“Research shows that people’s initial reactions to CDR are usually tied to their values, beliefs and sense of identity.”

Chapter 4 | Public perceptions

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How Carbon Dioxide Removal (CDR) is perceived will play a critical role in its future prospects. Awareness of CDR is still low in studied countries, but social media attention is growing fast. People are generally supportive of CDR research, but they have more complicated views about deploying it at scale, depending on the specific method.

Box 4.1 Key findings

- A systematic search of the English-language peer-reviewed literature reveals a small but growing evidence base, with 39 papers specifically on public perception of Carbon Dioxide Removal (CDR).
- Only ten of these peer-reviewed publications are from outside of Western Europe and North America, with none covering public views in South America, Eastern Europe or West/Central Asia.
- Among the general public in the countries studied, awareness of CDR (as a general topic and regarding specific CDR methods) is low. Perceptions of this nascent field are still forming.
- Despite low prior awareness, studies find reasonable public support for research into CDR but more concerns about deployment at scale. These involve perceptions of potential adverse side effects and tampering with nature, among many other factors.
- The number of tweets on CDR has grown rapidly over the last decade, increasing from about 15 tweets per day in 2010 to about 350 tweets per day in 2021. This is much less than for climate change in general, at 10,000 tweets per day, but growing faster.
- Of the tweets mentioning specific CDR methods, 70% involve biological storage on land and in oceans, such as soil carbon sequestration, afforestation/reforestation or coastal wetland (blue carbon) management. There are comparatively few mentions of novel CDR methods such as Direct Air Carbon Capture and Storage, but these are growing rapidly.
- Public perception research and analysis of the sentiment of tweets suggest that familiar CDR methods (particularly afforestation/reforestation) are generally preferred, and ocean fertilisation is viewed as most risky.
- Sentiments expressed in tweets on CDR methods have become more positive over time, with the single exception of Bioenergy with Carbon Capture and Storage.

4.1 Understanding public perception

Two different and complementary sources – peer-reviewed scientific literature and Twitter – can offer insights into public perception of Carbon Dioxide Removal (CDR).

If CDR is to scale to several gigatonnes of removals by mid-century, the next two decades will be critical. Alongside progress in developing and deploying the CDR methods themselves, how CDR is perceived will play a vital role. Similarly, attention to CDR in public discourse reflects the salience of the debate in addressing climate change. Studies show that public acceptance of new technologies is crucial to their widespread adoption[5,90–92], meaning that how technology adopters and the wider public perceive different CDR methods will influence the prospects for scaling them up[5,93–95]. Understanding perceptions on and engaging people with CDR, if done well, can support responsible innovation efforts.

There are three broad lines of evidence for gauging people's perceptions: sampling of a large group of people (e.g. surveys or survey experiments); studies that focus on individuals and/or small groups (e.g. interviews or deliberative studies); and big-data analysis of social media (e.g. sentiment analysis or stance detection). In this chapter, we take two complementary approaches to analysing attention to and perceptions of specific CDR methods and of CDR in general: a synthesis of the main insights from the English-language peer-reviewed scientific literature on public perception and an analysis of Twitter activity on the topic over time. While the scientific literature provides very detailed insights into how citizens perceive CDR methods in different contexts, the Twitter analysis indicates how the salience and tone of communication about CDR has changed over time. As such, together these approaches provide complementary lines of evidence on perceptions of CDR.

Box 4.2 Types of evidence for assessing (public) perceptions

Working with multiple types of evidence (such as large sample studies, small group studies, social media analysis) is particularly useful when trying to assess perceptions towards nascent technologies, because each method has specific advantages and limitations and is rooted in its own set of assumptions. Therefore, the context and scope of the results may differ. Survey and participatory methods offer researchers greater control over how and from whom evidence is collected at a particular point in time, while data-driven analyses of social media content allow researchers to track attention to a topic and sentiment towards it continuously over time. Surveys can understand perceptions at the time of the study in relation to a fixed research question, while social media analysis allows continuous adjustment of the scope of the inquiry and re-analysis of historical data accordingly.

Who is "the public"? Different approaches to gauging public perception can define "the public" in different ways, and definitions such as "public" and "stakeholder" are not fixed. People also operate from different positions at different times, for instance acting as "professional" or "civic" actors depending on the context[96]. Survey studies (Section 4.2) often focus on the attitudes or opinions of a representative sample of a general population (for example, using recruitment quotas) but may not capture the diversity of "publics" within that sample. Communication on Twitter (Section 4.3) is dominated by experts, professionals and corporate interests and, as such, may not represent opinions held by the general population.

