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To cite this article: Finn Müller-Hansen *et al* 2025 *Environ. Res. Commun.* **7** 095008

IOP Publishing Environ. Res. Commun. 7 (2025) 095008 https://doi.org/10.1088/2515-7620/ae0099

Environmental Research Communications

OPEN ACCESS

RECEIVED
13 March 2025

REVISED
9 May 2025

ACCEPTED FOR PUBLICATION
28 August 2025

PUBLISHED
12 September 2025

PAPER

Technology, geography and collaboration networks: assessing global innovation and research funding patterns for carbon removal

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Keywords: carbon removal, climate mitigation, research funding, innovation

Supplementary material for this article is available online

Abstract

In addition to strong global emission cuts, experts see the rapid upscaling of carbon dioxide removal (CDR) as paramount for reaching the Paris agreement target. A comprehensive view of research and innovation dynamics is crucial for the rigorous assessment of the potentials of CDR options and for guiding strategies to close knowledge gaps. Here, we investigate funding patterns in CDR research across time, geographies and fields of research and identify key organizations and actors in collaboration networks. We use comprehensive search queries and machine learning to identify more than 6000 research grants on twelve different CDR options. Research funding increased strongly over the past 30 years (21% p.a.), more than funding for climate science and technology. In comparison to carbon capture and storage, CDR receives a higher number of grants, but less total funding, estimated at 4.2 bn$. Funding is highly concentrated in Europe and North America and mostly directed towards natural, engineering and agricultural science, with little but increasing support for social science. European funding seems to encourage research in larger consortia. However, our analysis finds little funding specifically targeted at CDR, highlighting potentials for strategic initiatives for accelerating innovation in CDR.

1. Introduction

In post-Paris climate assessments and governance, many scientists, policymakers and businesses have been devoting growing attention to carbon dioxide removal (CDR)—a diverse range of options and technologies for absorbing carbon dioxide from the air and storing it durably on land, in oceans, products or the underground. These CDR options include afforestation and reforestation, soil carbon management, bioenergy with carbon capture and storage (BECCS), direct air capture and storage (DACCS), enhanced weathering, and ocean alkalization. Many of these are in an early stage of development and a growing body of research is investigating underlying technological principles, economic potentials and social as well as political implications (Minx *et al* 2018, Lück *et al* 2025, Smith *et al* 2024).

While tackling climate change requires first and foremost dramatically reducing greenhouse gas emissions from fossil fuels and deforestation, scientists in the Intergovernmental Panel on Climate Change (IPCC) concur that in addition to deep emission reductions, CDR will be needed to accelerate the transition to net-zero, to counterbalance hard-to-abate residual emissions, and potentially to reverse temperature overshoot (IPCC 2022). In fact, more than 120 countries have set net-zero targets and thus, implicitly, committed to some form of CDR; yet only few have started to integrate CDR into their climate policy and to set out actionable implementation plans (Lamb *et al* 2024).

Innovation dynamics, funding patterns and modes of demonstration and deployment in the current formative phase will likely be decisive in whether CDR uptake occurs at the scale and speed necessary for meeting commitments under the Paris Agreement (Nemet *et al* 2023). Research and development (R&D) funding has long been positively correlated with driving innovation, increasing economic growth, and resulting in advances and breakthroughs in technology (Jones 1995, Geuna 1999, Bilbao-Osorio & Rodríguez-Pose 2004). Newer modes of funding governance often target societal problems such as climate change, biodiversity loss, and ocean acidification (Ravetz 2020). For energy and climate technology firms, R&D funding is a crucial aspect of enabling them to improve productivity, acquire competitive advantage, and expand markets. An examination of the funding patterns behind carbon removal is therefore of value for researchers, policymakers, funders and firms alike.

Funding programs and agencies provide key leverage points for policy makers to steer R&D in the field of science, technology and innovation in general (Smits and Denis 2014, Linquiti 2015, Reale *et al* 2017), and energy and climate change in particular (Fankhauser *et al* 2019, Sovacool *et al* 2022, Malhotra and Schmidt 2020). Funding has been shown to foster the creation of more relevant knowledge, increase learning from failures and enhance collaboration (Heyard & Hottenrott 2021). Grant funding for R&D can signal early-stage and emerging innovation dynamics and indicates the level of effort being made to advance novel technologies, methods and practices. Increased dedicated funding may thus accelerate innovation in particular technologies by advancing high-quality science and patenting (Poege *et al* 2019, Dechezleprêtre *et al* 2011). Competitive research funding is also essential at promoting collaboration among diverse research teams by motivating interdisciplinary work towards a shared goal, allowing researchers to discover their own complementarities, and by signaling which ideas are worth pursuing and worthy of further inquiry (Davies *et al* 2022).

Examining funding trends for carbon removal thus helps to identify where researchers and potential adopters see potential for future technology development but also to assess knowledge gaps. Future carbon removal funding patterns are highly malleable, especially given many institutions and actor coalitions have yet to form and determine their own stance on negative emissions technologies, remaining ambivalently neutral rather than 'for' or 'against' (Sovacool *et al* 2024). The implication is clear: the majority of research and funding investments in carbon removal options will be in the future. Therefore, a comprehensive view of past and present research and innovation dynamics is crucial for the rigorous assessment of the potentials of different CDR options and for developing intervention and stimulation strategies where needed.

Previous studies on the evolution and composition of research funding for climate and energy identified unequal distributions of funding, which are important to put our analysis into context: Looking at research funding for climate research overall, Overland and Sovacool (2020) find that the natural and technical sciences received 770% more funding than the social sciences over the last three decades - a pattern consistent with the split in the scientific literature on climate change (Callaghan *et al* 2020). This may point to understudied societal implications of and responses to climate change. A similar study on funding for climate and energy research shows that research grants have been allocated unevenly in favor of some specific technologies and topics such as resilience and adaptation, energy efficiency, energy storage and electric vehicles (Sovacool *et al* 2022), thus focusing on technical solutions to climate change. AbdulRafiu *et al* (2022) highlight how the recipients of this funding are heavily concentrated in Global North countries. Assessments of the research funding at the intersection of climate change and health also find considerable underfunding in view of prospective systematic risks (Ebi *et al* 2016) as well as missing integration of funding at the nexus, given the scale and interconnectedness of the problem (Sovacool *et al* 2024b).

Barely any research has examined funding patterns for carbon removal research. Only one recent study by Presty *et al* (2024) uses funding statements from CDR publications to investigate CDR funding patterns. Due to its construction, however, the study shows substantial alignment of publishing and funding activities. Further, the number of scientific publications, on which their analysis is based, is quite small compared to more comprehensive approaches (Lück *et al* 2025). We rely on the 'Dimensions' database to gain an aggregate view of patterns, priorities and trends in the CDR research funding landscape. Our approach allows us to assess grant funding independent from resulting publications. We leverage machine-learning classifiers to identify and further classify relevant research grants from a large collection of grants retrieved via comprehensive search queries for 12 different CDR options as well as general CDR-related terminology.

With this analysis, we offer insights into patterns of global research funding for carbon removal that provide a basis for setting future priorities for public and private investments in this research and innovation system. In order to identify emerging research communities and pinpoint potential 'epistemic inequalities' in the formation of CDR knowledge networks, we focus our analysis on distributional questions, tracing the allocation of funding across different CDR options, institutions giving and receiving funds and their geographical location, as well as the disciplinary distribution of grants. In this way, our study contributes towards the tripartite goals of benchmarking existing funding topics and patterns, mapping collaboration networks around CDR, and of signaling fruitful areas of convergence among scientific competition and practice.

2. Methods and data

In this article, we aim at providing a comprehensive overview and assessment of global patterns and trends in funding of research in carbon removal, using a systematic approach rooted in machine-learning to identify and classify third-party funded projects for a broad range of carbon removal options. Our analysis is based on a unique set of research grants, which we identify using a comprehensive search strategy based on queries, which we then refine by applying machine-learning classifiers. This machine-learning approach improves on existing methods to analyze research grants: compared to purely manual analyses that have to be selective, it provides the scale and scope required for a comprehensive assessment. Compared to approaches that purely rely on string-based searches (Overland and Sovacool 2020, AbdulRafiu *et al* 2022), it enables both higher levels of precision and recall in the selection of the underlying data. In the following, we introduce the different steps for data collection and analysis in detail.

