# Chapter 2

*Laura Diaz Anadon (University of Cambridge)*
*Jan C. Minx (Potsdam Institute for Climate Impact Research, PIK)*
*Marlene Bültemann (Potsdam Institute for Climate Impact Research, PIK)*
*Friedemann Gruner (Potsdam Institute for Climate Impact Research, PIK)*
*Finn Müller-Hansen (Potsdam Institute for Climate Impact Research, PIK)*
*Liz Pflugbeil (University of Cambridge)*
*D. Cale Reeves (University of Cambridge)*
*Tim Repke (Potsdam Institute for Climate Impact Research, PIK)*

***Chapter scientist:*** *Friedemann Gruner (Potsdam Institute for Climate Impact Research, PIK)*

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Scientist collecting a sediment core to assess carbon sequestration rates in a tidal seagrass bed. By Jeff Hester

# Chapter 2 | Research and development

Funding for research and development (R&D) has been increasing steadily. R&D remains concentrated in a few countries and on a few CDR methods, although signs of diversification are emerging. While the number of scientific publications continues to grow, patenting activity has been gradually declining. Across the CDR sector, consistent signals of a significant acceleration in R&D activities have yet to emerge – particularly at the interface with commercialization.

## Key insights

- Although the number of CDR research grants is declining, total funding is increasing due to a shift towards larger, higher-value projects. This structural shift has driven funding growth of approximately 13% per year between 2022 and 2025.

- Targeted CDR funding is rising, but most CDR publications continue to emerge from research supported by grants that are not explicitly focused on CDR, highlighting the continued importance of broader R&D programmes in enabling CDR research.

- The CDR literature continues to grow, with the overall number of publications increasing 15% per year on average between 2022 and 2025. Publication growth is strongest for ocean alkalinity enhancement (an average annual increase of 43% between 2022 and 2025) and DACCS (28%), while scientific publications on biochar (13%) forest-based methods (9%) and BECCS (6%) are growing more slowly. Innovation in CDR as measured by patenting has declined (an average annual decline of 4.0% between 2011 and 2019); this contrasts with slight growth in overall climate change mitigation patenting (average annual growth of 2.2% between 2011 and 2019). This downward trend in CDR patenting is partly driven by a significant reduction in patenting in BECCS.

- Some CDR methods reviewed for the first time in this edition – such as biomass burial and sinking, mineral and wood products, and ocean capture – receive little funding and generate few publications compared with other CDR methods. However, mineral products are a significant focus of CDR innovation, accounting for 14%–30% of annual patenting activity between 2005 and 2022.

- Knowledge about research activity, funding and patenting across CDR methods – combined with insights on their potential, costs and socioeconomic and geographic contexts – can help inform decisions about public funding for R&D and the early deployment of novel CDR.

Staying within the temperature goal of the Paris Agreement will require an unprecedented acceleration of innovation and scale up across low-carbon, carbon-neutral and carbon-negative, or CDR, technologies. While sustained innovation is essential over the long term to enable the deployment of CDR at climate-relevant scales, it is equally critical in the near term to support the development of a diverse portfolio of complementary CDR methods. Such diversity supports tailored deployment strategies subject to different geographic and ecological contexts as well as policy preferences. Diverse CDR portfolios also help hedge against the risks associated with overreliance on any single technology during technology development and scale-up.

Assessing the state of innovation in CDR is therefore vital. It enables a clearer understanding of how different CDR methods are developing, the pace at which they could be scaled, how their costs may evolve, and which risks and benefits are associated with them. Because innovation is a process that involves how technologies are conceived, developed and deployed, a diverse set of metrics is needed to assess its evolution.[1] At the same time, the innovation process should not be understood as a linear progression. Rather, it is a dynamic and iterative process in which different stages in the innovation chain are interconnected and often occur concurrently. Furthermore, feedback loops between research, development, demonstration and deployment phases play critical roles in shaping technology outcomes.

R&D activities, together with their associated outputs, are widely examined to understand the early stages of the innovation process. These activities encompass the discovery and assimilation of new scientific and technical knowledge and range from fundamental research to applied technology development and small-scale demonstration projects that precede broader commercialization and large-scale deployment (see Chapter 3). Developing a comprehensive understanding of the evolution of R&D in the CDR sector requires integrating insights across this full spectrum of activities and outputs. However, limitations in data availability constrain the ability to capture all aspects of R&D in a comprehensive manner. As a result, available indicators provide only a partial, albeit informative, representation of innovation dynamics within the CDR sector.

This chapter assesses the state of R&D in CDR using three complementary indicators.

1. Research grants serve as an input-related metric, capturing early-stage investments in R&D. This data provides insight into the level of effort dedicated to advancing CDR methods, including activities aimed at improving scientific understanding, evaluating risks and co-benefits and reducing costs.

2. Scientific publications are used as an output-oriented indicator of R&D activity. They reflect the generation and dissemination of new knowledge and provide a basis for assessing the evolution of the CDR knowledge base.

3. Patenting constitutes an additional output-oriented indicator of inventive activity, capturing the extent to which R&D efforts are moving technologies closer to commercialization.[2]

*The State of CDR 3rd Edition* provides updated estimates for each of these indicators, incorporating significant methodological improvements in the compilation and evaluation of the underlying data compared to previous editions. In addition, the chapter explores some of the linkages between indicators, for example by analysing research grants linked to CDR publications.

## 2.1 Funding of R&D

### Overview of research grants explicitly focused on CDR

Funding for R&D is a fundamental entry point for accelerating innovation in CDR. Yet, available data is limited, making it difficult to assess the development of funding for R&D activities globally and comprehensively. Public funding through grants can be used to steer R&D and stimulate knowledge creation in specific areas.[3] Grant data thus provides an input-based indicator of efforts to expand knowledge on CDR through basic and applied research at public universities and research facilities, sometimes in cooperation with private companies.[4,5] For this report, we use data from the Dimensions database, which provides global coverage of public and private project-specific funding through R&D grants. We leverage comprehensive search queries to identify potentially relevant grants and use machine-learning classification to determine whether they are discussing CDR and if so, which CDR methods they are covering. The Technical Annex and Mueller-Hansen et al. (2025)[6] provide further details on the database, its coverage and the methods applied to identify grants on CDR. While this does not provide the full picture of CDR R&D activities, as it does not cover base funding of universities and research institutes or privately funded research activities on CDR, it nevertheless gives some indication of recent developments at this early innovation stage.

Our analysis finds about 7,300 CDR research grants that started in the 21-year period from 2005 to 2025, covering different CDR methods to various degrees. About 1,400 (20%) of those started within the last three years (between 2023 and 2025). In total, we estimate a funding volume for these grants of US$5.6 billion (10th–90th percentile range: US$3.9 billion to US$6.4 billion), of which US$1.9 billion (34%) falls within the last three years, which *The State of CDR 2nd Edition* did not cover. The 3rd Edition also compares research grants awarded to CDR to those awarded to a diverse set of low-carbon technologies, including renewable energy and carbon management technologies.[6] We estimate that CDR research grants represent 4.4% of all low-carbon technology grants awarded between 2005 and 2025 and 3.3% of total funding volumes. While funding for low-carbon technology grants saw an average growth rate of 12% per year between 2005 and 2025, funding for CDR grew by 15% per year over the same period.

