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YSSP Report
Young Scientists Summer Program

Carbon Dioxide Removal Governance in Practice: Assessing developments in Brazil, China, India and Russia

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Approved by

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Abstract

Deliberately removing carbon dioxide from the atmosphere is an important building block of decarbonization pathways in line with the climate targets agreed in the Paris Agreement. The new ENGAGE model intercomparison project provides scenarios that aim at reducing temperature overshoot and reduce the amount of carbon dioxide removal (CDR) by avoiding global net negative emissions. To achieve global net CO_2 emissions by mid-century, however, scenarios require some regions to turn to achieve net-negative CO_2 emissions. This raises important questions about the distribution of future CDR deployment across world regions and the feasibility of CDR deployment in different societal and political contexts. In this report, we focus on Brazil, China, India, and Russia, emerging economies located in regions that are – according to the model results – expected to deploy large amounts of CDR. Our analysis is an attempt to provide a systematic analysis of how the issue of CDR is currently being addressed politically in these countries. In a second step, we start an analysis of possible explanatory factors for the differences.

We propose a two-layered analytical framework to assess CDR-readiness and possible explanatory factors for differences across the four countries. In a first step, we systematically gather empirical material to assess the level of CDR-related regulation and the stages of CDR innovation. Following a synthesis of the results, we explore possible explanatory factors for the differences we identify. By investigating factors like state capacity and innovation performance we extend the analysis beyond geophysical potentials and aim at contributing to the broader debate of socio-political and institutional feasibility of large-scale CDR in different societal and political contexts. Furthermore, the results also contribute to the emerging literature on CDR governance case studies, which is so far limited to OECD countries.

Since the research project is still ongoing, this report presents our initial findings. As the project progresses, an ongoing consultation with country experts will allow for a more detailed analysis of the cases. In addition, a more detailed operationalization of explanatory factors should allow for a more comprehensive understanding of the reasons for differences across countries. To conclude this interim report, we propose working hypotheses that could inform future work on the political and institutional feasibility of large-scale CDR deployment and on the constraining and enabling conditions for effective CDR policy and governance.

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Disclaimer

This report contains initial results on the research project "Carbon Dioxide Removal Governance in Practice: Assessing developments in Brazil, Russia, India and China" kicked-off during the virtual Young Scientist Summer Program 2021. The findings on the four case studies presented in this version are mainly based on desk research; insights from an expert consultation aiming at gathering expertise on recent developments within the countries and started during YSSP are not yet systematically included in the report. Since the expert consultation is ongoing, the report should not be read as a concluding report with final results, but rather as an interim report that outlines preliminary findings and identifies next steps for the research project.

Introduction

Achieving the climate targets agreed in the Paris Agreement requires unprecedented changes in all aspects of society (IPCC 2018). In recent years, it has become increasingly clear in the climate policy debate that emissions reductions alone will not suffice to achieve the target "limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C". Integrated assessment models (IAMs) and national decarbonization modelling indicate that carbon dioxide removal (CDR) will be needed to balance hard-to-abate emissions for achieving net zero GHG emissions and net-negative emissions in some sectors and countries thereafter (see IPCC 2018 for IAMs and e.g. (CCC 2016; European Commission 2018; Prognos, Öko-Institut, Wuppertal-Institut 2020). Evaluations of different mitigation strategies agree that to keep within reach ambitious climate goals, there are no "silver bullets", but all mitigation options will be needed (Warszawski et al. 2021) and that all are associated with certain feasibility trade-offs (Brutschin et al. 2021)