2.1. Database

Data on research grants were collected from the Dimensions database. The Dimensions database claims to be 'the most comprehensive research grants database which links grants to millions of resulting publications, clinical trials and patents' (Dimensions.ai Webpage), thus offering an integrative database bridging various research information objects (Hook *et al* 2018, Herzog *et al* 2020). Indeed, we are not aware of any other database with such a broad coverage of funding data. Over 600 research funding organizations worldwide register their funding activities in Dimensions. These are national science foundations, research councils and national institutes such as the National Natural Science Foundation of China or the National Institute of Food and Agriculture from the US. Table S3 gives an overview of the top funding institutions for CDR. As of early 2024, the grant database overall includes more than 7 million grants that were successfully funded.However, the overall coverage is not possible to gauge, as there are no benchmarks available for comparison (Dimensions 2024). The database contains information on many different aspects relevant for grant funding analysis (Thelwall *et al* 2023).

2.2. Search strategy

In a first step, we used comprehensive keyword searches for CDR in general as well as for the following specific CDR options: DACCS, BECCS, ocean fertilization, ocean alkalinization, enhanced (rock) weathering, afforestation/reforestation, forest management, peatland restoration, soil carbon sequestration, biochar, blue carbon and agroforestry. In this first round of data collection, we furthermore included search terms for carbon capture and storage (CCS) as well as carbon capture, utilization and storage (CCUS). These search queries were based on a previous set of queries developed and validated for comprehensive retrieval of CDR publications (Lück *et al* 2025). The data retrieval, conducted in March 2024, resulted in 15,106 grants potentially relevant for CDR research.

2.3. Classification of grants

In a second step, we applied a machine-learning classifier (ClimateBERT based on DistilRoBERTa; Webersinke *et al* 2022), previously trained on a large set of annotated scientific abstracts (Lück *et al* 2025) to establish the relevance of the respective grants for CDR. Furthermore, we manually coded a test sample of 550 grants in order to evaluate the performance of the classifier. For the coding, we followed the protocol developed by Lück *et al* which has a rather inclusive approach to coding texts as relevant to CDR. For example, biochar grants are included even if they do not mention permanent carbon sequestration directly—as we assume that technology for biochar pyrolysis can be used in carbon removal applications irrespective of the context they are discussed in a text. We find an overall good performance of the relevance classifier (F1-score of 0.84). In addition, we use another multi-class model to code which CDR options a grant focuses on, which only works with a moderate average performance (weighted F1-score 0.72). More details about the classifier performance for each CDR option are provided in table S7.

By applying the classifiers, we remove about 44% of the initially retrieved grants—a percentage similar to the non-relevant grants in the manually annotated sample (40%). In cases where manual annotations and machine learning predictions do not match, we use the manual annotations. Our cleaned dataset, after excluding CCS and CCUS, consists of 6245 CDR-relevant grants. For comparison, we also analyze CCS and CCUS grants separately, which adds another 1905 grants to the dataset, making up only 23% of the grants, but more than 56% of the reported funding volume.

2.4. Benchmarking

To benchmark our results, we also compile three different datasets of grants based on the following queries for the broader field of climate research and climate mitigation technologies: First, we use the comprehensive search string from Callaghan *et al* (2020) and translate it to be applicable to the Dimensions database, resulting in 156,365 grants. Second, we extend the keywords from Bettencourt *et al* (2013) for a broad coverage of climate mitigation technologies, resulting in 157,163 grants. Finally, we apply the long list of climate research and climate mitigation keywords from Overland & Sovacool (2020), resulting in 231,677 grants. These different approaches allow us to estimate a range of active grants and funding values per year for comparison with our CDR grants, while at the same time serving as a robustness check against each other.

2.5. Descriptive statistics and funding values

For most of the reporting on the distribution of grants over CDR options, geographies and research fields, we use the grant year counts as the main metric. We choose this metric for the following three reasons: First, the simple grant counts show stronger fluctuations when looking at the development over time because some years have seen more grants starting than others. As these fluctuations are smoothed out by looking at the counts of grants that are active in a particular year, it is easier to observe longer-term trends. Figure S1 shows a comparison between the counts of all CDR grants by start year and the active CDR grants over time. Second, better funded grants often run longer, which is why the grant years at least capture some aspects regarding the size of grants.

Third, funding volumes of grants are not available for about 32% of the grant data (27% for the extended dataset including CCS), which is why using this as the main metric would make the results more prone to errors. As figures S5 and S6 show, the percentage of missing data varies between CDR options and over time, with data coverage increasing over the last two decades. The data gaps seem to depend on funders, with some countries having complete records of funding values, while others having no funding values available at all (see table S2).

2.6. Network analysis

Using the collaboration of organizations and researchers on grants, we build two types of networks: First, we construct a network, in which nodes are organizations and links are collaborations between organizations on at least one grant. Second, we do the same for researchers, who collaborate on at least one grant. We use different centrality measures to evaluate how different organizations and researchers are positioned within the network: While the degree centrality simply indicates how many partners a node is linked to, the betweenness centrality highlights how important a node is for connecting all other nodes in the network. The closeness centrality indicates how far a node is on average from other nodes. Finally, the eigenvector centrality gives a score on how well connected a node is to other nodes with high scores. We use the different metrics, which are correlated but highlight distinct characteristics about the node’s position in the network, to identify central actors from the long list of organizations and researchers.

Apart from the centrality, we analyze whether the network is well connected in a giant component or falls into many smaller connected components. We also compute the clustering coefficient of the network, indicating how likely two nodes that are connected to the same neighbor also establish a direct link, thus forming a triangle. Last but not least, we analyze how well different types of organizations mix, computing the assortativity coefficient using equation (2) in Newman (2003).

2.7. Limitations

In summary, our dataset of CDR grants is the most comprehensive collection of funding information we are aware of. Compared to other efforts to map funding of CDR (Presty *et al* 2024), we use an approach that is independent of subsequent scientific publications. However, a number of limitations need to be taken into account when interpreting the data. First, limited transparency on how the Dimensions database is collected results in uncertainties in particular regarding the coverage of low and middle income countries (Dimensions 2024). Second, there are some data gaps particularly for funding amounts. We address these by estimating the value of grants without funding data and provide more information on data gaps in the supplementary material. Third, we only consider data for third-party funded projects; research activities conducted as part of academic institutions’ core-funding are not accounted for. Consequently, nationally varying science policies and funding cultures (Aksnes *et al* 2017) as well as developments in funding cultures over the past decades (Bloch & Sørensen 2015) deserve greater attention in future work.