Recent trends emerging from our data on R&D grants present a mixed picture, with declining total numbers of grants but increases in funding amounts. The number of active research grants declined by 1% between 2023 and 2024 (see Figure 1a), while the number of new grants dropped by 32% over the same period. (Data for 2025 is likely incomplete due to reporting lags.) The trends are different across CDR methods: while there is a stronger decline in active research grants for biochar soil amendment and afforestation, reforestation and forest management, the following methods experienced increases: direct ocean capture, mineral products, alkalinity enhancement of water bodies and ocean fertilization. The remaining methods stayed relatively stable.

The total amount of funding for CDR offers a different picture: average funding per project increases over time, resulting in higher total funding despite the decline in project numbers. The mean funding amounts of projects that started between 2023 and 2025 are almost double those for projects that began between 2005 and 2022. Despite the decrease in the total number of grants, funding has grown between 2023 and 2025 at 13% per year. This is similar to the funding growth over the full period covered by the data (15%) and is broadly in line with the 15% growth in CDR publication output (see Section 2.2).

Funding patterns show a concentration on specific CDR methods (see Figure 2.1b). Soil carbon sequestration comprises the largest share (24%) of active grants between 2023 and 2025, followed by biochar (18%) and afforestation, reforestation and forest management (14%). While DACCS (11%) and BECCS (4%) only make up small percentages of active grants, they get much higher shares of the funding amounts (22% and 17%, respectively) due to substantially larger project sizes.

Grant funding for CDR is concentrated in Europe and North America. Between 2005 and 2022, 53% of funding originated in North America, 32% in Europe and only 15% in all other regions combined, measured by the number of years that grants were funded in the respective regions. For the period between 2023 and 2025, which was added for the 3rd Edition, the figures are 39% for North America, 44% for Europe and 17% for all other regions combined. In terms of funding amounts, the largest shares between 2005 and 2022 came from North America with 48% and Europe with 43%. Between 2023 and 2025, Europe took the lead with 63%, followed by North America with 35%. While our data for 2023 to 2025 for China, South Africa and Russia has gaps, the larger pattern of a strong concentration of funding in Europe and North America remains valid. European and North American grants tend to focus more on novel CDR (except biochar), while grants in other regions have higher shares of conventional CDR and biochar. For example, grants awarded by funders from Asia have a high share of peatland and coastal wetland restoration research (see Figure 2.1c).

### Other research grants leading to CDR publications

In addition to research grants that explicitly mention CDR in their high-level summaries (title and abstract), this edition of *The State of CDR* introduces a new indicator – grants co-funding CDR research (hereafter "co-funding grants"). This indicator tracks the number and funding volume of grants that are acknowledged in CDR publications but not classified as CDR-specific by our machine-learning approach (see Technical Annex A.2.1). As such, the indicator provides insight into the extent to which CDR research draws on or contributes to a broader portfolio of funded projects in which CDR is not the focus. For example, a grant focused on forest fires and their impacts on vegetation and soils may result in a CDR-relevant publication assessing drought-resistant tree species and their carbon storage potential. Similarly, a materials engineering grant developing next-generation membranes for fuel cells and electrolyzers may co-fund research that leads to a publication on membrane development for DACCS.

We find that there has been substantial acknowledgement of co-funding grants within the CDR literature. Using the Dimensions database, we built a dataset of 18,238 CDR publications issued between 2005 and 2025 that contain supporting grant information. Of the 14,573 unique grants acknowledged across those publications, approximately 11,000 are not classified as CDR-related based on their high-level summary. (Note, however, that CDR could be mentioned in the full text of grant applications, which are not publicly accessible.) Co-funding grants thus support a substantial portion of CDR research activity; a majority of publications (56%) acknowledge only co-funding grants, while just 27% are funded solely by research grants that explicitly mention CDR. The remainder acknowledge both CDR grants and co-funding grants (17%).

Research support from co-funding grants – measured in terms of grant acknowledgements in CDR publications – appears to have been consistently high over time for both conventional and novel CDR methods (see Figure 2.2). For conventional CDR methods, the share of co-funding grants in total grant acknowledgements has remained relatively stable at around two-thirds between 2005 and 2025. For novel methods, this share was higher in the early 2000s but has decreased substantially since then and is now on par with the share for conventional methods.

