German Environment Agency

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The Research Landscape of Carbon Dioxide Removal (CDR)

An Overview of Emerging Trends and Key Resources on CDR Research Activities

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1 Overview of recent developments

1.1 Introduction

Carbon Dioxide Removal (CDR), also referred to as negative emissions technologies or greenhouse gas removal (GGR), encompasses a range of methods designed to counteract anthropogenic climate change by **extracting carbon dioxide from the atmosphere and permanently storing it in geologic, terrestrial, or oceanic reservoirs**. In some cases, CO_2 can even be stored in products through carbon capture and utilization (CCUS), though the overall scale of this approach will remain limited in relation to the scale of anthropogenic emissions.

By removing carbon dioxide on a large scale, its atmospheric concentration could be reduced, potentially slowing global warming. CDR technologies are generally viewed as **complementary to conventional emission reduction efforts**, although serious concerns remain about the technical, economic, and political feasibility of organising CO_2 capture at the required scales.

Typically, CDR methods are divided into **three broad categories: natural or terrestrial**, **engineered, and marine**. Terrestrial and engineered CDR (tCDR) methods include bioenergy with carbon capture and storage (BECCS), direct air capture (DAC), biochar, enhanced weathering, and, in some classifications, afforestation and reforestation. Marine CDR (mCDR) methods include coastal wetland restoration (often referred to as blue carbon), ocean alkalinization, artificial upwelling, and ocean iron fertilization. These classifications, however, are not rigid, and other subdivisions are possible.

All IPCC climate pathways rely on CDR to offset so-called **hard-to-avoid emissions**, and most scenarios also depend on CDR to counterbalance **carbon budget overshoots**. Since the 2015 Paris Agreement and the 2018 IPCC Special Report on the 1.5°C target, CDR has inadvertently become a central tenet of mitigation. On February 6, 2024, the European Commission presented its strategy for industrial CO_2 management, followed later that same month by Germany's long-term strategy on negative emissions (LNe) to address unavoidable residual emissions, published by the Federal Ministry for Economic Affairs and Climate Action.

This acceleration in governance and regulation is mirrored by a dynamic in the field of research and development. Given the vast scale of research in this field, gaining a comprehensive overview of CDR developments is challenging. In 2022 alone, there were 4,700 publications on the topic—a reflection of the **rapid growth of CDR research**, which has expanded **significantly faster than the overall body of climate change literature** in recent years (Smith et al., 2024). The following section provides a brief insight into key scientific and policy reports from recent years that have advanced the topic of CDR in research and policy.

The aim of this factsheet is to offer a concise overview of significant trends in research funding and the research landscape on CDR over the past few years, followed by additional guidance through an annotated collection of regularly updated resources on this topic.

1.2 Recent Reports on CDR

- The IPCC's Sixth Assessment report addressed the need for CDR, its potential for implementation at scale, and its place within the large regime of mitigation efforts. It also included a fact sheet.
- The National Academy of the Sciences published reports on tCDR (2019) and on mCDR (2022) classifying and stimulating the research field.
- In Germany, the large and publicly research consortia CDRmare and CDRterra, funded by the Federal Ministry of Education and Research, consolidate research on mCDR and tCDR, respectively. In their tenure, they publish reports, factsheets, knowledge summaries, infographics, and science-policy documents on both mCDR and tCDR.
- The German Environment Agency (UBA) has recently published a report on the EU Commission Proposal for CDR Certification, as well as a factsheet on a typology differentiating prominent CDR methods.
- The 2024 State of Carbon Dioxide Removal report is a is a global assessment of the state of CDR. In its second edition, it is published by a set of lead institutions, among them the *Smith School of Enterprise & Environment at the University of Oxford*, the German *Stiftung Wissenschaft und Politik*, and funded by public and private sources.
- The CDR Primer, edited by J. Wilcox, B. Kolosz and J. Freeman (2021) is an online publication aimed as a resource on the fundamentals of carbon removal and its role in addressing climate change. The project was philanthropically funded.