Elicited versus non-elicited information: The benefit of surveys, experiments or deliberative approaches for eliciting information is that these studies operate within an artificial environment, allowing researchers to control and analyse the context. However, public awareness of many CDR methods is low, which can lead to methodological challenges. For example, participants may need to be presented with a certain amount of information on the topic, on which to base their response. This can lead to responses being influenced by the way the question is presented, known as "framing effects". Nevertheless, a large body of work suggests that, in general, people are competent in their deliberations and are capable of discussing complex and novel topics even with low prior awareness[97]. Analysis of social media is based on non-elicited statements by people who already have an awareness of CDR. People may express their opinion differently online than in more private settings or surveys, however. See Box 4.3 for further discussion of our methodology for social media analysis.

4.2 Scientific evidence on public perceptions

Evidence on how people perceive CDR has large regional disparities, and in studied populations awareness of CDR remains low.

Research on public perceptions of CDR is spread across a wide variety of social science disciplines, each of which carries certain assumptions. For example, there are differences in how researchers understand "the public", which are reflected in the methods used (see Box 4.2). However, most agree that public perceptions of CDR must be understood in relation to broader issues around emerging technologies and the environment. This area of research is partly driven by concerns about potential future public opposition, fuelled by past protests against technologies that CDR sometimes grouped with, such as solar geoengineering methods or Carbon Capture and Storage (CCS)[98].

To understand the existing field of research on public perceptions of CDR, we carried out a systematic search in February 2022 of the English-language academic databases Scopus and Web of Science. A search for papers labelled as "public perceptions", "attitudes" or "opinions" on CDR returned 36 papers[99–114], with a further three new papers added in September 2022[93,115,116]. A large number of studies have been published on perceptions of related techniques, such as CCS, bioenergy, forestry and ecosystem restoration. These were only included in our review if they specifically discussed carbon dioxide *removal*. Thus, for example, CCS of point-source emissions was not included, as it reduces CO_2 rather than removing it. This may exclude a large body of work on carbon sink management, for example forestry programmes such as REDD+ (Reducing emissions from deforestation and forest degradation in developing countries), which may include the perspectives and experiences of "frontline" communities. The literature we reviewed uses a number of methods for understanding public responses to CDR, including large representative surveys, experimental approaches using surveys and questionnaires, and qualitative inquiries such as focus groups, interviews and deliberative workshops. Despite low prior awareness, evidence shows that the general public is very capable of discussing complex and novel topics[97].

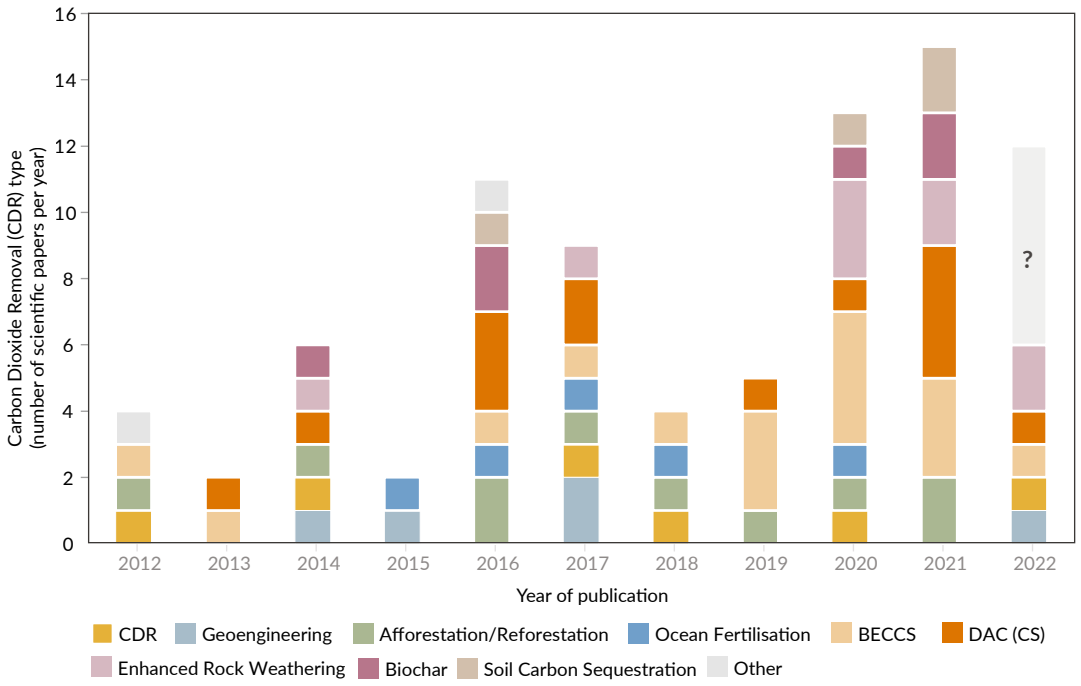

Figure 4.1. *Evidence in the scientific literature on how people perceive Carbon Dioxide Removal (CDR) is growing but still small. The figure shows the number of research papers on public perception of CDR by year and CDR method*. Total number of publications = 39. Many papers include more than one CDR method, so the total counts of publications across CDR methods in the graph adds up to more than 39. Data for 2022 includes January-September publications only. BECCS = Bioenergy with Carbon Capture and Storage, DACCS = Direct Air Carbon Capture and Storage.*