## Overview of R&D grants, 2005–2025

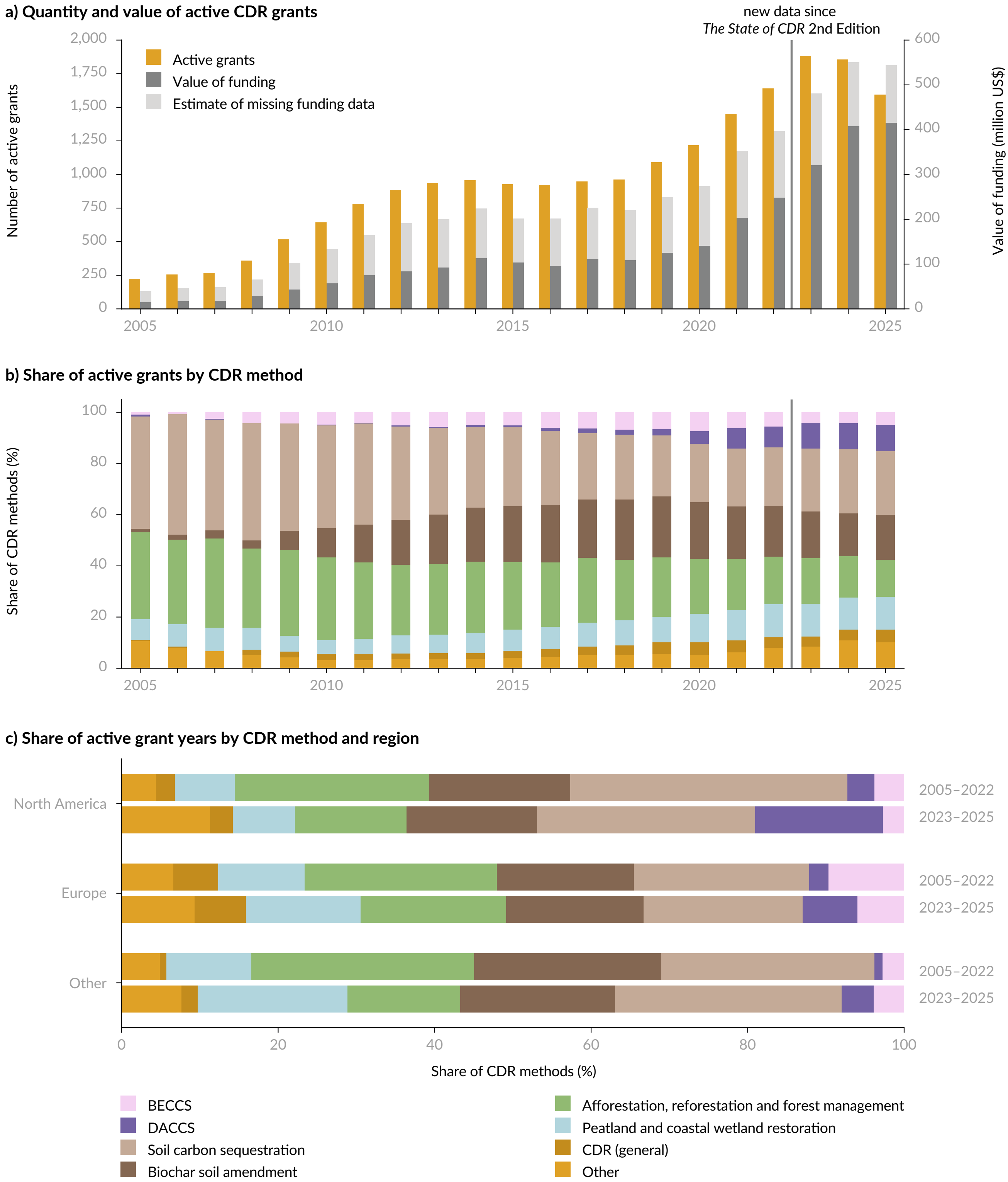



***Figure 2.1*** *(a) Active grants (left-hand axis) and funding over time (right-hand axis), (b) shares of CDR methods in active grants per year, and (c) regional shares in active grant years for early data versus new data. In panels (b) and (c), the "other" category includes the following CDR methods: enhanced weathering, ocean fertilization, mineral products, ocean alkalinity, durable wood products, direct ocean capture, agroforestry, biomass sinking and bio-oil storage. As data from the main Chinese funder was not available from 2022 onward, we also excluded earlier Chinese data from display so that data sources are consistent over time. Data from 2025 may be incomplete because of reporting lags.*

Number and share of co-funding grant acknowledgements, 2005–2025

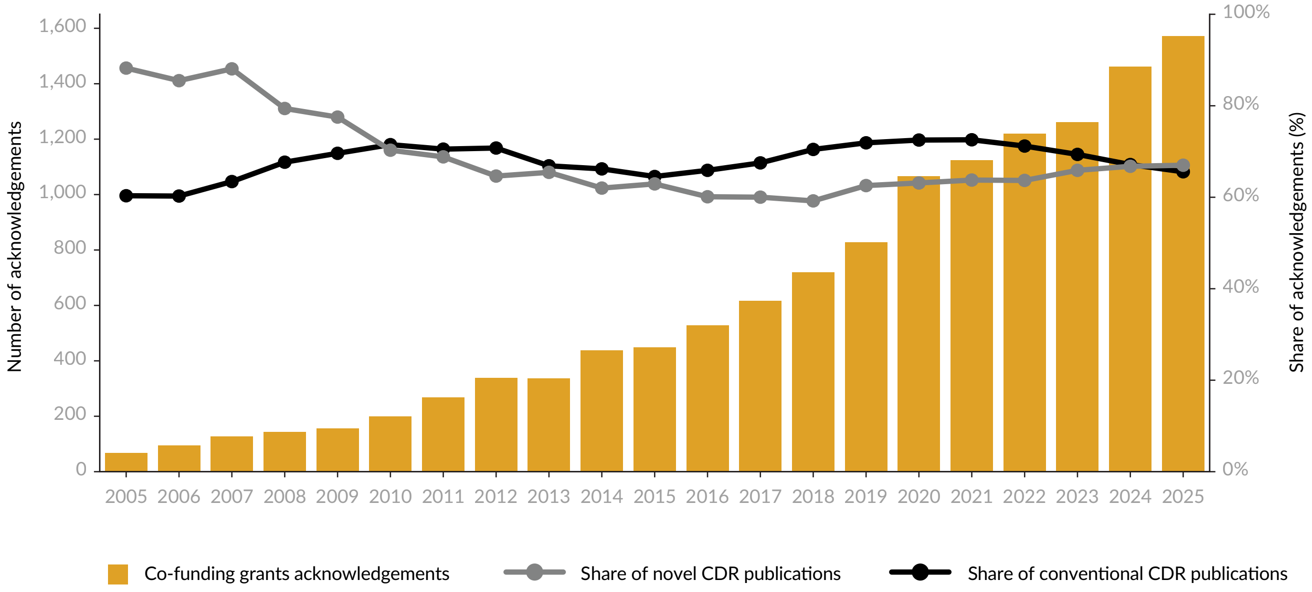



***Figure 2.2*** *Co-funding grant acknowledgements for CDR publications. Lines show three-year moving averages of the shares for novel and conventional CDR publications. As data from the main Chinese funder was not available from 2022 onward, we also excluded earlier Chinese data from display so that data sources are consistent over time. Data from 2025 may be incomplete because of reporting lags.*

In terms of specific CDR methods supported by co-funding grants, the pattern is similar to that observed for targeted CDR grants. About 35% of co-funding grants in our database are acknowledged by publications on biochar soil amendment or soil carbon sequestration, respectively. Moreover, 30% of co-funding grants are mentioned or acknowledged in publications on afforestation, reforestation and forest management. By contrast, novel methods such as BECCS (5%) and DACCS (4%) are associated with only a small share of co-funding grants.

About 83% of acknowledged co-funding grants include a reported funding amount. As a rough proxy for the portion of funding dedicated to CDR research, we weight each grant's total funding by the share of CDR publications among all publications citing that grant. This results in roughly US$2.5 billion in CDR-attributed funding. After imputing missing funding data for the remaining 17% of grants, the total estimated funding for CDR research from acknowledged co-funding grants rises to approximately US$2.7 billion (10th–90th percentile range: US$2.6 billion–US$5.2 billion). Together with the results for CDR-specific grants, we estimate a total CDR R&D funding volume through grants of around US$8.4 billion (10th–90th percentile range: US$6.3 billion–US$12.0 billion).

## 2.2 Scientific publications on CDR

In this section we use scientific publications and citations as early output indicators for R&D processes.

Scientific publications provide observable, standardized and comparable evidence of knowledge production.[7] Analysing the scientific publication landscape on CDR gives a bird's eye view of how research activities evolve over time and are distributed across the globe, as well as the extent to which they support development of individual CDR methods. Publications are also public goods that are accessible to other researchers. Citation counts reveal how knowledge flows through research systems, reflecting the broader impact of R&D investments and capturing knowledge spillovers.

### Rapid growth in CDR publications

A large body of English-language scientific literature on $CO_2$ removal exists. Our database currently contains around 119,000 publications published between 2005 and 2025, the period covered in this report. The literature continues to be dominated by biochar, forest-based methods (i.e. afforestation, reforestation and forest management) and soil carbon sequestration, which together account for 77% of all unique CDR mentions in our dataset. Note that the volume of literature is substantially larger than reported in previous editions of this report due to improvements in the search strategy (see Box 2.1).

More than one-third (37%) of the publications in our dataset were published between 2023 and 2025 (2022 was the last year reported in *The State of CDR 2nd Edition*) (see Table 2.1). This share varies substantially across CDR methods. Some methods exhibit comparatively smaller shares – for example, forest-based methods (28%), BECCS (32%), and ocean fertilisation (22%). Other methods display larger shares – for example DACCS (56%), ocean alkalinity enhancement (60%) and direct ocean capture (68%) – indicating that much of the literature is very recent.  Across the 44,000 new scientific publications on CDR released between 2023 and 2025, most deal with biochar (19,000), forest-based methods (10,000) and soil carbon sequestration (10,000). (Note that a single publication can discuss multiple CDR methods.) Interestingly, there were more publications dealing with DACCS (2,300; 4.5%) in recent years than with BECCS (1,600; 3.0%), even though the overall body of literature on BECCS remains larger. This is in line with trends in inventive activity as analysed in Section 2.3, potentially signifying a shift in early R&D activities away from BECCS and towards DACCS.