Overall, an emerging strand of literature finds that the current generation of decarbonization scenarios faces a number of plausibility and feasibility concerns; identifying and exploring these has recently received quite some attention (Brutschin et al. 2021; Jewell and Cherp 2020; Cherp et al. 2018; F. W. Geels, McMeekin, and Pfluger 2020; Turnheim and Nykvist 2019). Since CDR struggled onto agenda of climate policymaking in the aftermath of the Paris Agreement in many countries (Schenuit et al. 2021), the feasibility concerns and trade-offs with other aspects of climate policy-making and sustainability objectives attracted attention by scientists from various disciplines (Low and Schäfer 2020; Schweizer et al. 2020; Fuss et al. 2018; Smith 2016). Large-scale CDR as an element of integrated assessment models and climate policymaking received broader attention and provoked criticism, esp. since IPCC AR5 (Beck and Mahony 2018; D. McLaren and Markusson 2020). Despite the criticism, there is a broad agreement that the CDR will have to play a role in decarbonization pathways towards net zero and beyond. Even scenarios that do not rely on technical options like BECCS, and instead rely more on demand side shifts, assume ecosystem-based CDR like large scale afforestation (Grubler et al. 2018; IPCC 2018)

The more attention CDR received over the years, the broader the researched portfolio of different methods became, ranging from geochemical-based methods like different processes of direct air capture plus carbon capture and sequestration (DACCS) to ecosystem-based methods like soil carbon sequestration (for an assessment of the methods and their global potentials see Fuss et al. 2018). Furthermore, more and more empirical case studies on CDR policymaking and governance emerge (e.g.

(Buylova et al. 2021; Schenuit et al. 2021; Bellamy and Geden 2019) and find the prevalent "implementation gap" (Fuss and Johnsson 2021)and "incentive gap" (Fridahl, Hansson, and Bellamy 2020) . This strand of CDR policy literature investigates constraints and enablers of governing and deploying CDR in different societal and political contexts. So far, however, this literature has been limited to Annex-1/developed countries; CDR policymaking in major emerging economies and large emitters such as Brazil, China, India, and Russia (BRIC), which are also critical to achieving a global net zero emissions, have not yet been systematically studied.

In this report, we first introduce scenarios from the ENGAGE model intercomparison (Riahi et al, under review) to identify what kind of CDR is expected to be deployed where . We then particularly focus on CDR policymaking and niche innovations in Brazil, China, India and Russia. In order to do so, we propose an analytical framework for CDR-readiness based on the level of CDR-relevant regulation and stages of CDR innovation. In a second step, we explore a number of possible explanatory factors for the differences we found across countries. Finally, we formulate a set of hypotheses derived from our study that will structure ongoing work in this project and potentially future work on the feasibility constraints of large-scale CDR and the associated constraining and enabling conditions for effective CDR governance in the future.

A short history of CDR in IAMs and climate policymaking

IAMs are energy-land-economy models used to project different decarbonization pathways under different socio-economic developments (Kriegler et al. 2021). The Integrated Scenario Framework combines representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs) and bridges the physical climate science and IAMs (O'Neill et al. 2014; 2020; Riahi et al. 2017)and developed into a key building block of IPCC assessment reports and policy-relevant climate science more generally (Cointe, Cassen, and Nadai 2019).

Efforts to integrate deliberate carbon removal into IAM scenarios date back to the early 2000s (Obersteiner et al. 2001). With the IPCC's AR5 and the large amount of CDR required in the assessed scenarios to stay below the 2°C target, the more technical debate has expanded from a small community of scientists to commentary in leading science journals (Fuss et al. 2014; Geden 2015; Anderson and Peters 2016). While policymakers were reluctant in picking up the issue (Geden, Peters, and Scott 2019) the amount of scientific studies on CDR accelerated rapidly (Minx et al. 2018). In particular, in the run-up to IPCC's Special Reports on 1.5°C Global Warming (IPCC 2018) and Climate Change and Land (IPCC 2019), research communities worked on refining the knowledge about the geophysical and techno-economic availability of CDR, including its limits if sustainability goals are taken into account (e.g. Roe et al. 2019; Smith et al. 2019; Holz et al. 2018; van Vuuren et al. 2018).