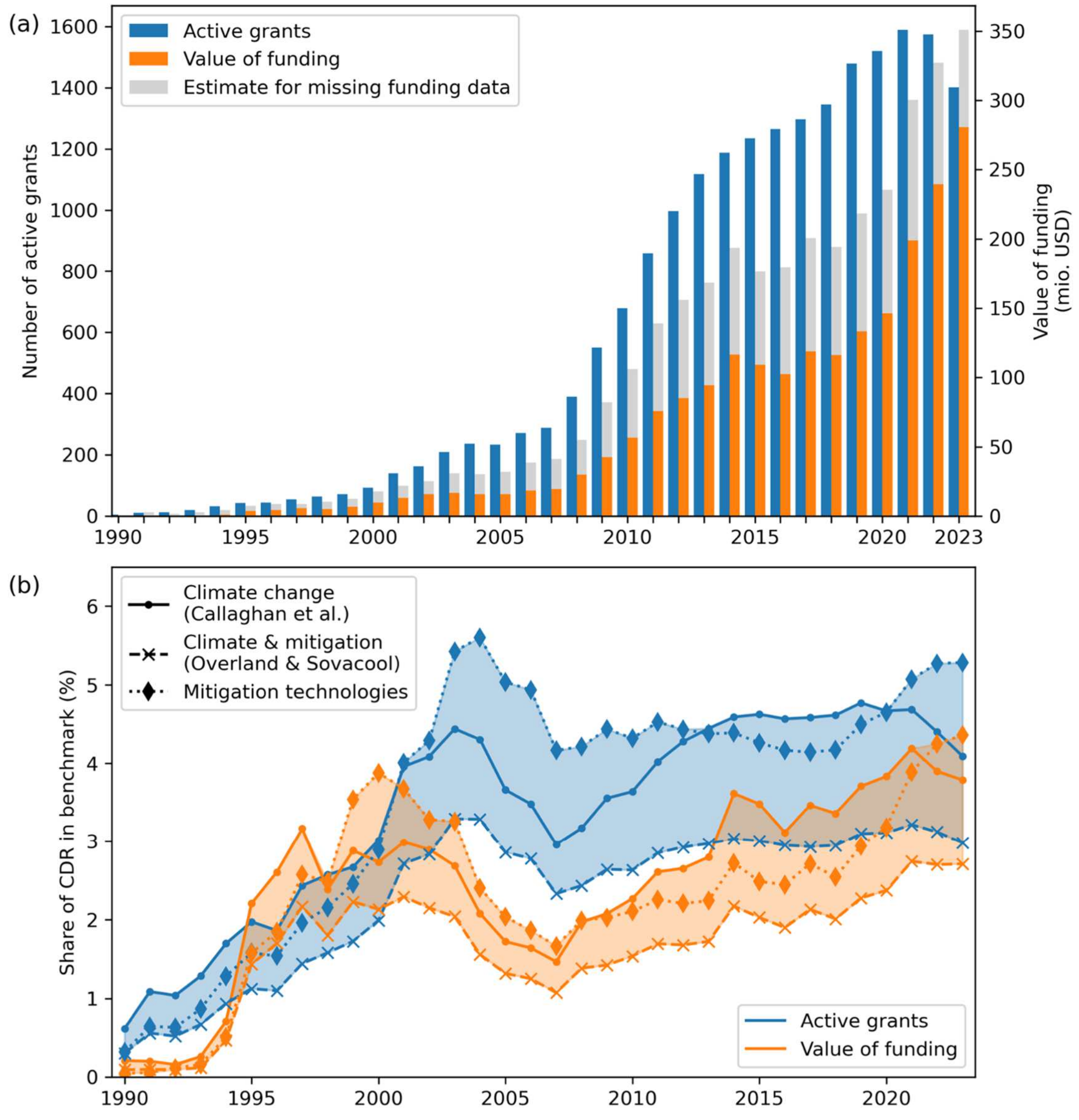

Figure 1. Growing active grants and funding over time. (a) Increase in all active CDR grants and funding allocated through them over time. (b) Percentages of active grants and funding compared to different benchmark grant datasets.

3. Results and discussion

We first provide a mapping of the funding landscape for CDR research, including its evolution in the past decades and its distribution across CDR options, geographies, and disciplines (section 3.1). Then, we analyse emerging networks of actors collaborating on third-party funded research projects on CDR (section 3.2).

3.1. Mapping the funding landscape of CDR research

3.1.1. Increasing research funding for CDR

Research funding of CDR increased considerably over the past thirty years. Figure 1(a) shows an accelerating growth trajectory of third-party funding for CDR research, both in terms of the number of active grants, as well as the total financial resources made available. While we only find a few dozen active research grants on CDR during the 1990s, this increased to more than 1500 per year in 2021 and 2022. The number of active grants increased on average by only 12 per year in the 1990s and early 2000s. A steep increase both in the number of active grants as well as funding followed between 2008 and 2013, with 126 additional active grants per year. A short period of slower increase for funding followed between 2013 and 2018, which is also visible in general climate change funding (see discussion of benchmarks below). Recent years saw another increase in funding values but not in projects. Overall, CDR funding increased on average by 21% and active grants by 17% per year between 1990 and 2023. This is comparable to the average annual growth of 17% in scientific publications on CDR reported by Lück *et al* (2025).

Put in perspective of third-party funding for research on climate change and mitigation technologies more broadly, a growing share of CDR-related funding can be traced, amounting to 2%–3% of the reported climate research funding and about 4% of clean-tech funding in 2023. This share has increased over the last three decades, but most strongly in the 1990s (see figure 1(b)). However, the overall funding in CDR is still small: Between 2000 and 2023, we record 2.86 bn$ funding for CDR. Using the average and 5 to 95 percentile values for the funding value per grant to fill the data gaps in the funding values gives us an estimated funding volume of 4.23 (2.90–6.83) bn$. The total funding on grants from Dimensions that mention clean-tech keywords is about 84 bn$, of which only 3% is on CDR.

However, these numbers certainly underestimate total funding into this sector. For comparison, we looked at the total public funding reported by the IEA, which its member countries spent on low-carbon energy technologies between 2000 and 2023 (IEA 2024). This added up to 406 bn$. When filtering for the clean-tech grants from IEA member countries only, we get 82.8 bn$ for the same period (95.5 bn$ including estimates for missing funding data), suggesting that the coverage of low-carbon research through the grants database is only 20.4% (23.5%). Hence, if the same ratio holds for the field of CDR, funding could be as large as 18.0 (12.3–29.1) bn$.

To inspect the provenance of funding, we also looked at the 700 unique names of the funding schemes provided in the Dimensions database for our CDR grants dataset. These funding schemes were the names of the funding instruments and calls, to which the grants in our database successfully applied. The analysis suggests that the great bulk of CDR research came out of general funding instruments and broad calls without any specific strategic or thematic focus. Those CDR projects that were tied to thematic funding schemes were predominantly funded under agriculture and forestry-focused programmes, followed by energy-focused programmes and climate-focused funding instruments. Only four funding instruments in the sample could explicitly be identified as targeted to carbon management, CCS and/or carbon removal research. While some caution interpreting is warranted due to incomplete reporting of exact names of funding schemes in our dataset, overall these observations suggest that so far CDR research has not emerged from strategic research priorities and policies. This contrasts with the interpretation of Presty *et al* (2024), who suggest that strategic funding drives CDR publications.

3.1.2. Diversification of funding across CDR options

The analysis of grants reveals an unequal distribution across different CDR options, reflecting the historical development and maturity of different CDR options. In the analysis of this and the subsequent distributions, we rely on the number of grant years, that is, the number of years a grant has been active, as a measure to compare shares in research funding consistently over time, across geographies and disciplines (see Methods and Data for the motivation behind this measure). For example, if there are two grants each active for three years, we will add 6 grant years to the count. Just two CDR options—biochar and soil carbon sequestration—reflect more than *half* of all CDR grant years in our dataset, with 31.8 and 20.0% respectively (figure 2, table 1). Other CDR options with high shares of grant years are forest management (16.4%), afforestation/reforestation (8.9%), peatland restoration (5.2%), BECCS (4.4%) and blue carbon (4.0%). Ocean alkalinity enhancement and agroforestry have the lowest shares of grants and grant years. This pattern is consistent with findings from the literature on CDR (Lück *et al* 2025), and is likely driven by the many co-benefits of carbon removal in agriculture and forestry—such as nutrient and water retention and soil health (Smith 2016, Prütz *et al* 2024).

For novel CDR options, most notably DACCS and BECCS, average funding volumes per grant tend to be higher: While forestry, soil carbon and biochar receive on average around 0.3 to 0.4 mio$ per grant, DACCS and BECCS grants have an average funding volume of 2.5 and 2.1 mio$, respectively. The amount of funding in value terms is accordingly less concentrated and more evenly spread across the CDR portfolio: While BECCS and DACCS amount to only 7.5% of active grant years, they receive 37% of the reported funding. The conventional CDR options afforestation/reforestation, forest management and soil carbon sequestration together receive a similar share (37%) of the total funding. Mineralization options such as enhanced weathering and ocean alkalinization have attracted little research funding.

From a temporal perspective, an increasing diversification of CDR options can be observed in the past decade, with novel CDR options such as DACCS, BECCS and biochar receiving increasing shares of research funding. We also observe a decline in funding for research on ocean fertilization - a CDR option that caused controversy in the early 2000s (e.g. Strong *et al* 2009).