### Number of CDR publications and long- and short-term growth rates by method, 2005–2025

| | Publications, 2005–2022 | Publications since SoCDR 2nd Edition, 2023–2025 | Growth in annual publications, 2005–2022 (%) | Growth in annual publications since SoCDR 2nd Edition, 2022–2025 (%)* |
|---|---|---|---|---|
| Afforestation, reforestation, forest management | 26,000 | 10,000 | 8.5 | 11 |
| BECCS | 3,300 | 1,600 | 17 | 5.2 |
| Bio-oil storage | 7 | 6 | 2.2 | 0 |
| Biochar soil amendment | 25,000 | 19,000 | 39 | 12 |
| Biomass burial | 29 | 24 | 10 | -9 |
| Biomass sinking | 11 | 46 | 9.8 | 10 |
| CDR (general) | 2,100 | 1,500 | 16 | 19 |
| DACCS | 1,800 | 2,300 | 24 | 21 |
| DOCCS | 45 | 97 | 16 | 22 |
| Durable wood products | 800 | 390 | 9.4 | 13 |
| Enhanced weathering | 1,800 | 1,100 | 13 | 17 |
| Mineral products | 740 | 740 | 21 | 33 |
| Ocean alkalinity enhancement | 410 | 610 | 14 | 36 |
| Ocean fertilization or artificial upwelling | 990 | 280 | -2.4 | -8 |
| Peatland and coastal wetland restoration | 7,400 | 4,500 | 15 | 11 |
| Soil carbon sequestration | 19,000 | 10,000 | 13 | 16 |
| CDR publications – Total** | 75,000 | 44,000 | 15 | 13 |

***Table 2.1* Notes:** *CDR publication counts and growth rates. Numbers are rounded to two significant digits. CDR methods with higher recent (2022–2025) than long-term (2005–2022) rates of growth in annual publications are highlighted.*
**Calculating the growth rate since The State of CDR 2nd Edition requires the inclusion of data for 2022.*
***Total indicates the number of unique publications. Counts for methods represent unique mentions in publications.*

While the number of CDR publications continues to expand, average annual growth has slowed slightly to 13% in 2022–2025 from 15% in 2005–2022. Growth patterns vary considerably across individual CDR methods. BECCS, biochar, and peatland and coastal wetland restoration are among the CDR methods that exhibit lower annual average growth rates in the recent period (2022–2025) compared with the previous period (2005–2022). Other CDR methods – such as afforestation, reforestation and forest management, soil carbon sequestration and ocean alkalinity enhancement – show higher recent growth rates, indicated in darker colors in Table 2.1.

Average annual growth in scientific publications between 2022 and 2025 was highest for ocean alkalinity enhancement (36%), followed by mineral products (33%) and DACCS (21%). Lower growth rates were observed for BECCS (5.2%), forest-based methods (11%) and biochar (12%). Ocean fertilization and biomass burial are the only methods for which the number of publications decreases (-8% and -9% respectively), but for biomass burial, publication numbers are small and there is thus a high uncertainty in the trend. While forest-based methods and biochar represent relatively mature CDR research fields with already high publication volumes, the BECCS literature remains much smaller in scale.

We further analyse the regional patterns of CDR research publications by the location of the first author's main affiliation. Overall, 69% of CDR research is concentrated in three regions: Eastern Asia, primarily in China (33%), Europe (22%) and North America (14%). This trend is driven by the dominant role of Chinese scholarship in biochar research. For other regions with fewer CDR publications – namely Africa, Southern Asia, the Middle East and Eastern Europe – we observe a larger share of research in recent years, indicating faster growth.

For most world regions, we observe substantial shifts in research focus across different CDR methods in recent years. Figure 2.3c shows the shares of CDR research for each of the ten world regions between 2005 and 2022 and between 2023 and 2025. For example, DACCS research led by North American authors increased from 4% between 2005 and 2022 to 14% between 2023 and 2025. At the same time, the share of forest-based CDR research declined (from 30% to 20%), and the share for soil carbon sequestration dropped (from 21% to 16%). While Europe shows a similar decline in the shares of forest-based CDR publications (from 28% to 22%) and soil carbon sequestration (from 19% to 17%), we see a more gradual increase in research shares for biochar (from 23% to 27%), DACCS (from 2% to 5%) and peatland and coastal wetland restoration (9% to 10%). Africa witnessed a similar trend away from forest-based (from 31% to 25%) and soil carbon sequestration research (from 24% to 21%) towards biochar (from 36% to 42%) and DACCS (from 0.1% to 1.1%). Research patterns in Eastern Asia were much more stable and continued to strongly focus on biochar research.