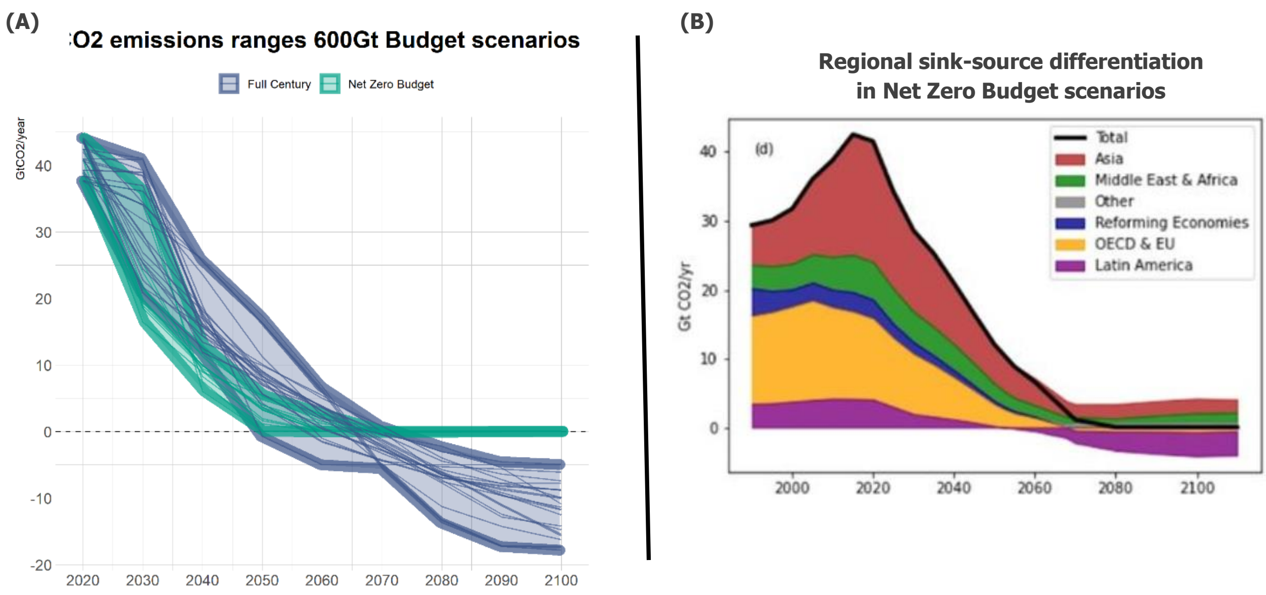
The rapidly growing importance of CDR also in current climate policy (Geden and Schenuit, n.d.)has been criticized in recent years. Two main criticisms have been raised in the ongoing debate: first, the sustainability trade-offs of certain CDR methods, particularly BECCS and afforestation. The main concerns include food security due to the amount of land required (IPCC 2019) and water resources needed to grow large amounts of biomass (Ai et al. 2021). Second, scientists have identified a moral hazard associated with CDR. They argue that the adoption of large-scale CDR allows climate mitigation efforts to be deferred due to modeling of a speculative technology (Anderson and Peters 2016).

Politically, this could lead to a "mitigation deterrence" (D. P. McLaren et al. 2019) or an "mitigation obstruction" (Morrow 2014), i.e., a situation where political pressure to reduce emissions decreases because CDR is expected to offset emissions.

IAMs reacted to the critique of large amounts of CDR and esp. of BECCS in two ways: First, by efforts to model a portfolio of CDR methods reduce the reliance on BECCS (for some examples, see: (Bistline and Blanford 2021; Fuhrman et al. 2019; Strefler et al. 2021; Hanna et al. 2021). Furthermore, studies on potentials of different CDR methods help inform the debate of which CDR method has highest potential where and what specific co-benefits and trade-offs in the energy, land or other sectors are to be expected. This knowledge will be vital for future modeling and is expected to become increasingly policy-relevant in actual policy instruments aiming at operationalizing net-zero pledges in the coming years.