Our review found large regional disparities in the peer-reviewed research on public perceptions of CDR. Only ten of the papers we reviewed researched public views outside of Western Europe and North America, of which only one was from Africa and two from East Asia; none were from South America, Eastern Europe, or West/Central Asian regions (Figure 4.2). This may be a limitation of our English-language sampling methodology, although some research papers also raise concerns about regional disparities[117,118]. Mitigation pathways that meet the Paris temperature goal, for instance those assessed by the Intergovernmental Panel on Climate Change (IPCC), often include scaling-up of CDR in precisely the regions where scientific literature on public perceptions is absent.

* Studies on "geoengineering" include participant information and/or questions on both CDR and solar radiation management, meaning that CDR is included as a component of "geoengineering".

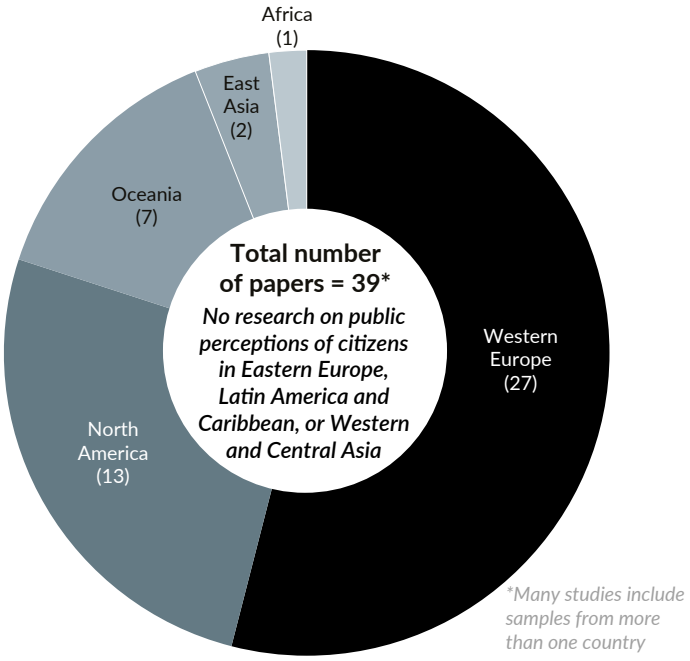

Figure 4.2. *Research on public perceptions of Carbon Dioxide Removal (CDR) shows large regional disparities, with only a small proportion of studies from outside Western Europe and North America.*

Public awareness of CDR

The scientific literature on public perceptions consistently finds low levels of awareness and knowledge of CDR in the populations of the countries studied, primarily Western Europe, the US, Australia and New Zealand. Table 4.1 summarises key results from the small subset of studies which contain quantitative awareness data. It is not possible to discern trends in this data, due to the small number of studies and the fact that awareness is measured and reported in a wide variety of ways.

Table 4.1. *Awareness of Carbon Dioxide Removal (CDR) is low among the general public in Western Europe, the US, Australia and New Zealand. The table shows public awareness of CDR, quantitative findings only, by year of data collection and country. Where multiple statistics are reported, these correspond to the countries listed, in order. Some studies aggregate across countries. Definitions: Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS).*

Year	Country	Method or CDR initiative investigated	Reported statistic	Measure	Reference
2012	Australia + New Zealand	BECCS + DACCS + Enhanced rock weathering	18%	"Aware"	Carlisle et al. (2020)[119]
2013	Australia	Carbon Farming Initiative	39%	"Aware"	Dumbrell et al. (2016)[120]
2013	Germany	Afforestation	60%	"Heard of"	Braun et al. (2018)[121]
2016	United Kingdom	Enhanced rock weathering	6.5%	"Know great deal / fair amount"	Pidgeon & Spence (2017)[122]
2018	United Kingdom	BECCS	21.2%	"Know fair amount"	Bellamy et al. (2019)[95]
2018	Switzerland	Afforestation BECCS Biochar DACCS Enhanced rock weathering Ocean fertilisation Soil carbon sequestration	3.15 (out of 6) 2.22 1.68 2.09 1.84 1.64 2.07	6-point scale 1: "never heard of it" 6: "know a lot"	Jobin & Siegrist (2020)[123]
2018	Australia New Zealand United Kingdom United States	BECCS + DACCS + Enhanced rock weathering	14% 15% 16% 18%	"Aware"	Carlisle et al. (2020)[119]
2018	United Kingdom	BECCS + DACCS + Enhanced rock weathering	19%	"Aware"	Carlisle et al. (2021)[124]
2019	United Kingdom United States	CDR	5.8% 9.6%	"Know great deal / fair amount"	Cox et al. (2020)[93]
2019	Australia United Kingdom United States	Enhanced rock weathering	26% 38% 30%	"Heard of"	Spence et al. (2021)[117]