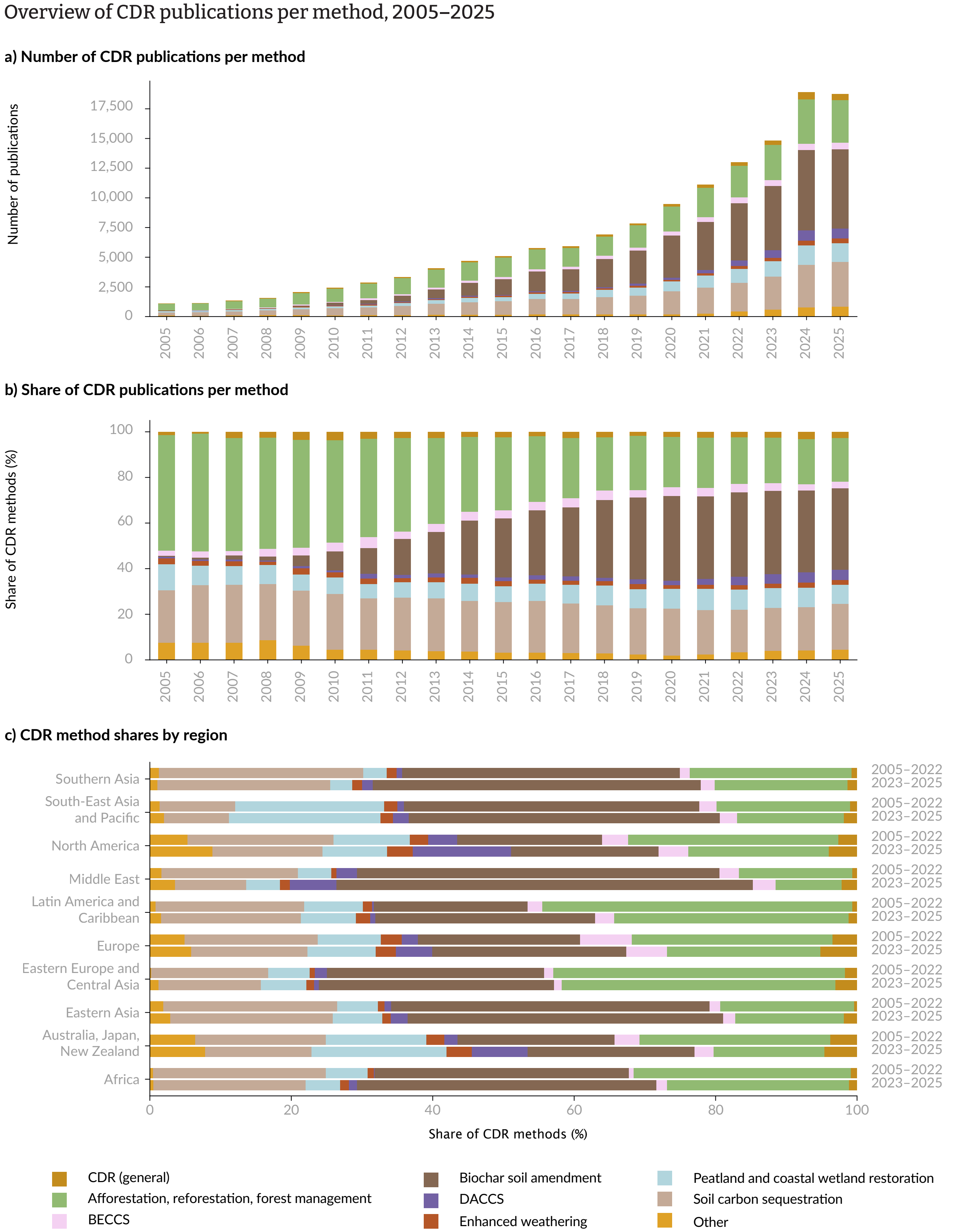



*Figure 2.3* CDR publications over time and by region: (a) total number of publications on CDR, (b) share of publications per CDR method over time and (c) share of publications per CDR method (2005–2022 and 2023–2025) per region of first author affiliation. The "other" category includes the following CDR methods: ocean fertilization, mineral products, alkalinity enhancement of water bodies, durable wood products, DOCCS, agroforestry, biomass sinking, biomass burial and bio-oil storage. Data for 2025 may be incomplete due to reporting lags.

## CDR cited more often than publications on low-carbon technology

As an addition to previous analyses, this edition of *The State of CDR* examines the wider impact of scientific publications about CDR by measuring how often they are cited in the scientific literature. The extent to which publications are cited is commonly used to quantify the intellectual influence or impact of scholarly works, authors and journals, and it can also be regarded as a measure of knowledge spillover. However, field-specific conventions and motivations beyond acknowledging intellectual influence caution against straightforward interpretations of results as a direct measure of influence.[8] As in other research fields, citations of publications on different CDR methods are very unevenly distributed. The least-cited 50% of publications only get 7% of all citations and the most-cited 10% get 54%. The number of citations also strongly depends on the year of publication, because it takes several years for publications to accrue citations.

To put the number of citations of scientific publications on CDR into the wider context of low-carbon technologies – broadly defined as technologies that reduce emissions, for example through renewable energy production, energy storage, energy efficiency and carbon sequestration – we use the citation frequency of low-carbon technology as our benchmark for the citation frequency of CDR publications (see the Technical Annex for details). However, a direct comparison can be driven by differences in the average age of publications, different journal outlets and other factors that influence citation numbers. Therefore, we use the methodology developed in Tripodi et al. (2024)[9] to correct for such confounding factors. The methodology controls for factors that have a strong influence on citations – matching each CDR publication to a low-carbon technology publication issued in the same publication year and in the same journal. It uses a negative-binomial regression approach and controls for other possible drivers of citations, including open access status and the number of authors.

CDR publications are cited 15% more frequently than comparable publications on low-carbon technologies. Significant differences emerge between low-carbon technology and CDR literatures at the level of individual CDR methods. The effect is largest for DACCS (+99%) and biochar (+36%) but also for general CDR literature (+73%). CDR methods less often cited than low-carbon technology include afforestation (-28%), peatland and coastal wetland restoration (-23%) and ocean fertilization (-33%). The citation patterns support a picture of CDR as a very dynamic and diverse research field, highlighting that CDR as a general topic – and especially novel CDR methods such as BECCS, DACCS, biochar and enhanced weathering – is gaining momentum as shown by the growing number of CDR publications and the greater extent to which CDR literature is being cited. Several factors may be responsible for the overall higher citation frequency, including that the total number of CDR publications is lower than the number focused on low-carbon technologies. This could increase the odds that any individual publication would be cited in an area of growing publication activity such as CDR.

Citation frequency of selected CDR methods compared to low-carbon technologies

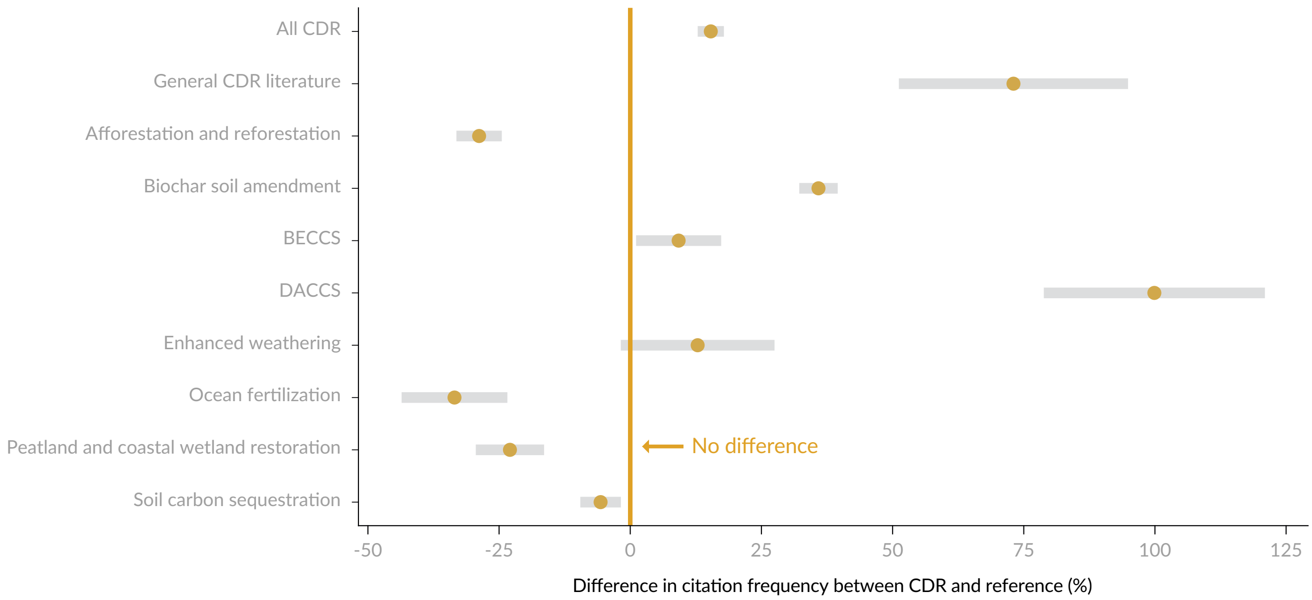



***Figure 2.4*** *Estimate of the difference in citation frequency of different CDR methods compared to low-carbon technologies. Central estimates are indicated as yellow dots and grey bars grey bars indicate 95% confidence intervals.*

## Box 2.1 Methodological changes and effects on reported numbers of publications

The publication numbers reported in *The State of CDR 3rd Edition* are substantially higher than in previous editions for five main reasons.

1. This edition draws on four major bibliographic databases (Web of Science, Scopus, Dimensions and OpenAlex) rather than just one (large effect).
2. The search strategy for identifying CDR-relevant literature has been comprehensively revised and harmonized (large effect).
3. The literature has expanded significantly since the 2nd Edition (large effect).
4. The underlying databases have continued to expand their coverage of scientific sources (medium effect).
5. Several new CDR methods, including CCU pathways with long-term storage and ocean capture, have been added to the sample (small effect).