Compared to 6245 grants on CDR, we find only about 2063 grants on CCS and CCUS, of which 158 also cover some CDR options. While they make up only 23% of the extended dataset of carbon management methods, there is much more funding reported to go into CCS: These grants receive on average 2.36 mio$ per grant, which is more than triple the value of an average CDR grant at 0.68 mio$, but comparable to funding for novel CDR options such as BECCS and DACCS as mentioned above. The total funding for CCS including estimates for missing data is 4.9 bn$. Thus, CCS receives more funding than any of the CDR options discussed

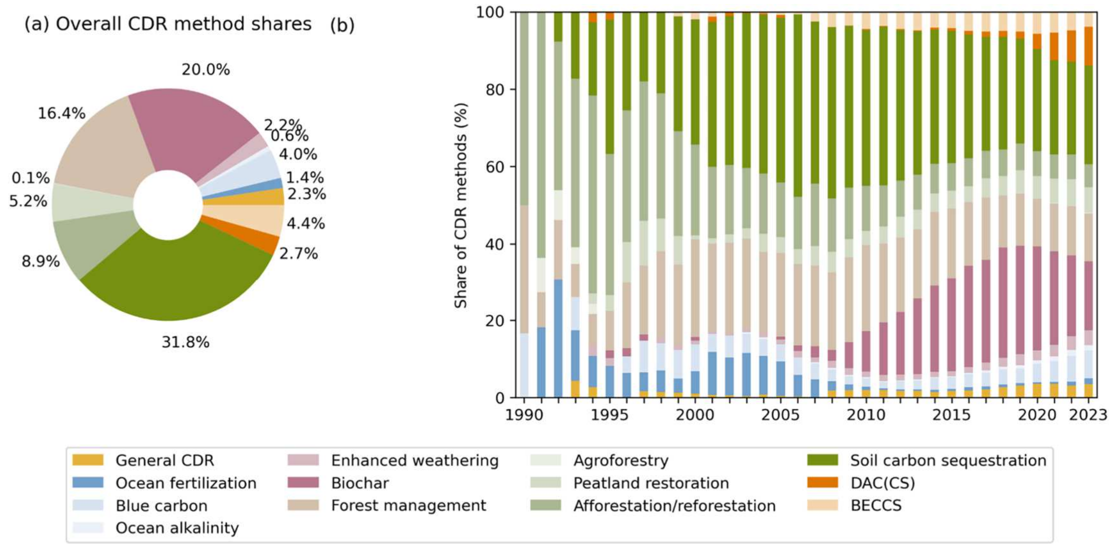

Figure 2. Active CDR grant years by CDR option: (a) distribution of overall grant years across CDR options and (b) distribution of grant years across CDR options over time. Note: CDR = carbon dioxide removal. DAC = direct air capture. CS = carbon storage. BECCS = bioenergy with carbon capture and storage.

Table 1. Number of grants, active years, total funding and funding per grant for each CDR option.

CDR option	# grants	# grant years	Total funding value (mio. USD)	Mean funding per grant (5th-95th percentile)	Missing funding data [%]
Afforestation/ reforestation	667	2213	138.64	0.33 (0.01–1.26)	36.43
Agroforestry	6	17	8.07	2.02 (0.02 - 6.59)	33.33
BECCS	302	1093	488.80	2.12 (0.02–3.95)	23.51
Biochar	1511	5022	368.41	0.36 (0.02–1.34)	31.97
Blue carbon	303	1113	109.56	0.45 (0.02–1.78)	19.47
DAC(CS)	255	813	574.62	2.50 (0.02–2.95)	9.80
Enhanced weathering	162	597	62.57	0.55 (0.02–3.00)	30.25
Forest management	1036	4063	414.72	0.67 (0.02–1.89)	40.15
General CDR	160	650	177.36	1.40 (0.02–7.85)	20.62
Ocean alkalinity	48	178	21.82	0.64 (0.03–3.50)	29.17
Ocean fertilization	96	362	35.06	0.40 (0.02–0.89)	8.33
Peatland restoration	386	1371	102.64	0.36 (0.02–1.27)	25.91
Soil carbon sequestration	2078	7949	560.93	0.43 (0.02–1.50)	36.62
Total	6245	22638	2863.62	0.68 (0.02–1.97)	32.35

here, and even more than the sum over all options (4.2 bn$). These strong differences are most likely driven by grants for demonstration projects, which usually have a much higher volume than pure research grants, as also evidenced by the stronger involvement of private companies (see section 3.2). The funding of CC(U)S and CDR over time in figure 3 reveals very similar trends. Main differences are more early funding of CDR research in the 1990s and early 2000s and a stronger increase of both funding and grants after a short period of stagnation in the mid 2010s. This is in contrast to research publication on CCS, which have seen no such increase since they reached a relatively stable release of around 1000 papers per year in the early 2010s (Smith *et al* 2023; figure 2.2).

3.1.3. Geographic disparities in funding of CDR research

Mapping aggregated funding across geographies reveals a concentration of research support for CDR, with the highest number of grant years in North America (USA and Canada, 43%) and European countries (including EU-27 and non-EU countries such as UK, Switzerland and Norway, 28%), followed by China (16%, see figure 4 and table S4). Funding and recipient institutions in Global South countries in Africa (0.4%), Latin America (5.2%) and other Asian countries (4.6%) are strongly underrepresented. Compared to the shares of all clean-tech grants (table S4), CDR is funded more strongly in the USA and Canada (clean-tech: 31%) as well as China (clean-tech: 10%) and less in Europe (clean-tech: 45%). For the other regions, the shares are similar. These

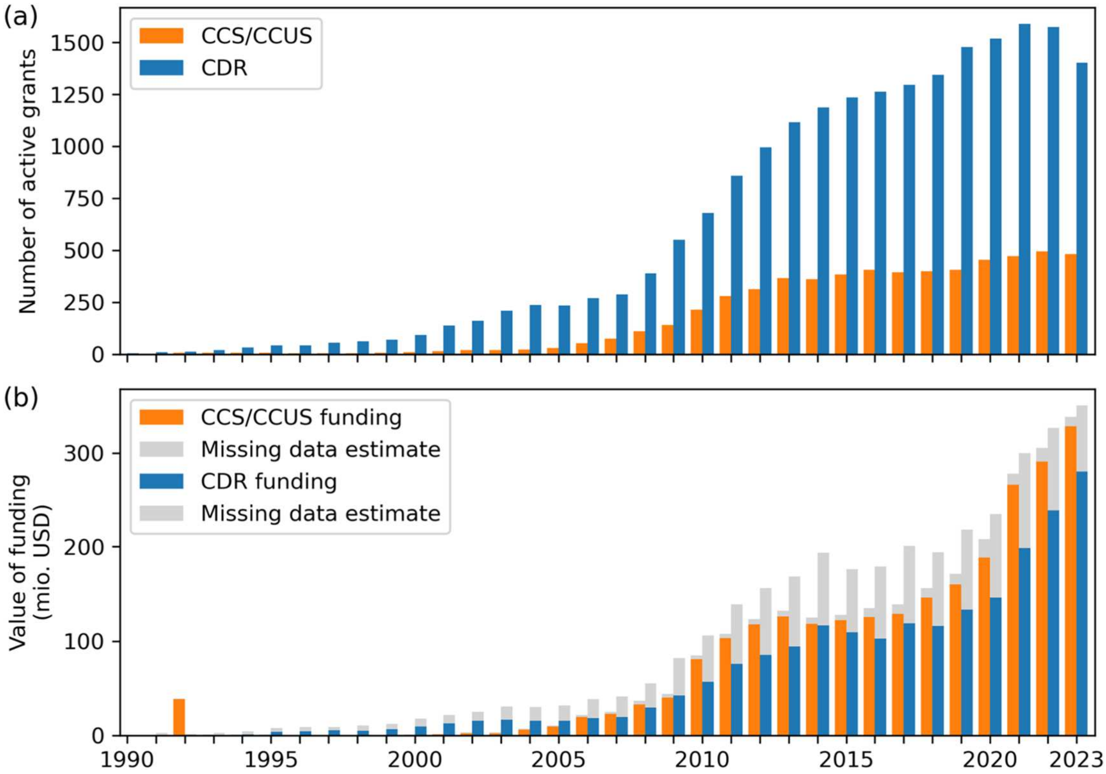

Figure 3. Comparison of time trends in CCS and CDR grant funding. (a) Number of active grants per year and (b) funding value per year for CCS and CDR research. Note: CCS = carbon capture and storage. CCUS = carbon capture utilization and storage. CDR = carbon dioxide removal.