Risks, benefits and specific CDR methods

Research shows that people's initial reactions to CDR are usually tied to their values, beliefs and sense of identity. Specific factors include trust in the actors involved, beliefs about tampering with the natural world, and perceived trade-offs against alternative approaches for mitigating or adapting to climate change[125]. For novel CDR methods (see Chapter 1 – Introduction for definitions) with low public awareness, perceptions are highly susceptible to how methods are framed by researchers. Deliberative research has shown that people may support CDR methods provided they meet certain conditions regarding elements such as impacts, risks, benefits and costs – for example, that they are feasible, controllable and reversible; that the side effects are minimal; and that scientific uncertainty is low[93,126].

Perceptions of CDR also depend on the policy context. For example, support may require a clear and joined-up approach to policymaking for climate action across sectors. Otherwise, CDR may be perceived as simply a "band-aid" to the problem of continued high emissions[115,121,127]. The policy context will also need to attend to other environmental and social goals, because support for CDR may be lower if it creates the same harms that it tries to avoid, for instance by damaging biodiversity or widening inequalities (see Table 1.1 in Chapter 1 – Introduction for potential hazards associated with different methods). Another concern about CDR is that it could reduce the incentive to tackle emissions[128], and public discourses around CDR are likely to evolve alongside emerging debates and concerns over "net zero" promises – in particular, whether CDR is simply a means of enabling particular sectors or sections of society to continue emitting CO_2. A strong body of evidence from multiple sectors demonstrates that attempting to overcome scepticism through campaigns to increase public awareness, understanding or scientific literacy is likely to be ineffective and potentially even counterproductive[129,130]. As innovation programmes gain pace, efforts to engage the public with CDR are vital but must go beyond notions of securing "acceptance".

Studies find a preference among participants for CDR methods perceived or framed by researchers as more "natural", yet definitions of what constitutes "natural" are vague and differ between studies. Familiar conventional land-based methods (particularly afforestation) tend to be generally preferred over others[94,120,123,131,132], and ocean fertilisation tends to be perceived as most risky[133,134]. Less familiar novel CDR methods, such as enhanced rock weathering and Direct Air Carbon Capture and Storage (DACCS), often encounter uncertainty and a high proportion of "don't know" responses[93,124]. Land-based CDR methods encounter concerns about land use, biodiversity and environmental impacts, although for some CDR methods such as afforestation this greatly depends on how it is carried out. Bioenergy with Carbon Capture and Storage (BECCS) in particular appears to arouse concerns about land competition, food prices, biodiversity and the sustainability of feedstocks[135,136]. Research on methods involving underground CO_2 storage builds on a much larger body of literature on CCS perceptions and finds concerns around safety, monitoring, leakage and earth tremors, and perceptions of the deep underground as unknowable and unpredictable[93,135]. Ocean-based CDR methods may be perceived as most risky because of perceived uncontrollability and irreversibility, although this may also depend on the degree to which the methods are perceived as "natural"[98,123,131].

4.3 Tracking CDR on Twitter

Attention to CDR on Twitter has proliferated in recent years, growing faster than attention to climate change in general. Some methods, such as afforestation/reforestation, are discussed more favourably than others.

The social media platform Twitter is known for driving online political debates. Twitter data shows how communicators who are aware of CDR talk about it in public. The fact that users are dedicated communicators such as experts, policymakers, and media and company representatives means that the results are not representative of general populations[137–140]. Nevertheless, analysing this data allows us to track the development of communication around CDR over time. In this chapter, we search and analyse English-language tweets in the full Twitter archive (2010-2021). Our queries capture general CDR keywords as well as those related to specific CDR methods (see Box 4.3).

Box 4.3 Method for analysing Carbon Dioxide Removal on Twitter

We focus our analysis on ten Carbon Dioxide Removal (CDR) methods – DAC(CS)*, coastal wetland (blue carbon) management, Bioenergy with Carbon Capture and Storage (BECCS), soil carbon sequestration, ecosystem restoration**, afforestation/reforestation, biochar, enhanced rock weathering, ocean fertilisation and ocean alkalinisation – as well as general CDR mentions.

For each of these, we develop and test a set of keywords in an iterative process to retrieve tweets from the Twitter full-archive search application programming interface (API) during the period 2006-2021. We download tweets separately for each set of keywords, excluding non-English tweets and retweets. In addition, we use the Twitter count API to get estimates of the volume of all English-language tweets on Twitter, as well as the number of tweets mentioning "climate change".