Compared to the 2nd Edition, these changes led to a substantial increase in the total number of publications identified for the period 2005–2022 (2nd Edition: 26,000; 3rd Edition: 75,000). The revised methodology particularly affected the total for forest-based CDR methods, which now show a similar total number of publications (36,000) to biochar (44,000) across the period 2005–2025. Despite the large increase in the total number of publications, both the yearly shares of CDR methods displayed in Figure 2.3a and the trends over time are broadly consistent with earlier editions. For more details on the methodology for this section, please refer to Technical Annex A.2.2.

## 2.3 Inventive activity (patenting)

Patents are a measure of inventive output and are often used as a proxy for innovation in the literature on technological change and the economics of innovation.[10–12] However, patents do not cover all inventive activity since not all inventions are patented or can be patented.[10,13] Patents are typically filed at the end of the invention process to protect the invention from being used commercially by others for a fixed period of time. Technical characteristics of inventions are described in detail in patent documents, enabling the analysis of technology developments over time. Patent families comprise multiple patents that relate to a single inventive output across regions or updates.[14] We analyse patent families – patents granted in at least two jurisdictions – as an indicator of high-quality inventive activity that we refer to as "patenting".[15] Patent classification is accomplished through machine-learning methods; details on how the approach has been refined since the 2nd Edition, including methodology and limitations, can be found in the Technical Annex.

Patenting for CDR inventions has decreased between 2011, the year in which CDR patenting reached a peak, and 2019, the last year for which we have patenting data that is not truncated. Initially, annual patenting increased by 11.3% per year between 2005 and 2011. Between 2011 and 2019, by contrast, we find an annual average rate of decline of 4.0% (see Figure 2.5a). Consistent with findings in the 2nd Edition, the decrease in CDR patenting is partly explained by the decline in BECCS patenting. In comparison, climate change mitigation patenting (as defined in the Technical Annex) increased gradually between 2011 and 2019 at a 2.2% annual average growth rate. In total, cumulative CDR patenting between 2005 and 2022 represents 0.8% of all climate change mitigation patenting during the same period.

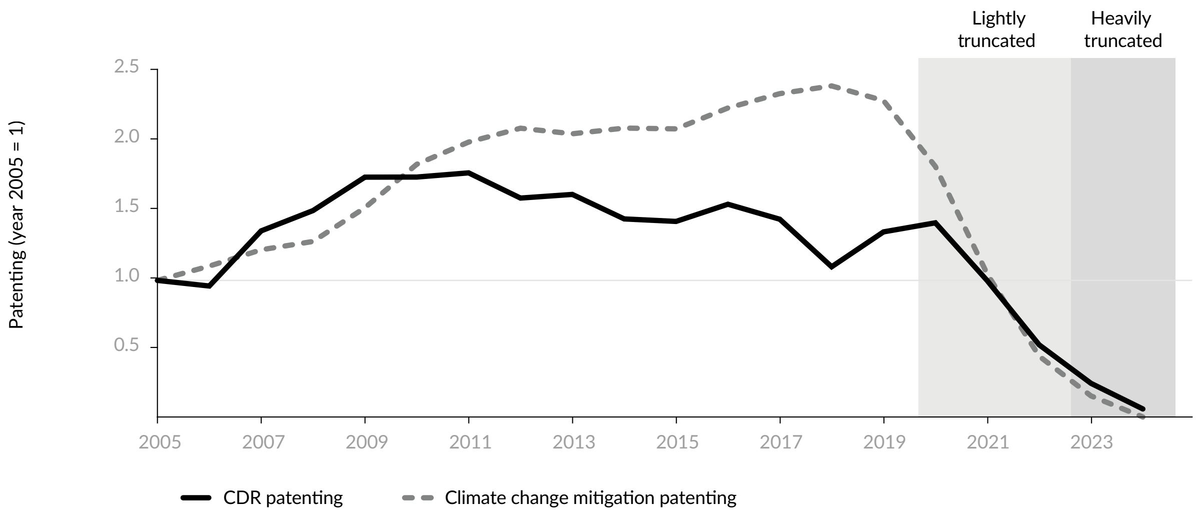
It is important to mention that the data from 2020 onwards is truncated. Granting a patent application may take up to five years after initial submission, and it takes time for a patent family to have its patents granted in multiple jurisdictions. We differentiate between lightly truncated (2020–2022) and heavily truncated (2023–2024) time periods. In the lightly truncated period, there is substantial patenting activity, but we still expect increases in the patenting numbers as additional patents are granted. However, we do not expect there to be a difference in the delay of granting patents depending on the CDR method and therefore we do not expect the distribution of patenting across the different CDR methods to change substantially during the lightly truncated period. In the heavily truncated period, both the quantity and distribution are likely to change, which is why we do not comment on either the total patenting numbers or share by technology during the heavily truncated period.

The decline in the share of BECCS patenting, which peaked at 42% of patenting in 2009, is shown in Figure 2.5b. We also find that the share of DACCS patenting has varied over the years, accounting for between 12% and 23% of all annual CDR patenting. Mineral products, which have been newly included as a CDR technology in the 3rd Edition, contribute a significant share of total CDR patenting, representing 14%–30% of annual patenting. The increase in biochar soil amendment patenting observed in the 2nd Edition continues, with its share of CDR patenting reaching 12% in 2020. Overall, the inclusion of additional CDR methods in the 3rd Edition analysis has the effect of reducing the relative share of those methods included in earlier editions.

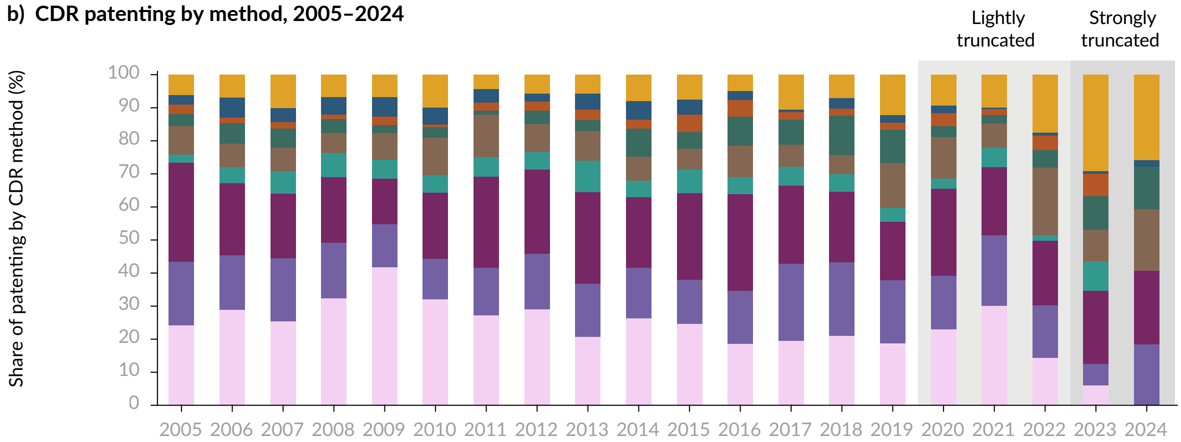
Turning to the geographic distribution of CDR patenting, we find that North America, Europe, Eastern Asia and Australia, and Japan and New Zealand are the four main regions where the inventors of a granted patent reside (see the Technical Annex), making up 93% of the total (see Figure 2.5c). There is considerable concentration in North America, which accounts for 38% of CDR patenting between 2005 and 2022, followed by Europe (31%). Eastern Asia accounts for 14% of all CDR patenting during the same period, while Australia, Japan and New Zealand combined account for 10%. The technological focus varies depending on the region. BECCS, for example, makes up a greater share of CDR patenting in North America and Europe, and mineral products are especially prevalent in North America and in Australia, Japan and New Zealand. In general, the share of CDR patenting by method in each of the regions investigated remains fairly stable over time.

