



What could responsible carbon dioxide removal look like in the Netherlands?

An exploratory study with recommendations for research and governance

Summary

WHAT COULD RESPONSIBLE CARBON DIOXIDE REMOVAL LOOK LIKE IN THE NETHERLANDS?

AN EXPLORATORY STUDY WITH RECOMMENDATIONS
FOR RESEARCH AND GOVERNANCE

A REPORT COMMISSIONED BY KLIMAATONDERZOEK INITIATIEF NEDERLAND (KIN)
AND CONDUCTED BY RESEARCHERS AT THE UNIVERSITY OF TWENTE,
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Summary

As existing climate change mitigation efforts continue to fall short, carbon dioxide removal (CDR)—techniques that both actively extract carbon dioxide from the atmosphere and prevent that CO₂ from re-entering the atmosphere—has risen higher on the political agenda, including in the Dutch government's latest National Climate Plan. Organisations such as the Intergovernmental Panel on Climate Change (IPCC) and the Wetenschappelijke Klimaatraad (WKR) argue that large-scale CDR is very likely to be required to achieve a CO₂-neutral society in time and to return from the virtually inevitable 'overshoot' in global temperature rise relative to the targets set in the Paris Agreement. However, the large-scale deployment of CDR techniques also raises many questions, particularly about the potential negative ecological and social impacts and the necessary policy frameworks. This discussion is made more challenging by the wide range of CDR techniques that are in various stages of development, have different resource use profiles, and come with different risks and uncertainties.

This exploratory report, conducted by researchers of the University of Twente, Delft University of Technology and Deltares, commissioned by KIN (Klimaatonderzoek Initiatief Nederland¹), answers the following central question:

What could responsible CDR governance and research look like in the Netherlands?

This question called for a multi-faceted critical assessment of which forms and configurations of CDR can potentially be deployed in the Netherlands. Therefore, this study assessed a broad set of CDR types to understand their possible benefits and impacts, as well as uncertainties and risks, which were then evaluated in the context of competition for resources within the Netherlands and available techniques for monitoring CDR for risk management. As all technologies exist within a social context, this study also takes a critical eye to the current social and political conditions present in the Netherlands to evaluate what conditions are needed to prevent mitigation deterrence or unjust risks and burdens transfer from CDR upscaling. The report brings together insights from a desk study conducted by researchers holding a wide range of academic expertise (i.e., engineers, social scientists, and philosophers), as well as insights gathered from interviews, written feedback, and a workshop with representatives of government, industry, NGOs, and research institutes. This study also identifies an extensive list of knowledge gaps that need to be filled before a definitive scale of deployable CDR can be quantified. We end with recommendations for policy makers and research program managers.

¹ trans. Climate Research Initiative Netherlands

Summary of cross-cutting issues for CDR deployment

Readiness	CDR systems are diverse, and many involve components that are currently commercially available. However, due to uncertainties about available resources, security of carbon storage, and technology integration, as well as governance and accounting gaps, no CDR technology is clearly ready for large-scale deployment in the Netherlands. Individual CDR projects are possible in the Netherlands across all types of CDR systems but must be evaluated on a case-by-case basis to assess their specific benefits and risks. It is not yet possible to estimate how much CDR may be available in the future.
Resource availability	The Netherlands is a small, dense country with limited resources available to support large-scale CDR within its borders. • Land: Almost all land in the Netherlands is already in use. Any deployment of dedicated land-based CDR or supporting activities (e.g., biomass production, solar energy production) would compete with existing and alternate land uses. • Biomass: Additional production of biomass in the Netherlands is limited by available land, as above. The use of imported biomass (e.g., for biochar or BECCS) is possible, but risks transferring ecological and social burdens to the region of cultivation. Applying CCS to existing waste biomass combustion is a lower-risk source of BECCS but its availability may decrease as competition for biomass increases, particularly for higher-value applications (e.g., biomaterials, chemicals, fertiliser) and biomass is used more efficiently over time. • Energy: Netherlands has a highly congested electricity grid and competition for additional electricity, as well as heat, remains high from both industrial and consumer actors. • Minerals: There are no significant deposits of minerals suitable for enhanced weathering in the Netherlands and therefore would need to be imported, increasing associated transport emissions. • CO₂ transport and storage infrastructure: The Netherlands has begun development of CO₂ transport and storage infrastructure, but active injection has not begun. Offshore geologic storage is available, including in the form of depleted oil and gas wells. Assessing future scalability of CO₂ storage will depend on learning-by-doing.
Risks	The greatest risk of CDR is that activities to decrease atmospheric CDR will instead, directly or indirectly, lead to increased warming. These risks arise from uncertainties of predicting net climate benefits and co-impacts, indirect effects from resource-use competition and mitigation deterrence, as well as the potential for stored carbon to re-release into the atmosphere. These risks compound as the scale of CDR increases. Risk management requires rigorous and conservative rules for measuring, reporting, knowledge sharing, and monitoring, as well as liability and contingency planning, all of which needs to be regularly reviewed and revised as knowledge on CDR improves.