In total, our consolidated dataset contains 471,386 unique tweets on CDR (both general mentions and mentions of specific methods). These tweets were posted by 171,233 distinct users, of which the most active 1% contributed 28% of the tweets. The tweets in our dataset were retweeted 1,004,533 times and received 200,055 replies and 2,776,170 likes – which is on average 2.1 retweets, 0.4 replies and 5.8 likes per tweet. Of the tweets in the dataset, 16,587 (3.5%) were matched by more than one query. Our dataset only contains original tweets containing at least one of the keywords from our search strings. These may be part of a conversation but do not include all other tweets in that conversation.

For each CDR method, as well as the general CDR keywords, we (1) measure attention by counting the number (and proportion) of tweets and (2) apply sentiment analysis to understand the tone of each statement, using the aggregated information as a proxy of perceptions towards CDR methods. We automatically label sentiment in our dataset using a state-of-the-art, transformer-based classification model[141] trained on public gold-standard training data[142].

There are several limitations of such an analysis. First, Twitter data is not representative of the general public, which can lead to differences in our analysis compared with representative surveys. However, we argue that the data is particularly useful for new and emerging technologies that are not yet well known among the broader population, by providing a large archive of statements by a large number of people with a general awareness of these CDR methods[119,134]. Second, our search for tweets is optimised to provide a high share (>80%) of relevant tweets (high precision), at the expense of not retrieving everything said about CDR on Twitter (lower recall). Third, we focus on English-language tweets only. This means that considerable parts of Twitter activity with respect to CDR are not represented here – particularly in non-English-speaking parts of the world. Fourth, reactions on Twitter might be biased by algorithmic prioritisation of tweets that users are presented with, and by bots. Fifth, since Twitter was only founded in 2006, the quantity and quality of tweets are influenced by the Twitter company's continuous development and growth of its user base. To this end, we exclude the early years from our analysis and focus on the timeframe 2010-2021.

*The keywords used for this allow for mentions of both Direct Air Capture (DAC) – which does not include utilisation and storage - as well as for Direct Air Carbon Capture and Storage. These additional steps are necessary for this to be classified as a CDR method. We therefore refer to DAC(CS) in this section, as distinct from DACCS, and recognise that these mentions may not necessarily refer to the entire CDR method but may only include the capture component without storage.

**The keywords used for this allow for mentions that go beyond the peatland and wetland restoration method outlined in Chapter 1 – Introduction.

Overall attention to CDR on Twitter

The public Twitter debate on CDR is still young. Since the start of Twitter in 2006, about 470,000 English-language tweets on CDR-related topics have been shared on the platform (see Box 4.3). This is comparatively small given that there are tens of millions of tweets on climate change[143].

However, attention to CDR on Twitter has grown rapidly in recent years – faster than the number of tweets on climate change overall. In the observed period from 2010 to 2021, the number of tweets on CDR increased from about 5,500 (~15 tweets per day) to about 130,000 (~350 tweets per day) – an average growth rate of about 33% per year (Figures 4.3 and 4.4). This is faster than the growth in tweets on climate change (~10,000 per day in 2021, with 28% annual growth) and the average increase in the total number of tweets posted on the platform (17% per year).