### Trends in CDR patenting, 2005–2024

**a) Annual patenting trends in CDR and climate change mitigation technologies, 2005–2024**



**b) CDR patenting by method, 2005–2024**




**c) Geographic distribution of inventor locations in CDR patenting, 2005–2022**

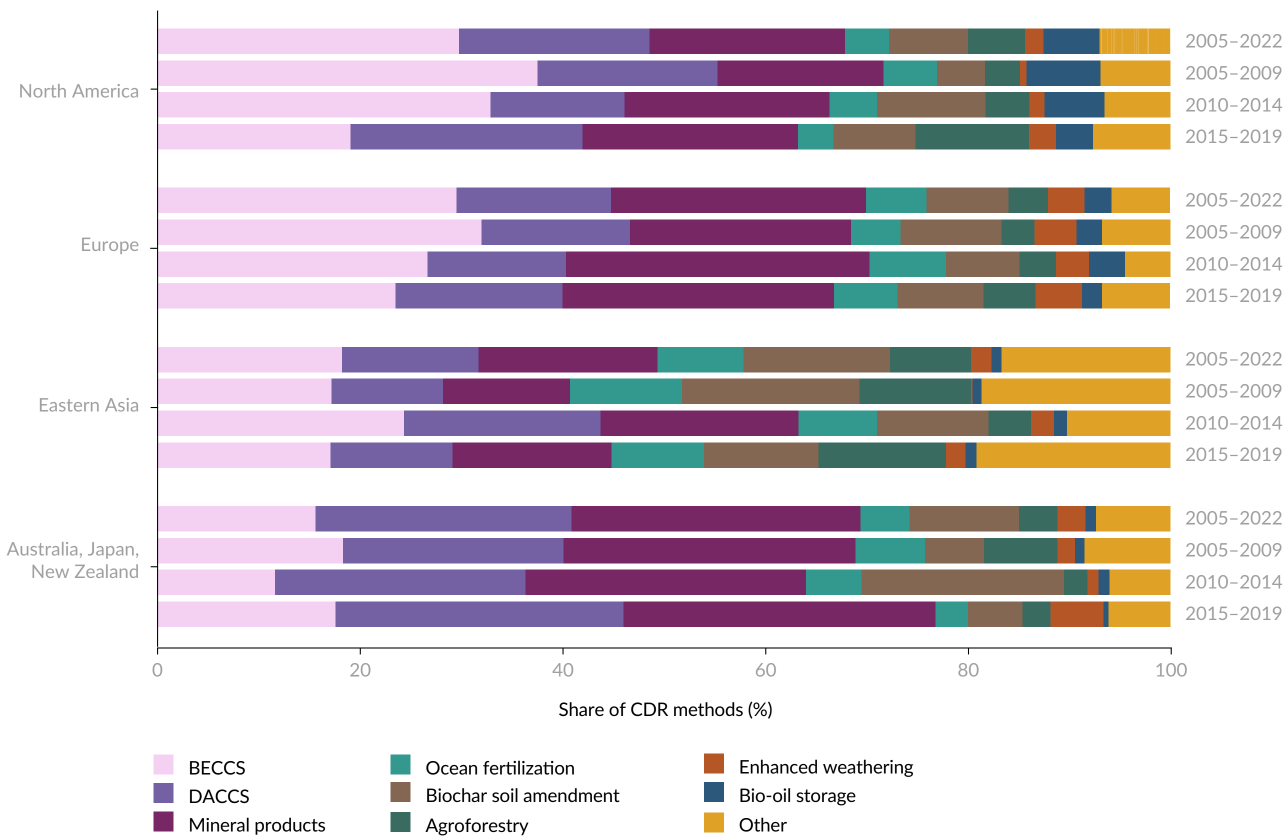



*__Figure 2.5__ (a) Patenting for CDR and climate change mitigation technologies between 2005 and 2024, (b) CDR patenting by method between 2005 and 2024, and (c) patenting by CDR method and region according to inventor location between 2005 and 2022. For CDR, only those patents that have at least one mention of a CDR method are included. Location refers to where inventors work and live, which may differ from their country of birth.*

## Box 2.2 Methodological changes and effects on reported numbers of patents

In this edition of *The State of CDR*, we draw on patent data from the new, openly available EPO Technology Intelligence Platform rather than the PATSTAT dataset used in the last edition. Previously, patents were classified by CDR method using a single query to an online version of the GPT-4 model. The 3rd Edition uses an offline version of the llama3 model and classifies each CDR method several times to improve reliability (see the Technical Annex for details). We updated the CDR classes to align with the new list of CDR methods used in Edition 3 (see the Glossary).

## Box 2.3 Limitations and knowledge gaps

- The estimates of investment in CDR research projects (see Section 2.1) do not reflect all research funding on CDR, as the Dimensions database only includes third-party projects and does not cover institutional funding from universities and other research institutes.
- The geographic coverage of the Dimensions database for tracking research grants is not fully transparent, and uncertainties remain over the scope of investments covered in some regions, such as Latin America, Africa and Asia. Similar uncertainties apply to the patent data from the EPO Technology Intelligence Platform.
- The approach used to search databases of grants (see Section 2.1) and scientific research publications (see Section 2.2) includes only research grants and articles with English-language titles and abstracts.
- The classification of research grants and publications by CDR method is not performed with very high accuracy, particularly for less frequently studied CDR methods, as there are fewer annotations with which to train the machine-learning classifier. Moreover, the machine-learning approach does not work equally well across all CDR methods and across time, which could lead to some biases in the numbers, particularly for CDR methods for which there is currently little research.
- Patents are only one measure of inventive activity, and many inventors may choose not to file for patents for their inventions.[10,13] This tendency may differ across countries and by type of CDR and low-carbon technology.
- While inventive activity as proxied by international patent families has been in slow decline since 2011, the raw number of individual patents has increased steadily. Due to concerns around patent quality, this report only shows international patent families. However, some CDR methods may be more likely to be patented than others depending on the actors, technology or region involved.
- Patent data is truncated to a greater extent than R&D grants and publications due to the duration of the granting process. Consequently, the data is likely to provide a less accurate reflection of the level of inventive activity from 2020 onwards and of its level and distribution across CDR methods from 2022 onwards.

## 2.4 Outlook

The previous sections separately presented the development of the three indicators covered in this chapter – grants, publications and patenting. Figure 2.6 synthesises these findings and compares their evolution over time (see panel a), their method-specific growth dynamics (see panel b) and their distribution by method in different geographical areas (see panel c). This comparison highlights the lack of a consistent signal across the CDR sector for a significant acceleration in R&D activities in recent years. Instead, the picture is diverse. Research input (funding) and output (publications) are more strongly aligned than either is with inventions. CDR-related grants rise and then stabilize and publications exhibit strong growth, while patenting activity has been declining over the last decade (see Figure 2.6a).