Secondly, models developed new sets of scenarios that deliberately reduce the reliance on CDR. The ENGAGE model intercomparison (Riahi et al., under review) provides a new set of scenarios that does not allow global net-negative CO_2 emissions in scenarios and therefore avoid large temperature overshoots and reduce the reliance on CDR (see Figure 1a). Riahi et al. show that these scenarios require a more rapid near-term transformation but provide long-term gains for the economy (Riahi et al, under review). Even though the amount of CDR is limited in the net zero budget scenarios of the model intercomparison, the decarbonization pathways still require substantial amounts of CDR to balance residual emissions from some sectors in some world regions (see Figure 1b). According to the scenarios, globally, the Agriculture, Forestry and Other Land Use (AFOLU) and energy supply sectors will have to act as net-sinks to balance hard-to-abate emission from transport, industry and industrial processes and other sectors. Regionally, Latin America and the OECD & EU are expected to provide net-negative emissions to balance emissions mainly from Asia and the Middle East and Africa (Riahi et al., under review).

Figure 1: Global CO_2 emissions in scenarios from ENGAGE model intercomparison, 600Gt CO_2 budget; (Riahi et al, under review)

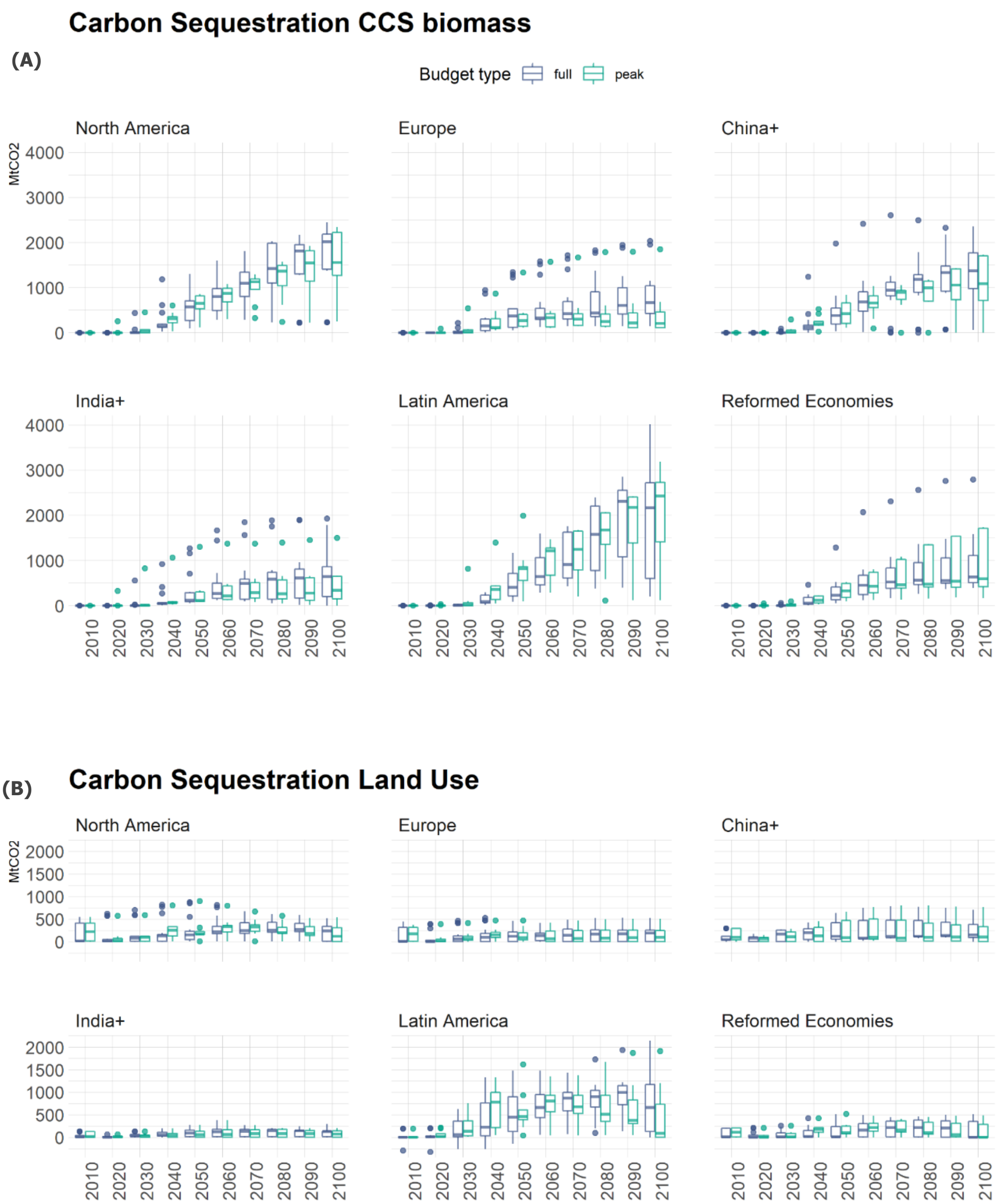


The regional differentiation raises the question where the scenarios expect the deployment. To do so, we explore what role CDR plays in decarbonsation pathways of different world regions. Figure 2a shows the amount of land carbon sequestration and Figure 2b the amount of BECCS deployed across six different world regions (North America, Europe, China+, India+, Latin America, and Reformed Economies) for ENGAGE scenarios with a 600Gt CO_2 budget. We chose this set of regions to provide a first overview of the role for CDR in developed and developing countries, with a specific focus on regions where BRIC countries are located.

It is important to highlight that these scenarios indicate opportunities for mitigation from economic perspective and do not consider political feasibility (Riahi et al, under review). The model intercomparison as well as other projects aiming at exploring where large amounts of CDR might be deployed highlight explicitly that political, institutional and social challenges of different CDR methods in different societal contexts are not yet part of the modelling (see also Strefler et al. 2021; Schweizer et al. 2020; Fuss et al. 2020). In order to grasp prospects of CDR deployment and its availability assessments should consider these feasibility concerns of CDR and - especially in a bottom-up and polycentric climate regime, where new importance is given to national and sub-national efforts in climate action.

Figure 2 – Carbon dioxide removal deployment across six regions