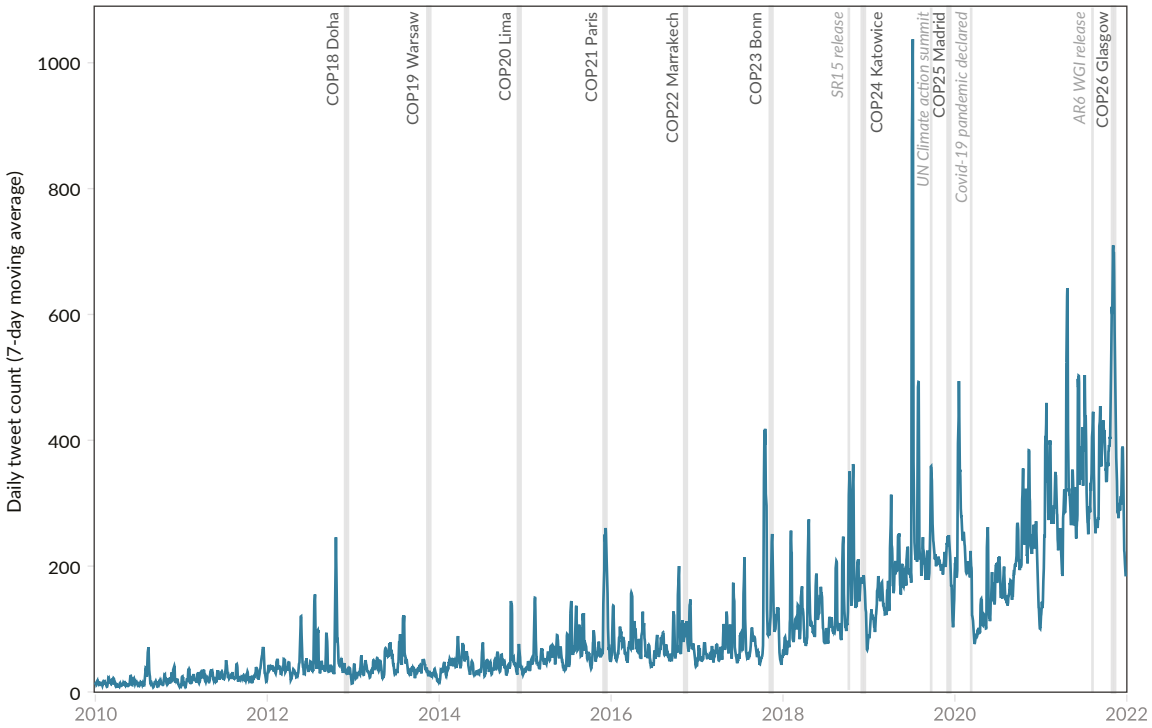

Figure 4.3. *Attention on Twitter is driven by events, particularly the annual United Nations Framework Convention on Climate Change (UNFCCC) Conferences of the Parties (COPs). Number of tweets on Carbon Dioxide Removal (CDR) per day shown as 7-day moving average (2010-2021). Attention spiked during the COPs and the releases of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5°C (SR15) and the Working Group I contribution to the Sixth Assessment Report (AR6 WG1). The peak in 2019 is related to the release of a high-profile scientific paper on global forest restoration[144].*

Due to the outbreak of the Covid-19 pandemic in early 2020, attention shifted away from CDR temporarily. However, attention quickly recovered in 2021, faster than the number of tweets on the general topic of climate change; the number of tweets was about 75% higher than in 2020 and 62% higher than in the years before the pandemic (Figures 4.3 and 4.4).

General versus specific aspects of CDR

About 30% of all CDR-related tweets concern general aspects of CDR, responding to general

keywords such as “carbon dioxide removal”, “carbon removal” or “negative emissions”. Over time, this share has increased from 3% in 2010 to 27% in 2021 and has grown faster than all CDR-related tweets together. In 2021, there were about 46,000 general CDR tweets discussing topics such as corporate plans to compensate emissions, the necessity of using CDR, or carbon-neutral products. This now regular and frequent reference to general aspects of CDR highlights the establishment of CDR as a part of the climate policy debate in its own right on Twitter.

Tweets that mention terminology related to specific CDR methods – such as afforestation/reforestation, coastal wetland (blue carbon) management, BECCS and DAC(CS) (see Box 4.3 for the full set) – account for about 70% of tweets in our dataset.

Attention to different CDR methods varies widely. More than 70% of all method-specific tweets are about CDR methods using biological storage: soil carbon sequestration (91,000 tweets; 27%), afforestation/reforestation (81,000 tweets; 24%), and coastal wetland (blue carbon) management (75,000; 22%) are all characterised by sizeable and continuously growing Twitter conversations. The debate on ecosystem restoration (20,000 tweets; 4%) is considerably smaller but is the fastest growing among these methods.

Novel CDR methods such as BECCS and DAC(CS) have received comparatively moderate levels of attention, but the number of tweets on DAC(CS) has seen substantial growth, at an average rate of about 57% per year over the last decade. Twitter activity on DAC(CS) tripled from 2020 to 2021, mirroring rapid dynamics in DAC(CS) investments (see Chapter 3 – Innovation). Similarly to the scientific literature (see Chapter 2 – Research landscape), enhanced rock weathering and ocean alkalinisation still receive little attention.