Summary of cross-cutting issues for CDR deployment, *cont'd*

Climate justice	Climate justice frames CDR research and innovation activities, emphasising the importance of international and intergenerational fairness in climate policy, as well as moral conflicts raised by CDR policies between global, regional and local scales. Key ethical concerns with CDR include delaying mitigation, unacceptable side-effects from large-scale implementation, overestimating technical abilities to remove CO ₂ , and the role of large emitters in benefitting from CDR.
Public acceptance	Public acceptance influences the successfulness of implementation of CDR and should be taken into account during policy development as well as decision making about specific projects.
Key research needs	• Assessing CDR governance and accounting practice to minimize risk of mitigation deterrence, undercounting of negative impacts, and double counting of benefits. • Time and space explicit assessment of risks and benefits, including warming and cooling impacts, as well as resource demand and co-benefits for all CDR techniques. • The interactions of CDR upscaling with other Dutch climate action and resource demand, including technical, economic, and social ramifications as well as potential synergies. • Determining the need for CDR by faithfully determining residual emissions that incorporates both highest possible ambition of emission reduction in conjunction with realistic deployment potentials of CDR.
Governance recommendations	• Dutch climate targets should not rely on a specific quantity of CDR until further research determines a realistic level of availability and scalability. • CDR initiatives should prioritise projects that integrate with existing activities in the Netherlands to reduce risks and resource demand as well as to maximize co-benefits. For land-based biological CDR, ecological soundness should take precedence over maximising carbon storage. • Private partners with track records of substantially contributing to GHG emissions and undermining climate policies should not receive public financing to undertake CDR or be involved in publicly (co)funded CDR research and innovation consortia.

Defining features of CDR

The defining feature of a CDR system is the uptake and storage of atmospheric carbon (that is, carbon dioxide, CO₂) whether via natural processes (e.g., via photosynthesis) or technological ones (e.g., via chemical solvents). Systems that only capture and store fossil carbon from exhaust gas (e.g., CO₂ captured from fossil fuel combustion or cement production) reduce the amount of CO₂ added to the atmosphere, but are not CDR.

Following the IPCC categorisation, CDR activities can be categorized into three main types: Land based biological (including living ecosystem and extracted biomass CDR) ocean-based biological CDR and (geo)chemical CDR:

1. **Land-based biological CDR** involves CO₂ uptake via photosynthesis into ecosystems. Living ecosystem CDR depends on natural, living systems capable of storing carbon in the living biomass and other organic matter. This type of CDR can be further grouped into afforestation and improved forest management, wetlands and peatland restoration, and agricultural soil carbon storage. In contrast, extracted biomass CDR, which is then harvested and stored elsewhere. This concerns biomass with carbon capture and storage (BioCCS/BECCS), where the biomass is combusted and the resulting CO₂ stored in geologic formations, and the formation of biochar through pyrolyses of biomass which then can be stored in soils or other reservoirs (e.g., burials).
2. **Ocean-based biological CDR** involves extraction of CO₂ from marine surface water via photosynthesis, which allows the ocean to take up more atmospheric CO₂. This can be done through cultivation and sinking of ocean micro- and macro-biomass, which is expected to end up in marine sediment (ocean fertilisation and macroalgae cultivation and sinking) or via the restoration or expansion of coastal vegetation. Ocean-grown biomass can also be harvested and used for bioCCS, with the resulting CO₂ stored in geologic formations.
3. **Geo-chemical CDR** includes terrestrial methods where the direct uptake of gaseous atmospheric CO₂ via physical or chemical methods is concentrated, purified and stored in geological formations (e.g., empty oil and gas fields, saline aquifers)—known as DACCS (direct air (carbon) capture and storage)—and the carbonation of atmospheric CO₂ into unsaturated mineral rocks (e.g., olivine and wollastonite), thereby forming carbonates and bicarbonates, which is then stored in the mineral itself (mineralisation) or dissolved into soils (enhanced weathering). This category also includes analogous methods where the CO₂ is removed from and stored in the ocean, such through spreading alkaline materials (e.g., silicates, carbonates) in the water, which will bind dissolved CO₂ (ocean alkalinity enhancement) or through direct ocean CO₂ capture (DOCCS) using, e.g., electrochemical processes.