Scenarios from ENGAGE model intercomparison with 600Gt CO_2 budget; with green colour indicating scenarios with peak budget (Global Net Zero) and purple full century budgets, see (Riahi et al, under review)



Towards an analytical framework to assess CDR-readiness

With the acknowledgement that CDR will be required to achieve climate targets, social science scholars turned to the question how carbon removals are currently and will be governed in different countries. We observe an increasing amount of conceptual papers on CDR policy and governance as well as in-depth case studies and comparative work (Honegger et al. 2021; Buylova et al. 2021; Fridahl, Hansson, and Bellamy 2020; Thoni et al. 2020; Bellamy, Lezaun, and Palmer 2019). This knowledge provides an increasingly fine-grained understanding of actual frontrunners in regulating and incentivising CDR and what methods are addressed by decision makers so far. Building on earlier comparative work by Schenuit et al. (2021), we propose an analytical framework comprising insights from CDR governance research, socio-technical transition literature and feasibility studies. The main objectives of the proposed framework are to systematically collect empirical material that can then be used to comparatively examine the sociopolitical and institutional feasibility of CDR deployment in different political and social contexts.

However, this approach also has its limitations. Large-scale CDR to achieve climate goals has only recently entered the climate policy debate, and policy and deployment initiatives are at a very early stage. So far, CDR is often only implicitly regulated and explicit CDR governance has only recently emerged. For this reason, it was challenging for this study to find comparable indicators and data sources across countries. However, we think that a first attempt at a systematic comparison is worth the effort. Not only because of the importance of CDR for future climate policy, but also because the initial attempts should stimulate future research aimed at revising the concepts and indicators used here.

A two-layered approach to assess CDR-readiness

In order to explore the state of CDR governance and its future prospects systematically, we draw on the conceptual work on socio-technical transitions for deep decarbonization (Geels et al. 2017). The influential work on Multi-Level Perspective on socio-technical transitions, is regarded as a promising tool to bridge social science and integrated assessment modelling (Geels, Berkhout, and van Vuuren 2016; F. W. Geels, McMeekin, and Pfluger 2020; van Sluisveld et al. 2020; Turnheim et al. 2015). Key idea of the concept is that in transition processes internal and external forces pressure the existing system, or incumbents (Geels et al. 2017). Scholars distinguish between three different levels (socio-technical landscape, socio-technical regime; niche innovations) that help to conceptualize and identify existing pressures.