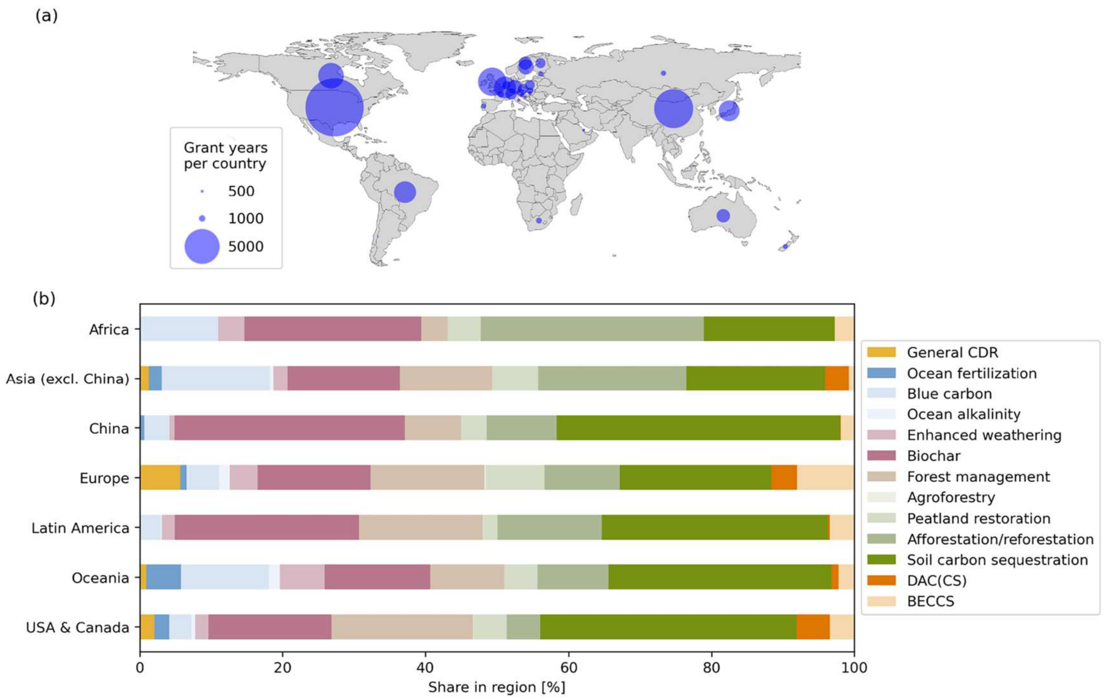

Figure 4. (a) Geographical distribution of CDR research funding, based on CDR grant years by country; (b) Share of CDR grant years by CDR option per region (location of the funder). Note: CDR = carbon dioxide removal. DAC = direct air capture. CS = carbon storage. BECCS = bioenergy with carbon capture and storage.

unequal funding patterns reflect geographic disparities in funding of climate and energy research more broadly (AbudlRaifiu *et al* 2022). Distribution of funding amounts (in USD) are similarly skewed, with some data missing for entire countries (see Methods and Data).

Roughly 40% of the research projects on CDR and about 50% of the research funding takes place in North America. With almost three times more CDR research projects and more than twice as much CDR research funding available than in the EU-27, total research investments into CDR are markedly higher in North America. Some European countries that are not members of the EU—mainly the UK, Norway and Switzerland—jointly fund almost as many CDR research projects as the EU-27, making up for about 13% of global funding support. Their per capita CDR funding levels are very high compared to all other countries (see table S2).

While the regional allocation of funding across CDR options broadly reflects the global focus on conventional CDR options, some regional differences in specialization or prioritization become apparent (see figure 4(b) and S2). Compared to the global average, funding bodies in North America have supported a larger share of CDR projects on soil carbon sequestration (+4 percentage points), DAC(CS) (1.5 pp), forest management (3.8 pp) and ocean fertilization (0.6 pp), while in China CDR research funding has focused more on biochar (+12 pp) and soil carbon sequestration (8.5 pp). European funding bodies have invested comparatively more into CDR projects on BECCS (3.8 pp), general CDR research (3.1 pp), for instance on inspecting political and socio-economic aspects, afforestation (1.9 pp) and enhanced weathering (1.5 pp) compared to the global average. CDR research in Africa is more focussed on afforestation/reforestation (22 pp), blue carbon (6.6 pp), biochar (5.0 pp) and enhanced weathering (1.3 pp).

For novel CDR options, we observe that DACCS research funding is concentrated in the US, followed by Europe and Asia, with none or no sizeable amounts in other regions. Funding for BECCS research has been most prominent in Europe, but has attracted at least some funds in all regions. Tracing funding flows from funding bodies to recipient organizations shows that funding mostly stays within a region: funding flows from a funding body located in one region to a recipient organization in another region are rare (see figure S3).

3.1.4. Disciplinary concentration of CDR research funding

Analyzing the disciplinary distribution of research funding for CDR shows that the vast majority of grants are attributed to natural science (56% of grant years) and agricultural sciences (52%), followed by engineering science (13%). A comparatively small fraction of grant years is allocated to social science and humanities research on CDR (11% and 0.5% respectively, see figure 5(a)). Note that grants can be attributed to several fields, such that the percentages add up to more than 100. The shares for social science and humanities are comparable to funding patterns in clean-tech, while the disciplinary shares for CDR are much higher for agricultural sciences and much lower for engineering when compared to clean-tech funding in general (with shares of 4% and 56%, respectively, see table S5). When looking at the funding amounts, the picture changes slightly, with the share of funding allocated to engineering research being much larger (30%), and thus coming second before agricultural research (26%) and after natural sciences (35%). Social science receives about 9% of the funding. Funding for health sciences and humanities in relation to CDR is negligible. Social science research constitutes a large share of grants on carbon removal in general, but is - with few expectations - less prominent in grants on specific CDR options (figure 5(b)). The comparatively strong prevalence of social science research in blue carbon and agroforestry can be explained with the strong need to involve local communities in the implementation of these CDR options, as also observed for the scientific literature on CDR (Lück *et al* 2025).

To explore the disciplinary distribution in more detail, we looked at the underlying specific research fields as given in the dataset, which are group names from the well-established ANZSRC scheme (Australian Bureau of Statistics 2020). Natural science grants are most often from research fields 'Ecology' (38%[6]), 'Environmental Management' (29%) or 'Ecological Applications' (22%)—mirroring the focus of many of these grants on ecosystem-based removals. Agricultural science grants, which have a focus on soil carbon sequestration, forest management and biochar, are most often attributed to 'Forestry Sciences' (60%), 'Crop and Pasture Production' (24%), 'Soil Sciences' (17%) and 'Agriculture, Land and Farm Management' (13%). Engineering grants, with large shares of BECCS, DACCS and biochar, are dominated by the groups 'Industrial Biotechnology' (42%) and 'Chemical Engineering' (33%). Social science grants, which often do not have a strong focus on particular CDR options, are most often classified as 'Climate Change Impacts and Adaptation' (57%), 'Environmental and Resources Law' (9%), 'Human Geography' (9%) and 'Sociology' (6%).

Early research until the mid 2000s was heavily concentrated on natural and agricultural science, but the last 15 years saw an increasing trend towards higher shares of grants in engineering and social science (see figure S4). While the increase in engineering is clearly driven by research activities on novel CDR options such as BECCS or DACCS, the relative increase in social science research is independent of shifts in funding between CDR options. It can be explained by an increasing interest in societal dimensions of CDR, such as public

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[6] Multiple of these categories can be assigned to a grant, thus all percentages add up to more than 100%.