Summary of CDR technique-specific issues: Land-based biological CDR

CDR technique	Readiness	Key resources	Integration potential	Risks	Key research needs
Afforestation, reforestation, and improved forest management	Technically mature practices. Continual management required.	Land; Limited possibility to intensify existing forestry practices.	Co-benefits with biodiversity, soil quality, and local temperature management.	Re-release of stored carbon due to pests, fires, drought, or human activity.	Potentials, risk, profiles and management under changing climatic conditions and competition for resources.
Peatlands restoration	Technically mature practices. Continual management required.	Land; current drained peatlands currently used for agriculture.	Co-benefits with biodiversity and water management, paludiculture.	Methane emissions from re-wetted peatlands; indirect impacts from repurposing of agricultural land.	Timing of climate impacts; Potentials, risk, profiles and management under changing climatic conditions and competition for resources.
Agricultural soil carbon storage	Technically mature practices. Continual management required. Need for knowledge sharing and social uptake.	Land; Can co-site with existing cultivated land.	Impacts on crop yields and supplemental nutrient needs can be positive or negative.	Carbon storage highly sensitive to changes management practices.	Effective measurement and monitoring; Practices to balance carbon storage with other environmental objectives.
Biomass with carbon capture and storage	Component technologies are mature, but system integration not proven at scale. Long infrastructure lead times.	Biomass, CO ₂ transport and storage infrastructure.	CCS can be applied to existing waste-to-energy, fermentation and biogas plants.	Technical challenges; CO ₂ storage stability; CCS scaling difficulties; climate impact of biomass supply chain; Indirect impacts from biomass imports.	Monitoring and managing direct and indirect impacts from imported biomass use, including non-climate impacts.
Biochar	Technically mature production process, but high uncertainty around decay and durability, monitorability, and co-impacts.	Biomass, Land; Can co-site with existing cultivated land.	Possible positive and/or negative impacts on crop yield, water retention, and nitrogen emissions, varying with specifics of implementation.	Methane emissions during biochar production; Uncertain decay rates; Impacts from soil interactions are difficult to predict; decreases in local albedo.	Decay under changing climate conditions; soil interactions; monitoring and verification of soil and non-soil storage.

Summary of CDR technique-specific issues: Ocean-based biological CDR

CDR technique	Readiness	Key resources	Integration potential	Risks	Key research needs
Ocean fertilisation	Limited field trials. Storage of sunk microalgae remains highly uncertain. Currently prohibited by international agreements.	Suitable ocean sites.	Unknown.	Ecosystem disruption; misestimation of climate benefits.	Measuring and monitoring carbon storage; Indirect impacts on ocean ecosystems.
Macroalgae cultivation and Sinking	Macroalgae cultivation is technically mature. Storage of sunk macroalgae remains highly uncertain.	Suitable ocean sites for cultivation.	Unknown.	Ecosystem disruption; misestimation of climate benefits.	Measuring and monitoring carbon storage; Indirect impacts on ocean ecosystems.
Coastal revegetation and restoration	Technically mature practices. Continual management required.	Coastal land and near-shore space.	Co-benefits with biodiversity and flood management.	Mis-estimation of carbon uptake, Re-release of stored carbon due to pests, fires, drought, or human activity.	Potentials, risk, profiles and management under changing climatic conditions and competition for resources.