If we consider the upscaling of CDR as one sociotechnical transition in the overall transition to deep decarbonization, we can argue that the sociotechnical landscape as an exogenous context has changed significantly since the adoption of the Paris Agreement, the IPCC's SR15, and the wave of net-zero pledges since then. As described above, the issue of CDR was not new to either scientists or specialized policymakers, but the new climate policy paradigm of the net-zero pledge, which requires all remaining emissions to be offset by carbon removals by about 2050, has put CDR on the agenda of the broader climate debate and on the policy priorities of climate policymakers (Geden 2016).

Following this line of reasoning, we need to examine what is happening at the other two levels to understand ongoing CDR developments and their prospects. First, the level of the *sociotechnical regime*, including CDR-related existing sociotechnical systems, the position and actions of incumbents with respect to CDR, and current climate policies. Second, the *niche innovation* level, which examines the entry and exit of new innovations and trial-and-error processes, adoption and market acceptance, and learning, improvement, and support of CDR methods. To assess the two levels, we propose two sub-frameworks that allow for systematic coding of each country. In both frameworks, the methodological approach consists of a first phase of desk research and coding in which we considered policy documents such as NDCs, long-term strategies, national climate policymaking, scientific publications and grey literature; in a second step, a set of country experts is consulted - a process that is currently still ongoing - and the results are considered in a second round of coding. Coding is conducted separately for land-based and technology-based CDR.

Building blocks of comprehensive CDR policymaking: Assessing CDR-related governance

To systematically assess the extent to which and how countries already regulate CDR through CDR-specific and CDR-relevant policies, we identified key building blocks of a comprehensive CDR policy. Based on a literature review of emerging research on CDR policy - both empirical case studies aimed at tracking and comparing CDR policies and conceptual work (Honegger et al. 2021; Buylova et al. 2021; Fridahl, Hansson, and Bellamy 2020; Thoni et al. 2020; Bellamy, Lezaun, and Palmer 2019) - we propose to distinguish between the following six elements, ranging from nonspecific and only implicit policies (1) to very specific and explicit policies (6). There are, of course, more facets and elements to CDR policy than these six building blocks, but conceptually narrowing the complex policy landscape to six elements helps track and compare CDR policies across countries. These elements may change in the future as CDR policy becomes well established and CDR becomes widespread; however, based on our literature review, we assume that these are the relevant building blocks at this time. Table 1 illustrates the building blocks and provides brief examples for each of them.

Table 1: Building blocks of CDR policymaking and illustrative examples

Building block	Example
(1) CDR-relevant accounting practices	An afforestation project generates 'credits' and helps achieve climate mitigation targets.
(2) R&D activity-oriented subsidies/incentives	Public or private financed monetary incentives for CDR-related R&D
(3) Mitigation results-oriented subsidies/incentives	Financial remuneration for removing carbon (direct payment, tax credit, etc.)
(4) CDR-related regulatory mandates • for tech-CDR: CCS legislation	Obligations to remove a certain amount of carbon, e.g to secure climate neutrality targets. Regulation that allows/forbids transporting and storing CO_2 underground

(5) explicit and legally-binding removal target	A quantified removal target as part climate policy (in addition to reduction targets.)
(6) fully-fledged carbon pricing incl. removals	Emission Trading Scheme or other carbon pricing that includes trading credits generated through CDR.

Stages of CDR innovation: developments in niches and & market uptake of CDR methods

Second, we want to assess at which stage CDR innovations are in different countries. Nemet et al. (2018) have conducted a literature review and show that although actual innovation processes are complex and not necessarily linear, the concept of "innovation stages" is informative in identifying which stage specific CDR innovations are in. Gathering empirical material on these different phases of CDR innovation makes it possible to track the entry and exit of new innovations, as well as the dynamics of trial and error. It also helps to trace processes of learning, improvement, and support for specific innovations (Geels et al. 2017) in different social and political contexts (see Table 2 for the five different phases). While the original concept includes a sixth dimension of public acceptance, in our study we limit ourselves to the first five. The reason for this is the lack of comparable data for the countries analyzed here and the fact that analyzing public acceptance of CDR methods is generally challenging (for a discussion of these challenges and initial results for the UK and the US, see Cox et al. 2020). Table 2 illustrates the stages and provides brief examples for each of them.