Similarly, the average annual growth rates for CDR method-specific subsets of research grants and publications are strongly correlated, while the growth rates in patenting were negative or only weakly positive for most methods (see Figure 2.6b). Finally, a majority of active grants and publications are focused on forestry, soil carbon sequestration, biochar and peatland and coastal wetland restoration. However, except for biochar, these CDR methods make up only a small percentage of CDR patenting during the same period (see Figure 2.6c). Instead, inventive activities focus mostly on CDR methods which may be subject to further technological improvements, such as BECCS, DACCS and mineral products, but also biochar.

The gap between the rising number of publications and grants and the gradual decline in patenting could reflect insufficient or uncertain incentives for commercialization and deployment as well as possible differences in patenting practices across CDR methods. Our data does not point towards the underlying reasons, but understanding these drivers will be important to accelerate early innovation in CDR. Examining the weight of different CDR methods in the three indicators across different geographies highlights how grants and publications show distinct but similar patterns in North America and Europe, while inventive activities are more aligned globally and focused largely on novel CDR methods. The strong research interest in biochar in Eastern Asia – mainly China – is also reflected in that method's larger share of biochar patenting and publications in the region.

The share of funding, publications and patenting covering different CDR methods has fluctuated over time, but some CDR methods are more prevalent than others. For example, most scientific publications have focused on biochar, forest-based methods and soil carbon sequestration, but the more recent growth has been in publications on enhanced weathering and ocean alkalinity enhancement. Regarding patenting, we see that a few CDR methods make up a majority of inventive activity over time with some fluctuations: BECCS represents the largest share but has been in relative decline since 2009, while the shares of patenting for DACCS, mineral products and biochar have reached double digits.

## Synthesis of CDR trends and shares across indicators

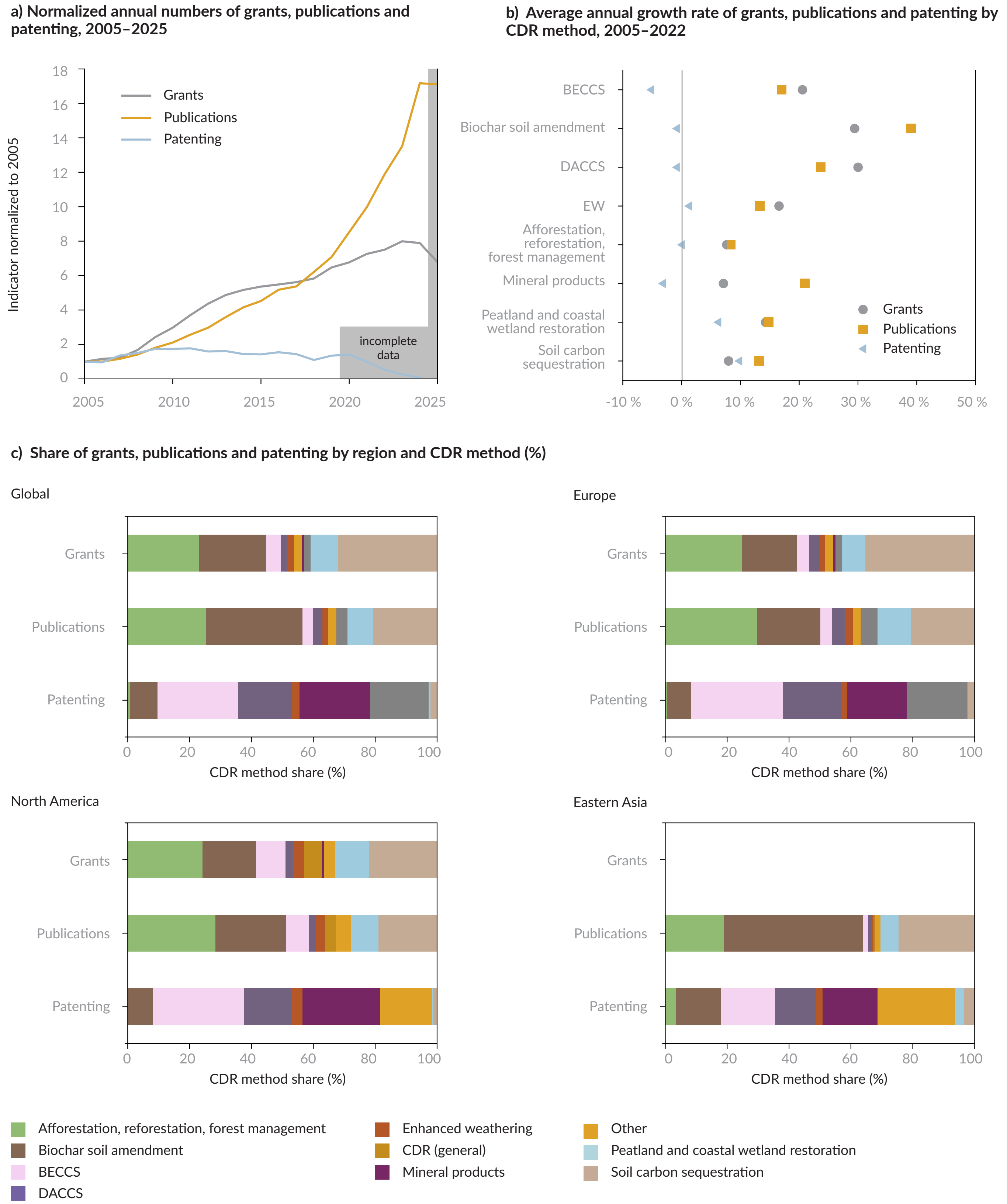



***Figure 2.6*** *Synthesis of trends and shares across indicators where comparable data is available: (a) normalized annual counts, (b) average annual growth rates across CDR methods, and (c) share by region and CDR method "Other" includes ocean fertilization, alkalinity enhancement of water bodies, durable wood products, DOCCS, agroforestry, biomass sinking, biomass burial and bio-oil storage.*

There may be benefits in fostering the development of a broad portfolio of CDR methods through a combination of supportive R&D policies and increased incentives for deployment, which would also incentivize R&D activities. Such a portfolio approach could help align research activities and outcomes with different regional capabilities and needs. Steering research efforts through policy development processes could help build a robust knowledge base, overcome early-stage barriers, identify negative impacts and prepare promising technologies for large-scale deployment. Here, the design of R&D funding and early deployment policies to support CDR can build on experience with other low-carbon technologies.[16,17]

Overall, the status of CDR in early-stage innovation is uneven. We do not find consistent signals of a significant acceleration in R&D activities. While research grants and scientific publications continue to grow, with the latter expanding at a much higher rate, much CDR R&D funding still comes from co-funding grants rather than from grants dedicated to CDR. We also find that inventive activity as measured by patenting has declined slightly in the period up until the last year without truncated data (2020), in contrast to slight growth in climate change mitigation patenting.

While *The State of CDR 3rd Edition* finds no strong evidence of a step-change in early-stage innovation for CDR, it is still possible that such signals may emerge in future. Since 2020, CDR has taken on a much greater role in discussions on climate policy, a shift that may become measurable, particularly in the patenting record, by the time of the next edition.

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