Summary of CDR technique-specific issues: (Geo)chemical CDR

CDR technique	Readiness	Key resources	Integration potential	Risks	Key research needs
Direct air carbon capture and storage	First-of-a-kind demonstration-scale technologies available but scalability uncertain, particularly regarding integration with CCS and energy systems.	Energy.	Unknown.	Technical challenges; CO ₂ storage stability; CCS scaling difficulties; competition for energy (and water for certain types of DACCS).	Reduction of energy and chemical needs; capture effectiveness with changing weather and climatic conditions.
Enhanced rock weathering	Component technologies are technically mature, but techniques to measure and monitor carbon uptake and storage are still in field trial development.	Energy, Minerals, Land; can co-site with existing cultivated land, as well as other in-use land, mining & transportation infrastructure.	Potential impact on soil quality and crop yields, but highly site-specific.	Mis-estimation of carbon uptake; ecological interactions; health risks from small particulate matter, increased mining efforts, reliance on imports.	Measurement and monitoring of CO ₂ uptake; potential ecosystem interactions.
Ocean alkalinity enhancement	Small-scale pilot studies, labwork, and modelling. Real-world carbon uptake and indirect impacts highly uncertain. Currently prohibited by international agreements.	Minerals, energy, mining & transportation infrastructure.	Unknown.	Ecological interactions may disrupt local ecosystems or reduce net climate benefits, increased mining efforts, reliance on imports.	Tracking of mineral dispersion; indirect impacts; separating activity effects from natural processes.
Direct ocean carbon capture and storage	Small-scale demonstration plants in operation.	Energy; coastal access; CO ₂ transport and storage infrastructure.	Co-locating with desalination plants allows sharing of infrastructure and energy.	Unknown ecosystem and indirect impacts.	Impact of local climatic conditions; ecosystem impacts.

CDR in the Netherlands

Currently, CDR at scale exists in the Netherlands primarily as afforestation, reforestation, and improved forest management as well as coastal revegetation and restoration. These practices have mainly been implemented with other objectives in mind than carbon sequestration. Especially nature conservation efforts for the purpose of biodiversity increase have been a major driver. Other CDR techniques exist on a negligible scale in the Netherlands, with start-ups and commercial pilot operations as well as research-led proof-of-concept efforts.

Research efforts by other groups have also resulted in advice reports on the application of CDR in the Netherlands. CE Delft has released an extensive analysis on the need, and supply of CDR in the Netherlands (de Vries et al., 2025). In their report, they map the potential for CDR implementation (both technically possible and realistic scenario). This study, together with other literature, has been used by the Dutch scientific Climate Council to advise the Dutch government on CDR policy, which led to the CDR roadmap, proposed by the Netherlands' Ministry of Climate Policy and Green Growth in 2025. This roadmap emphasises the role of CDR as strictly supplementary to emission minimisation and the need for emissions of long-duration greenhouse gases (GHGs) to be compensated with permanent forms of CDR.

The Netherlands 2035-2045 Climate Plan envisions that, for CDR, the period towards 2030 is to be the "start-up" phase, focused on the creation of appropriate regulation and markets. Then, 2030-2040 is to be focused on upscaling with CDR deployment envisioned to reach annual removal rates of 20-25 Mt CO₂/year by 2040. These ambitions represent achieving, in the Netherlands alone, 7 to 28 times the current amount of CDR deployed globally, and doing so in just over a decade. This would require an unprecedented level of technological learning and deployment as well as an also-unprecedented level of initiative and cooperation within and between nations for collective global waste management.

It is also important to keep in mind that CDR systems are very diverse. Although many systems involve components that are currently commercially available, there are uncertainties about available resources, security of carbon storage, financial resources and technology integration. In addition, there are governance issues – such as accounting gaps, market-driven expansion and mitigation deterrence. Finally, CDR raises important ethical problems, especially in terms of unfair allocation of climate burdens at the global and intergenerational levels and of lack of inclusion of all those affected by the effects of CDR in the decision-making process. In light of these concerns, no CDR technology is clearly ready for large-scale deployment in the Netherlands. Individual CDR projects are possible across all types of CDR systems but must be evaluated on a case-by-case basis to assess their specific benefits and risks. Moreover, Dutch climate targets should not rely on a specific quantity of CDR until further research determines a realistic level of availability and scalability as it is not possible at present to estimate how much CDR may be available in the future. To reduce risks and resource demand as well as to maximize co-benefits, Dutch CDR initiatives should prioritise projects that integrate with existing activities.