Table 2: Stages of CDR innovation and illustrative examples

Building block	Example
(1) R&D	Public or private research funding dedicated to CDR methods.
(2) Demonstrations	Public or private funding and implementation of CDR demonstration projects.
(3) Scale-up: deployment of CDR projects	Initiatives to scale up deployment of specific CDr methods
(4) Voluntary/niche markets	Markets for trading credits generated through CDR deployment.
(5) Demand-pull	Established demand-pulls, e.g. through corporate commitments or net-zero regulation

Why do countries differ? Exploring possible explanatory factors

While on the one hand we are interested in assessing CDR-readiness in this group of countries, on the other hand we want to explore possible explanations for why countries approach CDR in different ways. Current research on CDR governance has increasingly tracked developments in different countries, but we have limited insights into the reasons for these significant differences. Starting this debate and conducting initial research has the potential to identify constraining and enabling conditions for effective CDR governance. This knowledge could be critical to better understanding the future availability and feasibility of large-scale CDR in different social and political contexts. Table 3 illustrates the explanatory factorss and provides a brief description and the metric and data source used.

Table 3: Overview and description of explanatory factors

Explanatory factor	Description	Metric and data source
Potential land-based CDR	Assessment of potential for land-based carbon sink enhancement, incl. afforestation/reforestation; forest management; peatland restoration; agriculture soil carbon sequestration.	land-based mitigation potential, carbon sink enhancement in 2020–2050 [in $MtCO_2e$/yr]; Roe et al. (2020)
Potential CCS-based CDR	Data on CCS potentials in different countries used as a proxy to compare available potentials for permanent geological sequestration that could be used for CCS-based CDR methods.	CCS potential, i.e. lower and upper estimate of estimated storage capacity [in Gt CO_2];Kearns et al. (2017)
Net zero emissions ambition	Systematic analysis of latest net zero pledges by each country. Based on official policy documents or legislation and their analysis based on 10 guidelines for high quality net zero targets.	"Gold Standard for net-zero targets": Rogelj et al (2021); coded as low, medium, high
State capacity Government effectiveness (GE) Regulatory Quality (RQ)	Using government effectiveness (GE) and regulatory quality (RQ) data as a proxy for the capacity of a specific state to adopt and implement specific policies. GE includes perceptions of the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies. RQ includes perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.	World Bank 2021: Worldwide Governance Indicators [rank, average 2016-2020]

Global Innovation Index	To capture different environments for innovation, the Global Innovation Index is used to compare countries. The index uses a broad notion of innovation and includes input pillars that capture elements of the economy that enable and facilitate innovation and output pillars which include results of innovative activities.	WIPO 2021: Global Innovation Index [average reports from 2017-2021]

In the following, we discuss the methodological challenges with each of these indicators and highlight why we chose this selection factor and the corresponding data sources. First, the potential for different CDR methods. For both land-based and CCS-based CDR, scientists are currently working to specify the geophysical potential for different CDR methods at different sites (for an overview, see Fuss et al. 2018 and XX for the latest analyses on different methods). However, no global dataset with geophysical potentials for different methods in different regions is available yet. We therefore selected two data sources that can be considered as approximations of the total potential of land- and technology-based CDR. For land-based CDR, we selected Roe et al. (2020) as the underlying data source because the research team combined a review of modeled pathways and the literature on mitigation strategies to conduct a bottom-up assessment of mitigation potential in different countries. Their data on mitigation strategies, grouped under the term "carbon sink enhancement," includes key land-based CDR methods such as afforestation/reforestation, forest management, peatland restoration, and soil carbon sequestration through agriculture. The potentials identified for this subcategory of land-based mitigation strategies are therefore a useful guide to land-based CDR in the various countries studied here. Less specific is what is known about technology-based CDR potentials, for which there is not yet a systematic and comparative analysis for the countries studied here. We therefore use the CCS potentials identified by (Kearns et al. 2017)). Although CCS as such is not a CDR method, key technology-based CDR methods such as BECCS and DACCS rely on the storage of CO_2 in geological formations. Therefore, the available potentials indicate the geophysical limitations of CCS-based CDR and are a proxy for technology-based CDR, but should not be overinterpreted.