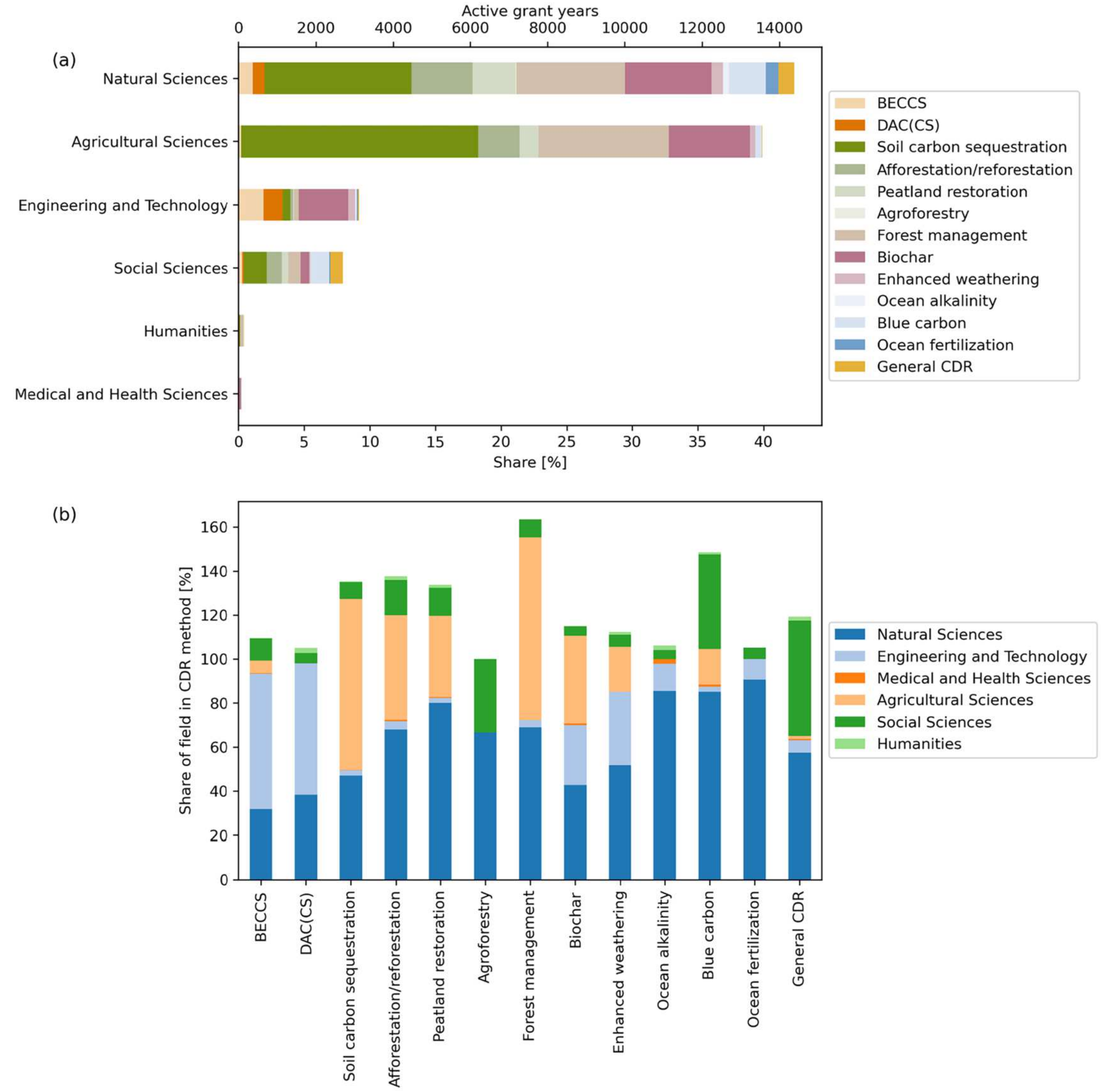

Figure 5. Active grant years by discipline and CDR option. (a) Absolute counts of active grant years by discipline (FORD) and colored by CDR option. (b) Share of disciplines in each CDR option. Note that some grants are attributed to several disciplines, hence the sum over percentages are sometimes larger than 100. Note: CDR = carbon dioxide removal. DAC = direct air capture. CS = carbon storage. BECCS = bioenergy with carbon capture and storage.

perceptions and communication (Cox *et al* 2024, Bellamy & Raimi 2023), policies (Schenuit *et al* 2021) and governance (Lück *et al* 2024).

Looking at the abstracts of the 10 biggest social science projects suggests that social science perspectives on CDR are often only a small component of large modeling and engineering-focused projects. Capacity building, stakeholder engagement, networking and outreach frequently appear as tasks, suggesting at least in parts an instrumentalist conception of social science as facilitator of technology implementation (Waller *et al* 2024, Fritz *et al* 2024).

3.2. Actors and collaboration networks

To shed light on who drives CDR research, we investigate both receiving organizations as well as individual researchers listed as investigators in the grants. Our main tool to analyze this data are collaboration networks. We construct them by linking organizations (or researchers) that are jointly listed as receiving funding in the same grant. Because the organizational network is much more connected than the researcher network, it allows for a more comprehensive analysis using standard network analysis tools. Not all organizations have collaborations, therefore the network is not fully connected. But most of the organizations with collaborations are part of the largest connected component (87%).

Overall, only 13% of the CDR grants list more than one receiving organization, indicating that most funding is not specifically targeting collaboration. This percentage is considerably lower than for CCS grants

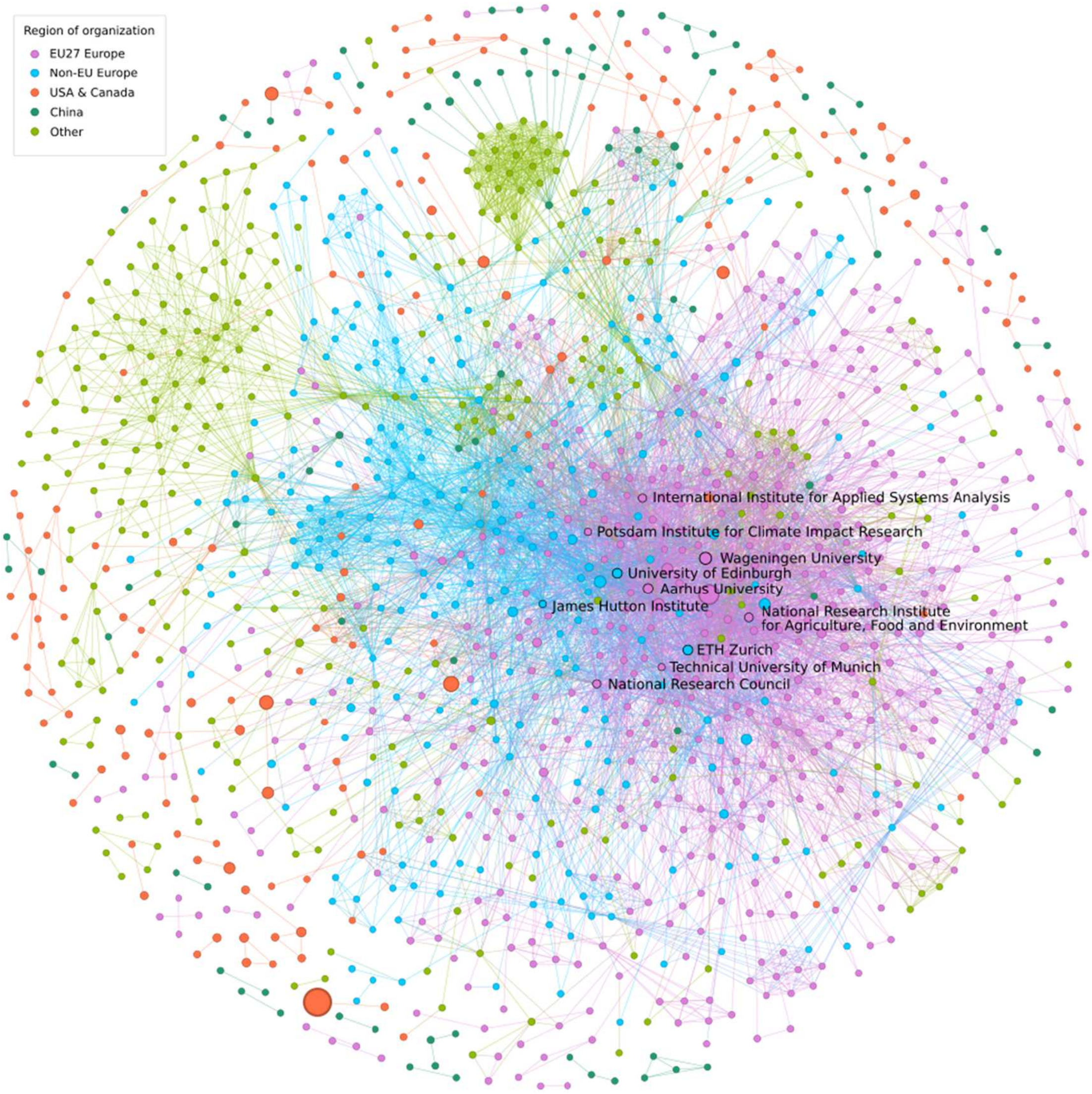

Figure 6. Overview of collaboration network between organizations, based on CDR grants. The nodes of the network are organizations receiving funding as listed in the grants data and colored according to their location. Node sizes are scaled with funding amounts that the organization is receiving. Links between nodes indicate that organizations work together on at least one CDR grant. The 10 organizations with the highest degree are highlighted and labeled (cp. table 2).

(20%) and clean-tech (23%, see table S6) and could be explained by the still early phases of R&D compared to more mature clean technologies such as renewable energy.

Figure 6 displays all connected components of the organizational network, colored by region of the receiving organization. The network consists of several densely connected parts and a periphery with many organizations that are only attached to one or a few other organizations. A higher proportion of collaborations happens between organizations from the same region, compared to few collaborations between different regions. This tendency can be quantified by the assortative mixing coefficient, which is high for regions (0.47) and a little lower for countries (0.29), on a scale from 0 indicating connections between organizations independent of regions and 1 full correlation of connections and regions. It can be explained by the lower propensity of funders to support research in other countries and regions.