When it comes to scaling CDR in the Netherlands, several risks stand out. First and foremost, the Netherlands is a small and densely populated country with limited resources available to support large-scale CDR within its borders. The Netherlands has a highly congested electricity grid and competition for additional electricity, as well as heat, remains high from the existing and future demand of both industrial and consumer actors. In addition, almost all land is already in use so any deployment of dedicated land-based CDR or supporting activities (e.g., biomass production, solar energy production) would compete with existing and alternate land uses. The use of agricultural residues for biochar or BECCS via applying CCS to existing waste biomass combustion are potential sources of biomass-based CDR, but such availability may decrease as biomass is used more efficiently over time and competition for biogenic carbon increases.

The limited possibilities of CDR at scale here, increases the risk of putting the burden of CDR on countries and communities elsewhere. There are no significant deposits of minerals, for instance, that are suitable for enhanced weathering in the Netherlands and therefore would need to be imported, increasing associated emissions and resource extraction concerns. As additional production of biomass in the Netherlands is limited by available land, for instance, an increase in e.g., biochar or BECCS would come with an increase in the use of imported biomass. This, however, risks transferring ecological and social burdens to the region of cultivation.

And although the Netherlands has begun development of CO₂ transport and storage infrastructure, and there exists offshore geologic storage potential, no CCS facility is operational yet and future scalability of CCS-reliant CDR technologies (i.e., BECCS, DACCS, and DOCCS) is uncertain due to the decades' long difficulty of scaling CCS technology in the first place.

Nine key concerns about CDR

Several concerns around CDR are important to consider when aiming to develop responsible CDR. Understanding the uncertainties and risks raised by these concerns, and how they interact with each other and competing technical, economic, and social processes, represents a key area for further CDR research. First, **the future availability of CDR is unknown**. Most CDR technologies are currently nascent, with many technical and implementation uncertainties that remain to be solved. Also, CDR systems are typically resource intensive, starting with carbon and energy, and may also require large quantities of land, minerals, water, underground CO₂ storage reservoirs and other resources. While some synergies are possible, large-scale CDR will compete with demands for food production and infrastructure, other economic sectors as well as other mitigation and adaptation technologies. Finally, the effectivity of many types of CDR depends on climatic conditions, which are already changing, injecting additional uncertainty into its long-term potential.

Second, **CDR has impacts beyond the reduction of atmospheric GHGs.** While some of these can be positive, such as biodiversity or soil quality improvement, there are many risks of negative impacts. Further, resource requirements can lead not only to competition for resources, but potentially other impacts to ecosystems and human health from the CDR activities, their supply chains, and their wastes. The resource demands and risks of a given CDR activity are specific not only to the type of CDR but the specific siting and configuration of the CDR system.

Third, **mitigation deterrence is a major problem.** For CDR, this is the concern that the prospect of removing CO₂ from the atmosphere later will lead to the delay of meaningful and impactful greenhouse gas emission reduction today. Indeed, based on arguments given and choices made by governmental and industry actors, there is evidence that mitigation is already being deterred by CDR-related arguments and actions, despite frequent emphasis that CDR remains supplemental to emission reductions. If the idea of future CDR reduces near-term emission reductions, climate-related risks and harm increase. Such climate-related risks are amplified by the uncertainty surrounding what scale of future CDR deployment is even plausible, thus also increasing long-term climate-change harms in case the presently envisioned scale of CDR never becomes available.

Fourth, **the duration and security of carbon storage is critical.** Where and in what form the atmospheric carbon is stored is the main determinant of the expected durability of a CDR activity. For example, CO₂ stored in geologic formations aims for indefinite storage, while storage in forests requires continuous management to reduce risks of re-release. From a scientific perspective, any future re-release of stored carbon results in renewed global warming and thus will have to be re-removed if we aim for “net-zero” emissions of greenhouse gases. However, some argue that CDR with storage time-horizons on the order of several decades to a few centuries can provide near-term respite from warming while mitigation efforts are on-going. Different forms of CDR require different forms of management to select suitable storage sites, monitor storage, and prevent (or remediate) re-release. All forms of CDR introduce risks of reversal, which makes emission reductions inherently preferable.