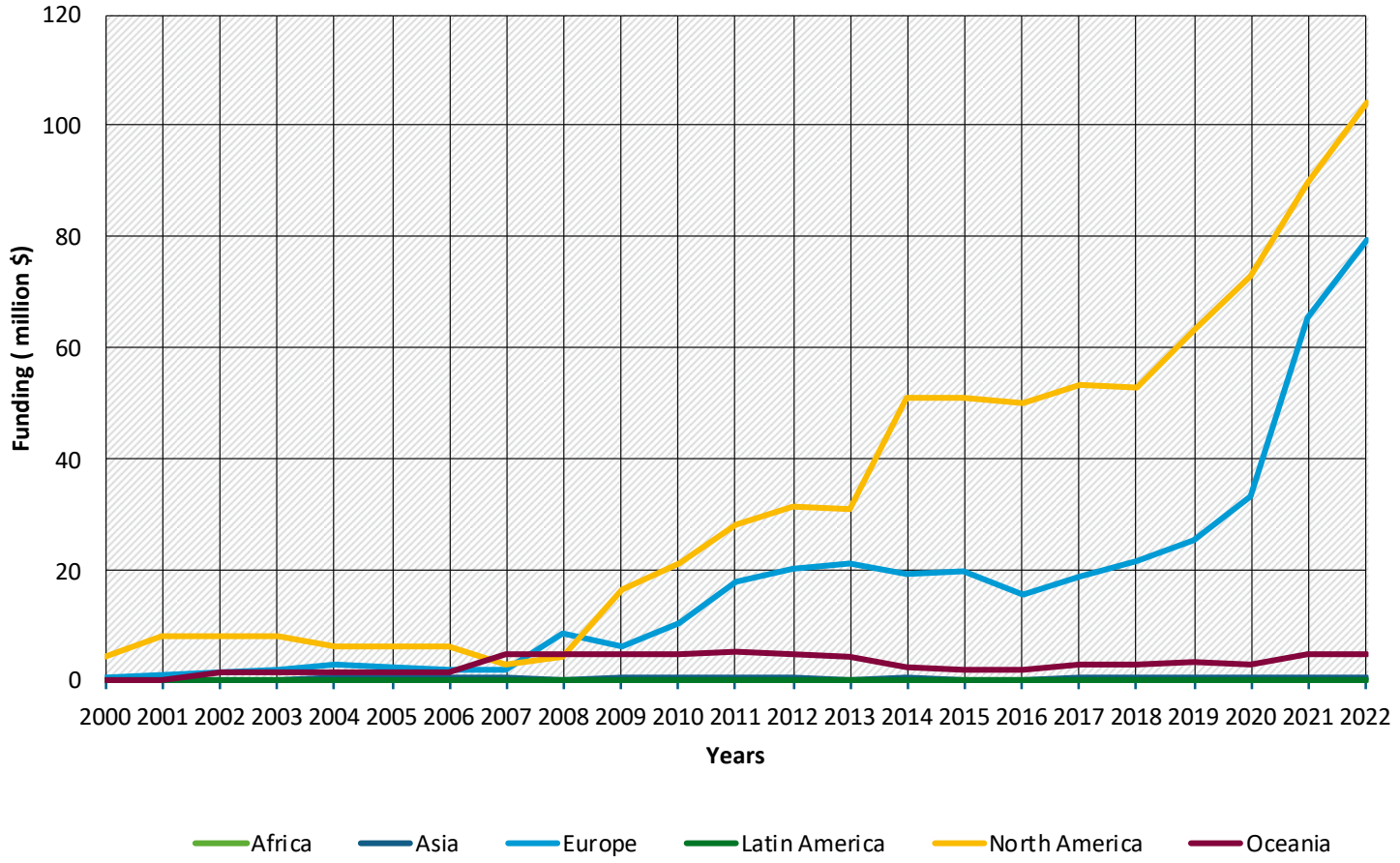
2 R&D Developments

The dynamic developments outlined above highlight the need for comprehensive overviews and analyses in this field. In recent years, one particularly noteworthy contribution is the systematic mapping of CDR publications: Lück et al. (2024) have developed a literature map collecting and visualizing this expanding body of research. Insights from this mapping can be found in a separate publication by the authors. The 2024 State of Carbon Dioxide Removal report (Smith et al., 2024) includes a chapter (Minx et al., 2024) on research developments, using machine learning to analyse the rapid growth of CDR literature, research funding, and innovation (measured by patents). The report highlights some inaccuracies in evaluating less common CDR methods and notes that only about two-thirds of research grants included are fully transparent in terms of funding disclosure (Minx et al., 2024). The report website also hosts a data explorer tool that allows for exploring various research & development (R&D) variables