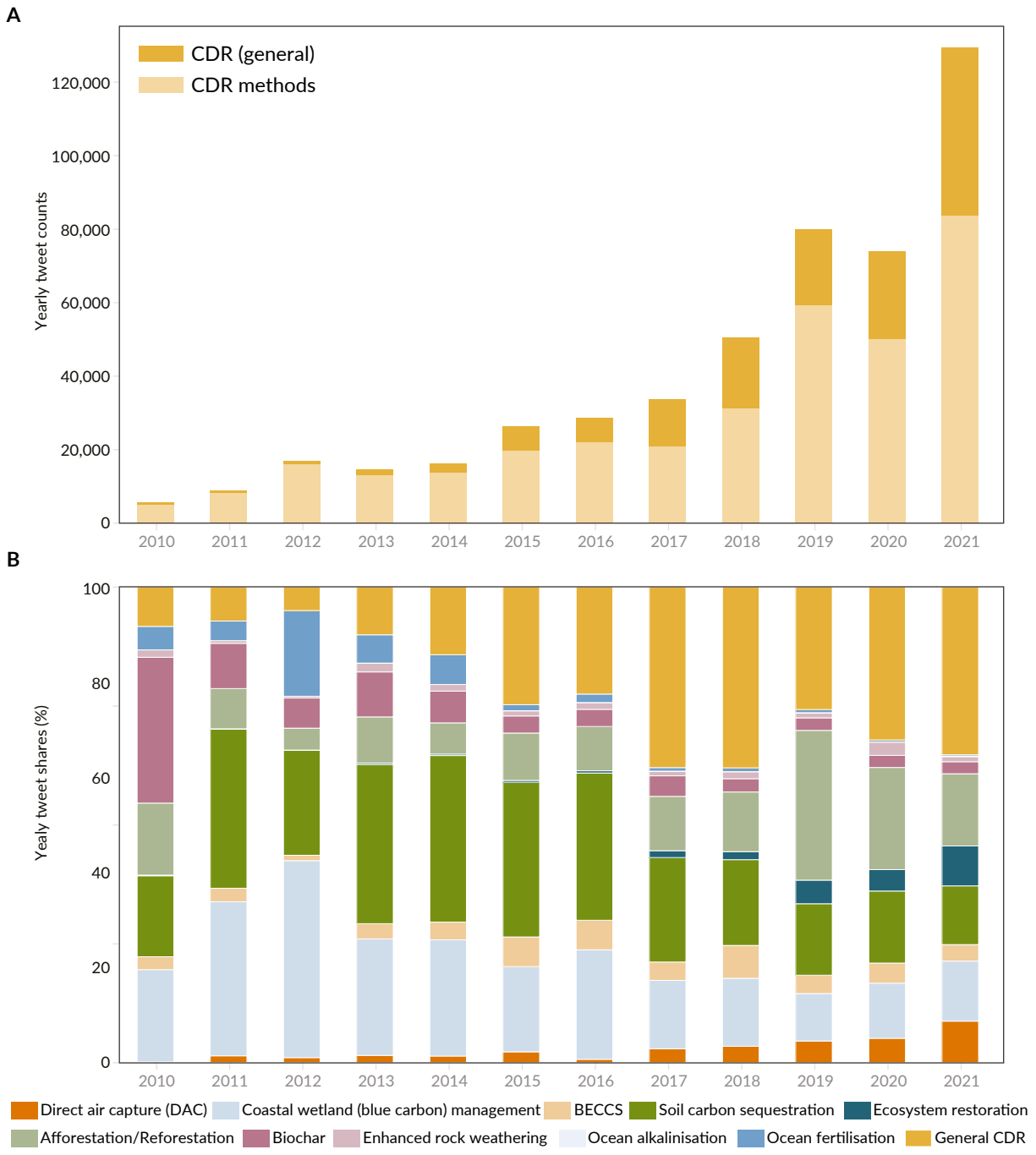

Figure 4.4. *Number of tweets per year on general Carbon Dioxide Removal (CDR) and method-specific CDR (panel A). Relative shares of overall CDR tweets by method (panel B). General CDR discussions that do not feature specific CDR methods are reported under CDR (general). Definition: Bioenergy with Carbon Capture and Storage (BECCS).*

Sentiments in tweets on CDR

The sentiment of tweets refers to whether the tone of the message is positive, negative or neutral. Sentiments do not directly reflect the stance of Twitter users towards a CDR method, for example whether they support or oppose a specific CDR method. However, sentiments reveal whether a CDR method appears more often in a rather positive or negative context.

Compared with tweets on CDR methods, a smaller share of tweets on general aspects of CDR – responding to keywords such as "carbon dioxide removal", "carbon removal" or "negative emissions" – have a neutral sentiment, and that fraction is shrinking over time. However, the shares of positive and negative sentiments remained mostly balanced until a trend towards more positive sentiments emerged over the last three years (2019-2021), perhaps pointing toward an increasingly favourable framing of CDR on Twitter.

Tweets on individual CDR methods feature higher shares of positive than negative sentiments, except for ocean fertilisation. Ocean iron fertilisation is discussed very negatively following some failed field experiments[145]. This also corresponds to widespread scepticism found both in the scientific community and in public perceptions research with regard to its effectiveness and side effects[3]. The tone of tweets on afforestation/reforestation and biochar is more positive and less negative than for other CDR methods. This is also true for enhanced rock weathering, but the small number of tweets may skew the result. Most CDR methods show trends towards more positive tweeting over time. Only for BECCS do we find negatively trending sentiments. This may reflect growing concerns in the public debate about associated risks, as identified in perceptions studies (see Section 4.2).