Fifth, we must be able to **track both the amount of atmospheric carbon stored and the amount of GHGs emitted by the CDR system**, as well as the resources it requires, both to track progress and to avoid risks of ‘greenwashing’ by nations or companies. For a given CDR activity, this entails quantifying the net removal: the total amount of atmospheric CO₂ removed and subtracting the total amount of greenhouse gases added to the atmosphere in the processes and supply chains of atmospheric CO₂ uptake and storage, including post-storage processes. Otherwise, we risk that a CDR activity leads to an increase in global warming. This process of greenhouse gas accounting has the challenges of balancing data demands with scientific uncertainties, existing accounting conventions, and administrative burden that vary between types of CDR, with more complex CDR systems (e.g., bioCCS or biochar using imported biomass, ocean CDR) having higher risks of misquantification.

Sixth, **adequate regulatory frameworks for CDR are currently lacking** and would not reliably prevent negative side effects. While the EU’s Carbon Removal and Carbon Farming

(CRCF) framework seeks to set minimum quality standards for different CDR activities leveraging existing European regulations, policy goals regarding the use of CDR are leading ahead of efforts to ensure that CDR is coherently embedded in the policy landscape as a whole. Already, the European Union is exploring the inclusion of CRCF-certified credits in its Emissions Trading System (ETS) and is considering the use of international CDR credits, under mechanisms such as Article 6.4 of the Paris Agreement, to offset domestic emissions. Similarly, at the Dutch level, policy discussions increasingly propose CDR as a flexible compliance option, in some cases allowing it to substitute for direct emission reductions, despite its fundamentally different characteristics and uncertainties. The current policy architecture is at odds with the strictly complementary role that the CDR roadmap assigns to CDR in relation to emission reductions.

Seventh, **CDR can create conflicts of distributive justice**. Distributive justice concerns how the benefits and burdens of CDR are shared among different groups, especially across nations, social classes, and generations. There are three main distributive justice issues raised by CDR. The first is the issue of risk transfer to the vulnerable, which is linked to the issue of regional and social inequality: large-scale CDR deployment (especially bioCCS and afforestation) could threaten food security, biodiversity, and access to land and water. In the Netherlands, where land competition is mostly with agriculture, these risks are most likely to affect domestic food production and farmer livelihoods, whereas the use of imported biomass or international CDR credits may transfer risk to low- or middle-income countries and are most likely to fall on the global poor and future generations, who have little say in current policy decisions. The second is the problem of potential benefits to current polluters, such as via allowing offsets or financial windfall from CDR, while shifting risks to others. The third is the problem of intergenerational injustice: relying on future CDR to compensate for delayed action means future generations may face a moral dilemma in which they are forced to choose between extreme CDR deployment (with all its risks, resource demands and uncertainties) and accepting extreme impacts from global warming.

Eighth, **procedural justice is essential in decision-making concerning CDR**. Procedural justice relates to inclusive and fair decision-making processes, ensuring that all stakeholders, and especially affected and marginalized groups, have a voice in climate-related decisions. Currently, fossil fuel actors and other profit-driven stakeholders continue to exert significant influence in the policy space, often shaping outcomes in ways that preserve existing economic structures.

Finally, **public perception and acceptance are important to take into consideration** from democratic and ethical perspectives, but also as they influence the successfulness of CDR implementation. Public awareness of CDR options varies, with many CDR options being rather unknown to the public. Acceptance of CDR options also varies, with CDR options that are considered more “natural”, to have fewer side-effects or risks, and that are more familiar to people, having higher acceptance. People tend to have a more positive opinion of CDR when they have more concern about climate change, have more technology optimism, perceive more benefits and less risks of CDR, perceive less tampering with nature and more naturalness of the CDR option, and have more trust in various institutions. Participants in various studies expressed similar concerns as mentioned in this report, including who is

paying the costs, durability of the storage, and negative environmental side-effects. Most studies emphasize the need for organising public engagement in decision-making processes about CDR. Little research has yet been conducted in the Netherlands, which begs the question what the public acceptance for all the specific CDR options and projects would be in the Netherlands, and what its determinants are.