Many European organizations are part of the densely connected parts of the network, but this is not the case for most US, Chinese and other organizations. This pattern is partly driven by varying funding amounts from different regions but also points to considerable variation in how funding is allocated: In Europe a larger proportion of grants are allocated to larger consortia, the US and other parts of the world grant more of the funds to single organizations. This is also supported by the average size of consortia, which is 1.2 both in China and the US/Canada, 5.6 in EU27 and 3.3 in non-EU European countries.

We find that a few organizations are much more important to the network than most others, based on centrality measures which describe different kinds of importance of a node for the entire network structure. First, we look at the degree centrality, which describes the number of partners that an organization collaborates

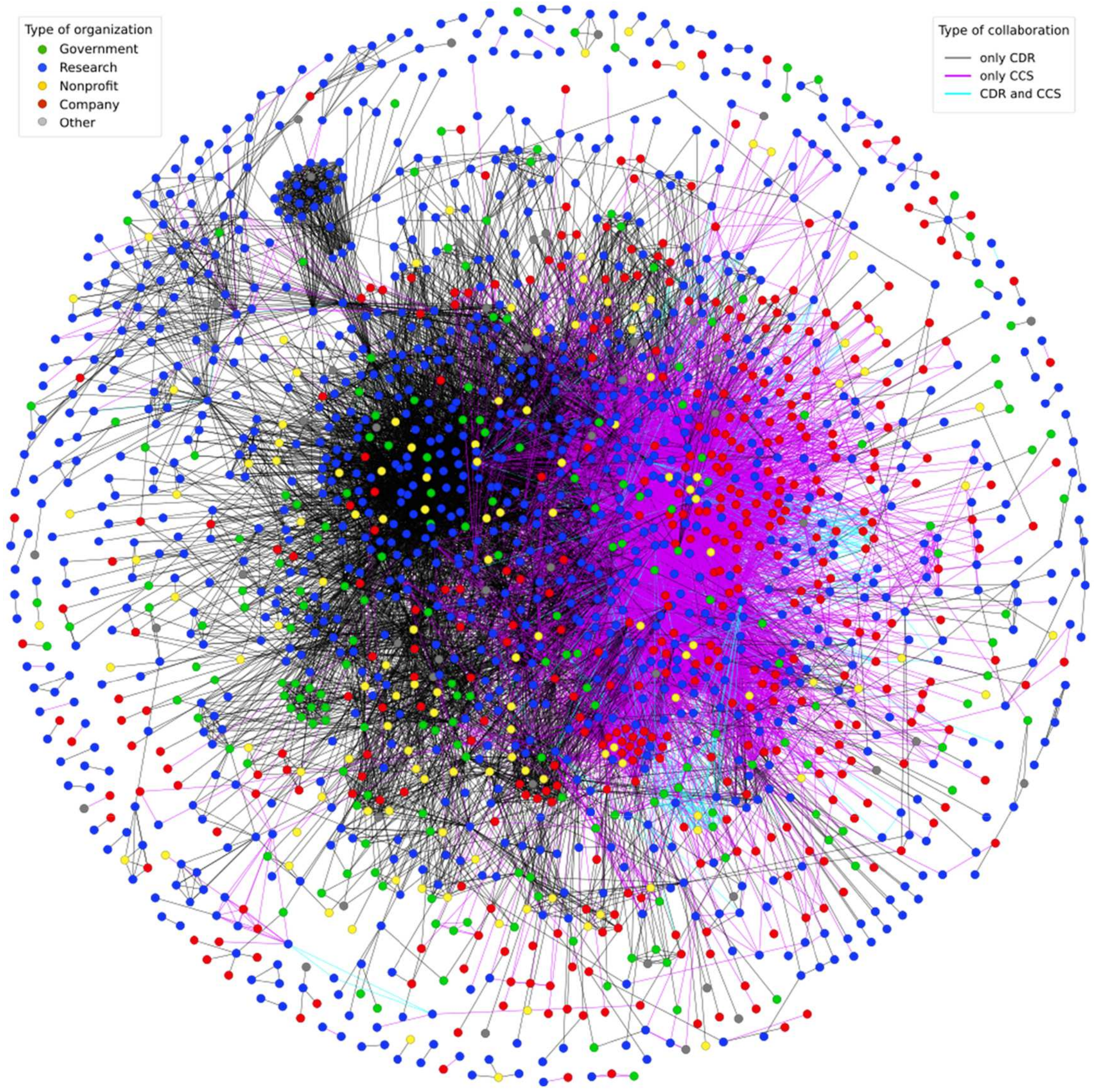

Figure 7. Collaboration network from dataset including CCS and CCUS grants. Nodes are colored according to organization type and edges are colored according to whether grants focus on only CCS/CCUS, only CDR or both.

with. While on average, each organization collaborates with 12 others, the distribution of degrees across all organizations is very uneven: many organizations only collaborate with few others, while few organizations have many collaborations. These come sometimes from single grants, some of which have up to 25 collaborating organizations. Organizations with a high degree centrality also tend to rank high with respect to their betweenness and closeness centrality . Based on a similar analysis, we found much less concentrated centrality measures for the network of researchers, which is partly due to the much lower overall connectivity.

Table 2 lists the 10 most central organizations from the collaboration network based on CDR grants. They are dominated by research universities and institutes, but some nonprofit organizations and government agencies are also central to the network. Companies have low average degree, betweenness and eigenvector centrality and hence do not feature in the list of the most central organizations. Still they are well represented in the largest connected component, because they tend to collaborate with research organizations to qualify for research grants. Overall, the list features many research organizations that are known and important for key fields related to CDR, such as ecology, agricultural science, forestry, climate research and environmental engineering.

The network analysis also reveals that the collaboration between different types of organizations varies across CDR options. Overall, the majority of collaborations happens between research organizations and collaboration between the same type of organization is more likely (assortativity 0.14), i.e. collaboration between research institutes is more frequent compared to collaborations with private companies when comparing the same organizations in a randomly connected graph. While on average, only 3.4% of the collaboration is between research and companies, this rate is much higher for BECCS (10%) and DACCS (9.5%). Similarly, the collaboration of research with nonprofit is more frequent for afforestation/reforestation

Table 2. The 10 most central organizations in the collaboration network by degree centrality.

Organization name	Country	Organization type[a]	Number of grants	Funding amount (mio. USD)	Rank in degree	Rank in betweenness	Rank in eigenvector centrality
Wageningen University & Research	Netherlands	Research	38	111.62	1	1	1
National Research Institute for Agriculture, Food and Environment	France	Government	21	70.29	2	7	2
Aarhus University	Denmark	Research	15	83.6	3	4	3
ETH Zurich	Switzerland	Research	27	62.51	4	8	5
Potsdam Institute for Climate Impact Research	Germany	Research	13	33.1	5	6	4
University of Edinburgh	United Kingdom	Research	53	30.21	6	5	15
James Hutton Institute	United Kingdom	Nonprofit	19	22.63	7	10	20
Technical University of Munich	Germany	Research	19	18.18	8	17	14
National Research Council	Italy	Nonprofit	12	33.54	9	3	36
International Institute for Applied Systems Analysis	Austria	Nonprofit	7	49.86	10	22	6

[a] Based on classification provided in the dimensions database.

(7.1%, compared to an average of 5.4%) and with government agencies for soil carbon sequestration (9.8%, compared to an average of 7.5%). Grants on other CDR options are more spread between different non-research partners. These differences are related to varying shares of organization types engaging with the different CDR options: For example, the share of companies is larger for DACCS (27%) and BECCS (11%) than for other CDR options, while for land-based CDR options, there are comparably higher shares of government agencies involved in the research grants (7%–12%).

We also find a much higher involvement of companies, especially fossil fuel companies, in CCS and CCUS research in comparison with CDR research. While the share of companies in organizations involved in CDR research is only 11%, it is 23% for CCS research, contributing to 15% of the collaborations. Figure 7 highlights different types of organizations (research, government, nonprofit, company and other) in different colors in the network constructed from both CDR and CCS grants. Actors collaborating mainly on CCS form a distinct community from those mainly collaborating on CDR, i.e. there are relatively fewer connections between these communities than within them. Many collaborations in the network are based either only on CDR or only on CCS grants, with only about a third of the organizations engaging in both types of projects. The set of these intermediary organizations is dominated by large UK universities, such as the Universities of Edinburgh, Nottingham and Sheffield, and research institutes from Norway, Switzerland and EU countries, for example the Spanish National Research Council, ETH Zurich and the German Fraunhofer Society.