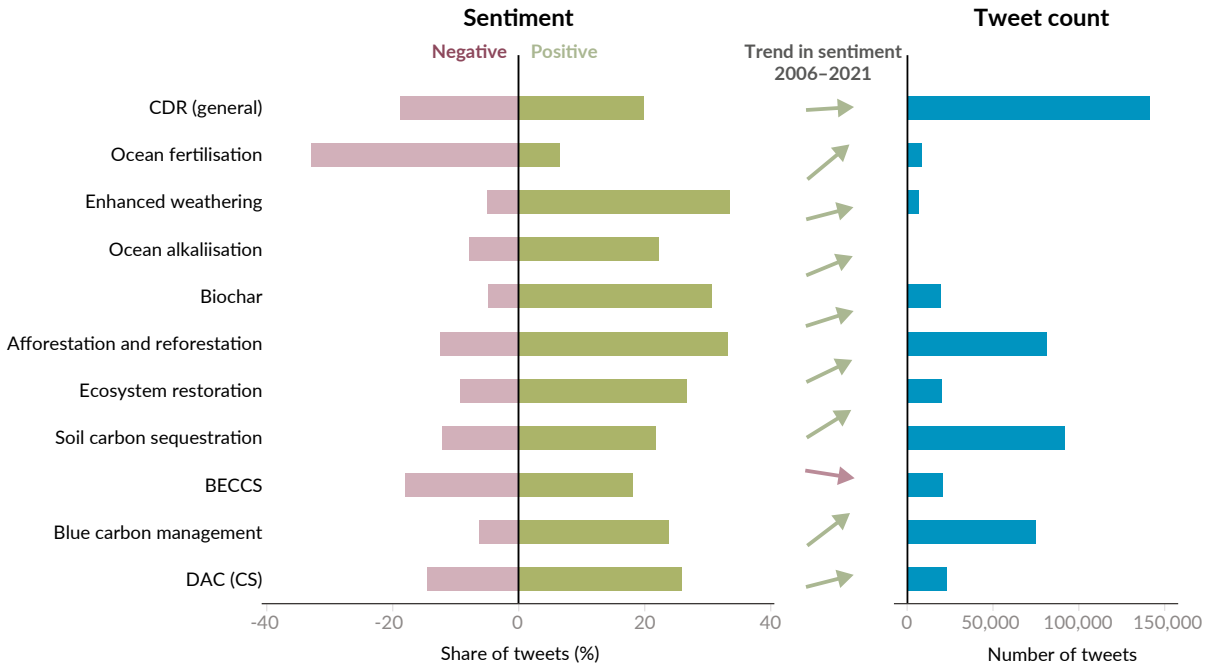

Figure 4.5. *Share of original tweets on Carbon Dioxide Removal (CDR) that express either a positive or negative sentiment (2010-2021); trends in sentiment (positive - green arrow; negative - red arrow) over time; tweet counts for different CDR methods (2010-2021). Definitions: Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Carbon Capture (DAC) and Direct Air Carbon Capture and Storage (DACCS).*

4.4 Future needs

Engaging the public with CDR requires policymakers and investors to understand the nuances of how different methods are perceived, extending beyond English-language scientific literature.

Meeting the Paris temperature goal will require maintaining carbon sinks from conventional CDR on land and most likely also substantial scaling-up of novel CDR. It is well established in the scientific literature that perceptions of CDR by investors as well as the general public can influence the speed and direction of innovation and deployment.

Our analysis here highlights that public awareness of CDR as reflected in English-language social science studies is still fairly low. This may be related to low awareness amongst policymakers, reflected in the lack of concrete plans to scale CDR in many countries and regions of the world (see Chapter 5 – Policymaking). Analysing and understanding the public debate on CDR-related issues, especially method-specific topics, is therefore critical, especially in the coming years as CDR methods are deployed in response to net zero commitments by governments and companies. There is a need to extend the analysis of public perceptions beyond English-language and scientific literature to further specify insights and knowledge gaps in other contexts.

Our Twitter analysis also shows that attention to CDR is growing rapidly and that these discussions feature an increasingly positive tone. Real-time tracking of public perceptions using social media platforms such as Twitter, Facebook, Reddit and other locally relevant networks could provide a sort of "early warning" system for shifts in CDR debates. However, such analysis can only contribute to robust social science alongside mixed methods approaches that generate qualitative insights in situations where participants have low prior knowledge of the investigated CDR methods. In addition, as CDR moves from research into deployment, local issues are likely to come to the fore, for instance around demonstration and scale-up projects, siting proposals, and policy implementation. This will require much more attention to spatial dynamics, perceptions of specific stakeholder groups (notably those directly involved in and affected by CDR deployments, and frontline and "fenceline" communities) and the existence of many diverse "publics".