Recommendations: research needs

Five groups of research gaps are identified. While not exhaustive, they focus on the key questions for Dutch governance of CDR. In particular, they do not include the specific technical and scientific uncertainties that remain for each CDR techniques.

1. Research needed to reduce uncertainties, trade-offs, and risks of CDR in the Netherlands

Understanding the potential deployment of CDR in the Netherlands requires understanding the locally available resources and conditions that affect CDR suitability. Research is specifically needed to understand how the climatic features of the Netherlands would affect CDR deployment across CDR types, and in particular account for future climate scenarios. Another unresolved question is how CDR deployment interacts with other land-use transitions. Across all CDR approaches, a key research gap is also the development of consistent and scalable monitoring frameworks that can robustly quantify net carbon removals across heterogeneous systems. Finally, a critical look is needed at the models and metrics we use to evaluate CDR, as well as other climate change mitigation options. Understanding the influence of such assumptions and data sources on model results is a key first step towards more robust and transparent decision-making over CDR.

2. Research needed to improve transparent governance of CDR in the Netherlands

Critical attention is needed to implement a CDR governance structure that explicitly accounts for the risks and uncertainties of CDR and includes societal perspectives by means of stakeholder and citizen engagement of relevant groups. Such governance structures include developing adaptive policy pathways, as well as liability mechanisms, and understanding of which CDR risks are independent or co-dependent. Greater emphasis is also needed on placing CDR in the context of other demands for resources, both in modelling and in policy development, including for other mitigation options, as well as adaptation needs and other societal demand for resources, and how these may change over time. Given restricted availability of resources as well as the heterogeneity of CDR implementation systems, it is important to establish selection criteria for a 'merit order' of CDR opportunities available in the Netherlands that considers local resource availability, local technical and ecological synergies and trade-offs, expected removal rates, costs, and social considerations.

3. Research needed to address ethical aspects of CDR

From an ethical perspective, more research is needed to systematically integrate values and principles into CDR projects and activities, such as autonomy, justice, nonmaleficence, beneficence, informed consent, integrity, and respect for nature. This research needs to be carried out both in relation to CDR research and development and in relation to CDR deployment. Another important point is that the literature on CDR should engage more explicitly and more comprehensively with questions of epistemic plurality and knowledge systems. The framing of “responsible CDR” would not only rely on scientific, technical, and policy-oriented perspectives; there is room to further engage with Indigenous, relational, and situated understandings of human–nature relations, as well as broader questions of epistemic justice and whose knowledge counts in shaping climate futures. In addition, since mitigation deterrence represents one of the most important (ethical) risks of CDR, more research is needed to find the conditions or requirement that would make it possible to avoid or at least mitigate the risk of mitigation deterrence in CDR policies and projects. Finally, more conceptual clarity is needed in scientific, political, and economic discourses on CDR, typically on terms such as “durability” and “residual emissions”.

4. Research needed to facilitate responsible CDR governance and regulation

Several important governance questions remain insufficiently addressed and warrant further research. First, research is needed on how residual emissions should be defined, assessed, and governed in ways that are transparent, scientifically robust, and socially legitimate. Second, an important research question relates to CDR governance beyond carbon markets. Further research is also needed into alternative governance models for supporting CDR that do not rely primarily on offsetting or carbon credit markets. Third, more research is required to develop accounting and governance approaches that adequately capture differences between removals, reduction, and avoidance—as well as between different types of removals and greenhouse gas emission—and avoid treating carbon removals as fully equivalent to emissions that were never produced. The fourth research question that needs more scrutiny is related to the geopolitics, political economy, and policy stability of carbon removal. Research is needed on how these dynamics influence CDR governance and how climate ambition can be maintained in changing political contexts. Finally, there is the question as to the power and influence of various actors to delay or block just and effective climate action. More research is needed on the role of vested interests, incumbent industries, and other actors that may influence the development of CDR governance and deployment. It includes examining how different actors shape narratives around residual emissions, offsets, technological optimism, and climate ambition, as well as how power asymmetries affect decision-making processes. This includes how these actors influence accounting and monitoring rules that govern the deployment of CDR technologies, enabling them to displace rather than complement emission reductions. Finally, liability mechanisms need to be designed to ensure that long-term risks of carbon reversal are minimized and any reversals that do occur are both accounted for and rectified with additional removals.

