*" is an advisory report to the Dutch government produced by the Netherlands Scientific Climate Council.

WKR report 002

The Netherlands Scientific Climate Council was established in November 2022. The Council advises the government and parliament on the transition to a climate-neutral and climate-resilient society, based on broad scientific insights and taking into account other challenges facing society.

The Council is composed of the following members: Prof. J.W. (Jan Willem) Erisman (chair), Prof. H.C. (Heleen) de Coninck (deputy chair), Dr S. (Sanne) Akerboom, Prof. K. (Kornelis) Blok, Prof. M. (Marjolijn) Haasnoot, Prof. M. (Machiel) Mulder, Prof. W. (Wouter) Peters, Dr W.D. (Wieke) Pot, Prof. E.M. (Linda) Steg, Prof. B. (Behnam) Taebi, Dr R.W. (Ruud) van den Brink (secretary-director).

The following persons participated in expert meetings convened for the purposes of this advice: Menno van Benthem (Ecorys), Holly Jean Buck (University at Buffalo), Mathias Fridahl (Linköping University), Conor Hickey (University of Oxford), Oliver Geden (Stiftung Wissenschaft und Politik), Bettina Kampman (CE Delft), Kiane de Kleijne (Eindhoven University of Technology), Margriet Kuijper (independent consultant), Kenneth Möllersten (KTH Royal Institute of Technology and IVL Swedish Environmental Research Institute), Felix Schenuit (Stiftung Wissenschaft und Politik), Samantha Eleanor Tanzer (TU Delft), Paul Zakkour (Carbon Counts). Discussions were also held with CDR policymakers of the Ministry of Economic Affairs and Climate Policy, the Ministry of Agriculture, Nature and Food Quality, the Ministry of Infrastructure and Water Management, and the European Commission. This advisory report does not necessarily reflect the views of the experts consulted.

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