for the years 2000-2022, such as funding per CDR method, the number of active grants, patents, publications or tweets on CDR. The following section highlights some key insights from the related report and links them with visualizations from the data explore.

- **Funding growth**: Total annual research funding has grown slightly faster than the number of projects, averaging a 16% increase over the last 20 years (see figure 2 for an overview of grant volume development).
- **Regional disparities in CDR funding**:
  - The **majority of funding originates from Canada and the United States**, accounting for 40% of all active research grants.
  - **Minimal R&D activity is observed in Latin America, Africa, and Asia**.
  - **Per capita,** funding is **higher in Norway, Switzerland, and the UK** compared to EU countries.
- **Growth in research grants**: Since 2000, there has been an annual growth of around 14% in third-party funded research grants, mainly in forest-based CDR, soil carbon sequestration, and biochar. This growth is reflected in increased research output for these methods.
- **Patent trends**: The number of CDR-related patents increased until 2011 but has since declined, primarily due to a slowdown in BECCS-related inventions. Ocean-based CDR methods lag behind land-based ones in terms of patent numbers (see Figure 3 for patent developments).

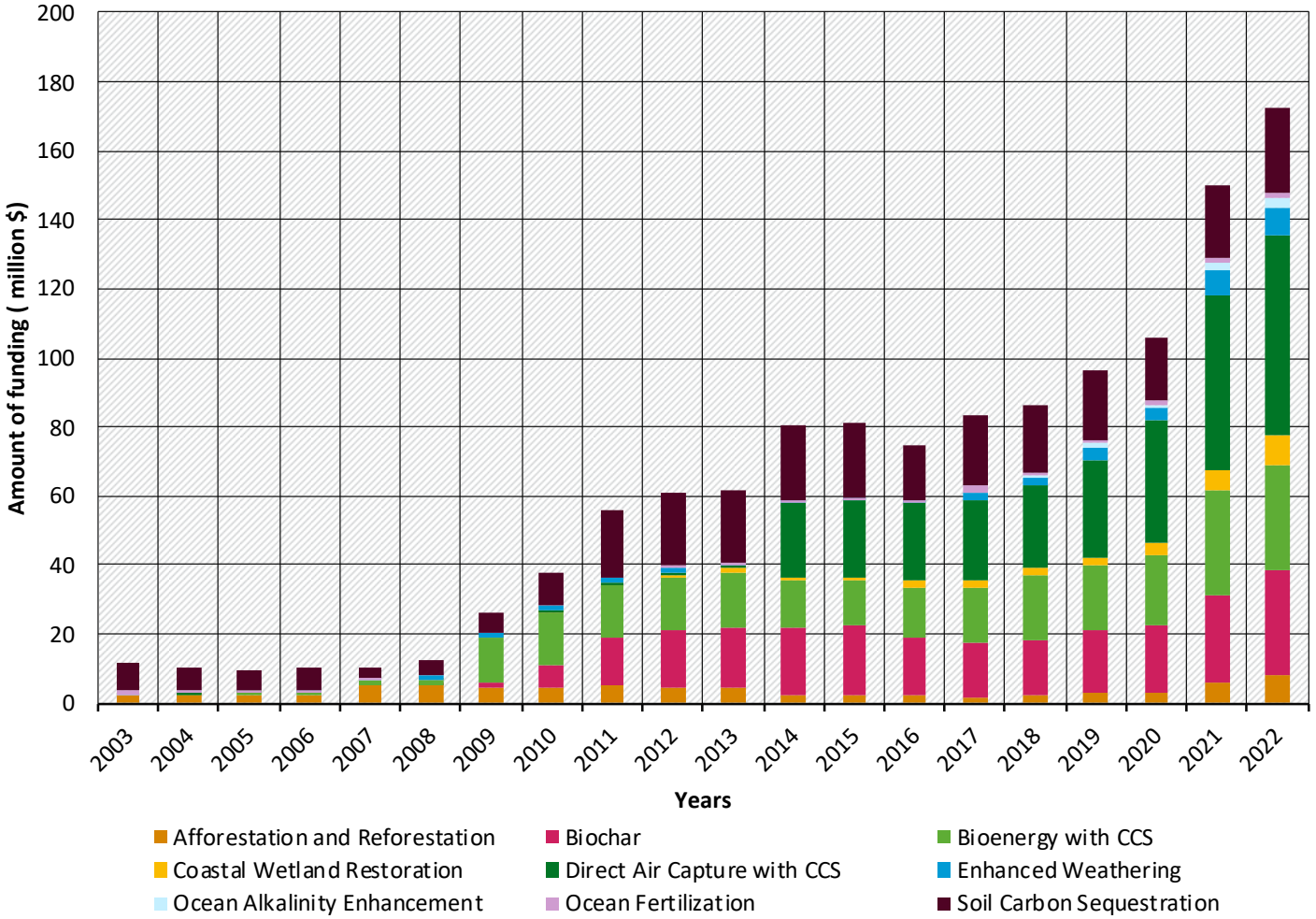
- **Rapid expansion in certain methods**: Over the last decade, research publication output has grown significantly for DACCS and enhanced rock weathering. By 2022, DACCS accounted for 11% of research grants. Despite fewer overall grant projects, DACCS and BECCS receive a larger share of financial support due to the scale of their projects (s. Figure 2).
- **Regional specialization in funding types**: Canada and the US allocate a larger share of grants to Direct Air Carbon Capture and Storage (DACCS) and ocean fertilization, while the EU focuses more on Bioenergy with Carbon Capture and Storage (BECCS) and enhanced rock weathering. In Africa, funding prioritizes afforestation/reforestation and coastal wetland restoration.