5. Research needed on better understanding societal needs and concerns

In order to increase inclusive and participatory decision making on CDR in the Netherlands, and to better understand under which conditions implementation of CDR projects is acceptable, it is important to understand how diverse audiences (including citizens, local communities, and other affected publics) perceive, evaluate and respond to CDR. This involves understanding audiences' views on CDR options in general, as well as related to specific CDR policies and projects. It is particularly important to understand what underlies publics' needs and concerns and what conditions, if any, can lead to acceptance. More application of participatory methods is needed to empower citizens to actively influence decisions affecting their lives. Media analysis studies analysing how different rationales and frames for conducting CDR, as well how different policies and technical options (including monitoring options) are portrayed, can provide insight on how the topic is discussed in the public domain, which will influence how citizens perceive and evaluate CDR. It is of particular importance also to understand and address the concerns of more vulnerable groups.

Recommendations: six principles for responsible CDR governance and research

Two of the main findings of the report are that (a) there are substantial ecological and political side effects of the insistence on, and possible scaling of, carbon dioxide removal and that (b) current regulatory and responsible research and innovation frameworks fall short of reliably preventing these negative side effects. Many of these shortcomings are bound up with the fact that short-term political and economic considerations often outweigh scientific evidence and ethical considerations in climate policymaking. To address these shortcomings, we propose that policymakers, research funders and researchers endorse the following six principles for responsible CDR governance and responsible CDR research.

Responsible CDR governance and regulation

Our report has assessed the current uncertainties of CDR systems and the risks of ecological harm and mitigation deterrence in public and private sectors. We argue that the Dutch government should explicitly limit such risks by subscribing to the following principles:

1. **Demonstrate maximum mitigation ambition.** This would include the honest consideration of—and serious experimentation with—underrepresented policy measures such as scaling down high-emitting economic sectors, as well as demand reduction and sufficiency measures.
2. **Restrict role of removal in mitigation ambitions to a minimum.** Taken together, current regulation risks enabling an unconstrained expansion of CDR demand driven by private actors. The anticipation of technological fixes whose future availability and impacts are still uncertain creates a high risk of weakening present action to reduce emissions.

3. **Act out of social and ecological responsibility.** Many of the CDR technologies discussed in this report have significant consequences for land-use and local communities. Both ecological and social justice concerns require thorough consideration of these consequences in the Netherlands and, through export or resource demands, in other parts of the world.
4. **Respect procedural justice.** A responsible approach to CDR governance implies adopting inclusive and equitable decision-making. This requires research into public acceptance, perceptions and concerns, as well as public engagement and co-creation methodologies with local communities and affected groups from the start of the decision-making process, ideally leading to decision-making processes that both include all affected stakeholders, especially vulnerable populations, and enable their meaningful participation on fair terms. Responsible research and innovation

The ethics of CDR—and climate justice more generally—not only concerns responsible governance and regulation, but also has clear implications for the funding of research and public-private partnerships that may be supported through such funding. Based on the findings of our report, we argue that funding transparency – e.g., publicly disclosing which actors contribute to CDR research – is a necessary but insufficient measure to ensure responsible research and innovation. We argue for two additional principles:

5. **Responsible research funding.** Plans to fund research and innovation on CDR should not compete with existing funding for mitigation. Further, given the current technical and systemic uncertainties of CDR, funding for CDR research should also be predicated on transparent and public reporting of all findings and underlying data, which should be synthesized into the larger context of ecological and social impacts.
6. **Responsible research collaboration.** To limit mitigation deterrence risks, those private partners that have track records of (1) substantially contributing to GHG emissions and (2) undermining climate policies should not receive public financing to undertake CDR or be involved in publicly (co)funded CDR research and innovation consortia. Accordingly, fossil fuel extraction companies with a track record of climate policy obstruction would be ineligible for public funding. By contrast, companies with limited past and present GHG emissions, companies rapidly moving away from fossil fuel investment, and/or companies with no record of climate policy obstruction could participate in public-private CDR initiatives.