In the CDR and CCS collaboration network, fossil fuel companies like BP, Total, Equinor and Shell are among the highest-ranking companies in terms of different network centrality measures. Even though they are only involved in a small fraction of CCS grants (0.8%), they are deeply involved in the CCS research network. For example, the British oil company BP lists 115 collaboration partners in the CCS field even though it is only involved in 20 grants. These companies have much higher mean centrality measures both compared to other companies as well as to the average across all organizations. In the network not including CCS, fossil fuel companies are far less central compared to other companies and organizations.

4. Conclusion

The insights into global research funding patterns for carbon removal gathered in this article provide a basis for setting future priorities for public and private investments in this research and innovation system. In the following, we summarize key take-aways and draw conclusions for research funding, policy and practice.

Research funding for CDR has increased substantially over the last years, much more than general funding for climate science and technology, signaling the emergence of CDR as a central element in research on climate change mitigation. While conventional forest-based CDR options, soil carbon sequestration and blue carbon dominated the research funding landscape around the turn of the century, we do find diversification of funding across different CDR options in the last decade, with novel options such as biochar, BECCS and DACCS gaining traction, the latter especially in the last few years. Scientific publications show similar trends over time, with higher overall growth, larger shares of biochar and less focus on forest-based CDR (Lück *et al* 2025, Minx *et al* 2024, Presty *et al* 2024).

The increasing funding trends for CDR research presented in this paper are driven partly by external factors: First, they occur in the context of a general shift of public research funding from base funding to project-related third-party funding (see e.g. Bloch & Sørensen 2015). Second, CDR research funding profits from an increasing trend in climate change and mitigation technology research. In particular, CDR research funding needs to increase given the surge in national and firm-level net-zero targets (Hale *et al* 2022, Allen *et al* 2022, Greene *et al* 2025) and their implications for CDR deployment (Lamb *et al* 2024). Total CDR research funding volumes are still relatively small compared to CC(U)S and other mitigation technologies, but their share increases and can be expected to do so in the future. For example, the US started an initiative to build four regional DAC hubs with an announced dedicated funding of 3.5bn$, which is not covered by our data but would increase the total funding we quantified here by about 80%. Apart from these overall trends, several patterns in the distribution of research funding across geographies, disciplines and collaborations warrant attention:

First, research funding for CDR remains highly concentrated in a few countries. Mapping aggregated funding across geographies reveals a concentration of research funds, with the highest shares in North America, followed by European countries and China. This result differs from the only other study on CDR research funding (Presty *et al* 2024): We do not find as much research funding in China. This could either point to data gaps in the Dimensions database or overreporting of funding through Chinese publications. Funding and recipient institutions in Global South countries in Africa, Latin America and in other Asian countries are strongly underrepresented. These unequal funding patterns reflect geographic disparities in funding of climate and clean technology research more broadly (AbudlRaifiu *et al* 2022) and are strongly driven by financial possibilities of different countries. However, they are also the result of differences in third-party research funding in national science systems as well as of differences in reporting practices of funding organizations. Building capacities and granting researchers and organizations in the Global South access to CDR research funding and related collaboration networks is key to fostering the global endeavor of carbon removal and to avoid exacerbating persisting inequalities in shaping climate governance (Sovacool 2023). This is especially important for land- and ecosystem-based CDR options: Because the largest potentials are in the Global South (e.g., Benitez *et al* 2007, Lessmann *et al* 2022), there is a strong need for research on risks, benefits and side-effects in these regions before implementation can be cautiously scaled up.

Second, analysis of the disciplinary distribution of CDR grants reveals that funding is highly skewed towards natural, engineering and agricultural sciences. A comparatively small fraction of overall research funding goes to social science research on CDR, similar to funding patterns across disciplines in climate change research more generally (Overland and Sovacool 2020. Partly reflecting early stages in the development and low maturity of some of the technologies, this might suggest that CDR has been primarily conceived as a technological problem, with research focusing on getting the technology right rather than or prior to considering the social and political contexts of its implementation. As we move from basic research and technology development towards implementation and potentially large-scale deployment, particularly of novel CDR options, greater inclusion of social science perspectives is warranted to ensure social and political feasibility are accounted for. Our data analysis already shows an increasing trend in social science funding, but this is partly driven by accompanying social science research in large research projects that are dominantly technology focused.

Third, collaboration networks on CDR research show that relatively few research organizations, all located in the Global North, are central and thus influential in shaping the field. Private sector involvement in knowledge production activities is comparatively low, with most cross-sectoral research collaboration focusing on DACCS and BECCS. The analysis of the central research organizations highlights that key institutions from established research fields, such as agricultural sciences and ecology, are strongly involved in driving CDR research. The prominent role of options such as biochar and soil carbon sequestration in research funding further illustrate this point, mirroring their prominence in published literature on CDR (Lück *et al* 2025). Cross-sectoral research collaborations involving companies are more common for CCS research, where major players from the oil and gas industry appear as central and well-connected actors in the network. These collaborations deserve further attention in future research, not at last with an eye on potential dynamics of climate delay and mitigation deterrence identified as a key concern in CDR policy debates and scholarship (Lamb *et al* 2020, Lenzi *et al* 2018). With growing maturity we are likely to see more cross-sectoral collaboration emerge also in the field of CDR, necessitating a close look at power dynamics within research practice and collaborations (Fritz and Binder 2020).

Beyond the implications for research funding detailed above, our analysis highlights that there is little targeted funding for CDR. We thus recommend that policymakers reorient funding patterns in the following ways: Funders could establish strategic partnerships with countries that hold high potentials for certain CDR options, enabling both knowledge transfer and capacity building. For example, funders from industrialized countries could initiate financing of bilateral research on co-impacts and effectiveness of land-based CDR options in low- and middle-income countries with high potentials. This funding should be aimed to increase collaborations and knowledge transfer between domestic research institutions and those in the target countries. Funders could also mandate that institutions in the Global North collaborate with partners in the Global South (Sovacool 2023), or require that calls focus on interdisciplinary challenges and problems rather than particular topics, disciplines, or technologies, similar to how for instance ARPA-E (the US funding agency for advanced energy technologies) organize their funding efforts (Bonvillian *et al* (2011)). In industrialized countries, more funding should be targeted to collaboration between research organizations and across disciplines, as there seems to be a lower propensity to collaborate on CDR grants compared to other clean technologies. However, it seems important to not target too large consortia because this could favor already central research organizations at the stage of consortium formation—as seen for some of the European funding schemes. Last but not least, social science seems to be underfunded and amounts could be increased by targeted programs that foster research on pressing questions such as how to finance CDR, how to regulate CDR in ways to prevent mitigation deterrence and negative side-effects and how to design public engagement for responsible large-scale CDR deployment.

Research funding is only one element of R&D and the wider innovation system emerging around CDR. Future research should scrutinize the relationship between research funding through grants and overall R&D activities. For this, it could explore links between research funding described here and outputs of R&D such as scientific publications and patents (Kang *et al* 2022, Fleming *et al* 2019). In addition, grants could be linked to actual activities of firms selling removal credits on the voluntary carbon market. These links could help forecasting how CDR research will develop in the next few years and understanding how the observed concentrations in research funding could be better allocated to increase research performance (Aagaard *et al* 2020). Furthermore, as grants abstracts vary strongly in information content, more detailed data about the projects collected directly from researchers would be a valuable resource to explore which topics are covered and disciplinary and epistemic approaches are applied in CDR research. By drawing on these interconnected data about CDR research, future research can identify enabling conditions and disabling factors for successful technology development, implementation and policy.

Acknowledgments

We thank our student researchers Christiane Hamann and Evie Ackery for assistance in coding grant abstracts for validation of the classifier for CDR options. We also thank the library of the University of Leeds for providing access to the Dimensions API.

Funding

This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 Framework Programme as part of the projects 'GeoEngineering and NegatIve Emissions pathways in Europe' (GENIE) [grant agreement No. 951542] as well as 'Bridging current knowledge gaps to enable the UPTAKE of carbon dioxide removal methods' (UPTAKE) [grant agreement No. 101081521].

Data availability statement

The data cannot be made publicly available upon publication because they are owned by a third party and the terms of use prevent public distribution. The data that support the findings of this study are available upon reasonable request from the authors.

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