Figure 1: Funding for CDR research via Grants, by region, 2000-2022.



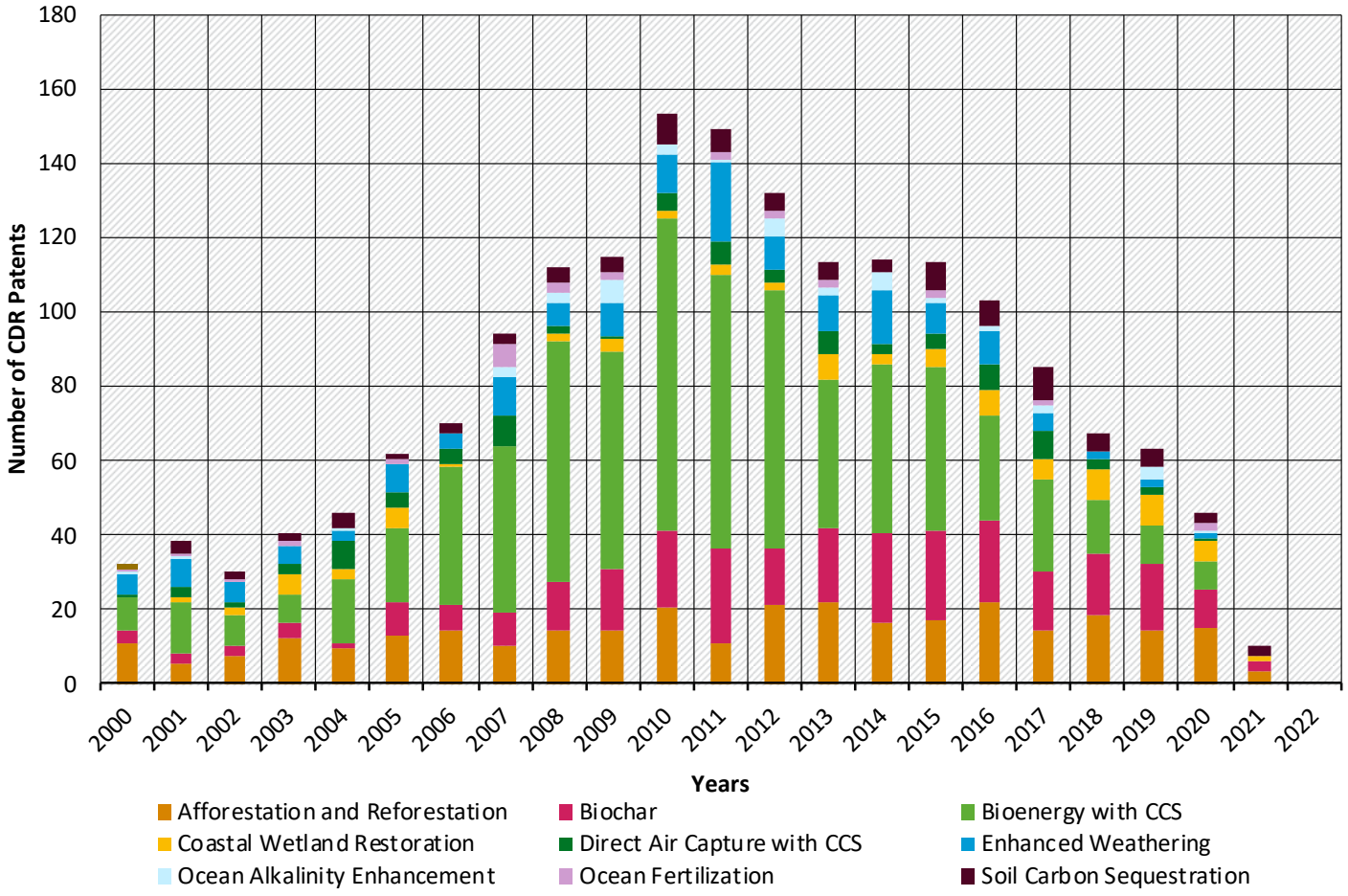
Source: Minx et al. (2024), data licensed under CC BY 4.0.

Figure 2: Funding for CDR research via grants, by CDR method, 2003-2022.



Source: Minx et al. (2024), data licensed under CC BY 4.0.

Figure 3: Annual number of new patents, by CDR method, 2000-2022.



Source: Minx et al. (2024), data licensed under CC BY 4.0.

Online Resource	Type	Publisher	Description	Link
		institute is philanthropically funded, e.g., by the Sloan Foundation & the Chan Zuckerberg Initiative)	grey literature. Log-in data is available on website.	
Netzeroclimate.org	Info portal; website	Oxford Net Zero, University of Oxford (the research initiative is funded both publicly and privately – e.g., by UK Research and Innovation and by Quadrature Climate Foundation)	Website including fact sheets, a progress tracker, and explanations of the net zero concept.	https://netzeroclimate.org/
Carbon Removal Policy Tracker – Cabon Gap	Database/Website	Carbon Gap (a non-profit organisation, funded philanthropically, e.g., by Quadrature Climate Foundation)	Data tool offering an overview and comparison of national and multi-national CDR targets, current and proposed legislation and policies on CDR in Europe.	https://tracker.carbongap.org/
Carbon Removal Map – CDR.fyi	Project overview/ Map	CDR.fyi is a Delaware Public Benefit Corporation with a "mission of accelerating carbon removal" through bringing "transparency and accountability to the durable carbon removal market".	The map an overview of private companies and other projects working on CDR. It allows for filtering by CDR method.	https://www.cdr.fyi/carbon-removal-map

Online Resource	Type	Publisher	Description	Link
International Energy Agency (IEA), section on Direct Air Capture	Info portal; website	International Energy Agency (IEA)	The International Energy Agency (IEA) publishes regular updates about energy developments. Increasingly, these now also include updates on CDR technologies, such as Direct Air Capture (The IEA is an intergovernmental organization).	https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture

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