The inclusion of *net-zero target ambition* in this set of factors is important because, in many countries, as argued above, it is the adoption of a net-zero target that facilitates the acknowledgement that CDR will be required to offset remaining emissions and meet the target. To capture the complexity and ambiguity inherent in net-zero targets, we apply an analysis of these countries' current net-zero pledges based on the gold standard for net-zero targets proposed by Rogelj et al. (2021). Although it is not possible to capture all the details and differences of the targets, especially when it comes to the legal and political status in different countries, it helps to compare the specificity and overall quality of the different pledges. Based on an analysis guided by the proposed ten elements that a credible net-zero target would need to include (Rogelj et al. 2021), we code the ambitions as low, medium, or high.

Recent literature on the multi-dimensional feasibility of decarbonization pathways (Brutschin et al. 2021)finds that political and institutional feasibility are key factors for these transitions (see also (Jewell and Cherp 2020; Cherp et al. 2018). Following on from this strand of literature, we propose to examine the *state capacity* of our cases by comparing their state capacity. We operationalize this factor by comparing the indicators of government effectiveness and regulatory quality published by the World Bank in its Worldwide Governance Indicators (WGI). The dataset is based on the views of businesses, citizens, and surveyed experts in developed and developing countries, and includes data from 1996 onward. Because we are primarily interested in the ability of a given state to adopt and implement

CDR-related policies, we focus on government effectiveness and regulatory quality, leaving aside the other four indicators (voice and accountability, political stability and absence of violence/terrorism, rule of law, control of corruption).

Since most CDR methods are at early stages of innovation processes (Nemet et al. 2018), we argue that it is also informative to compare the overall *innovation performance* of different countries. To this end, we use the Global Innovation Index, which provides a snapshot of the state of innovation across countries. One consists of five input pillars that capture elements of the economy that enable and facilitate innovative activities, and the other consists of two output pillars that represent the outcome of innovative activities within the economy (for details on the methodology, see (WIPO 2020)).

We also identified two other potentially relevant factors that are not yet part of this analysis but will be included in the next steps of specifying the analysis of explanatory factors in the ongoing research project: First, the current amount of CO_2 removed from the atmosphere by land sinks that are included in the LULUCF inventory. Comparing these numbers to country emissions might help provide an understanding of the importance of removals for policymakers in achieving mitigation targets. The exact operationalization and possible comparable data sources will be worked out in one of the next steps of the project. The same is true for another potential explanatory factor that we believe could improve future assessments using the framework proposed here. In the context of net-zero targets, the expected amount of residual emissions is key to CDR futures in different countries. The smaller the expected residual emissions, e.g., because agriculture or other hard-to-target sectors are comparatively small, the less CDR is needed in addition to conventional mitigation strategies. Therefore, a more advanced analysis of explanatory factors should also consider residual emissions.

Interim results for Brazil, China, India and Russia

Before we discuss the initial results based on a first round of desk research, we highlight important key data on the countries. Table 4 summarizes the indicators of population, surface area, GDP, GDP per capita, GHG emissions and GHG emissions per capita. The overview indicates how different the countries of the case selection are - not only in terms of size and economic strength, but also in terms of GHG emissions. Despite the significant differences, they form a group of countries that will play a key role on the path to decarbonization, not only in terms of emissions, but also politically, as all four countries are seen as very important players in international climate negotiations, with cooperation emerging between them as a group (Prys-Hansen et al. 2019; Downie and Williams 2018).

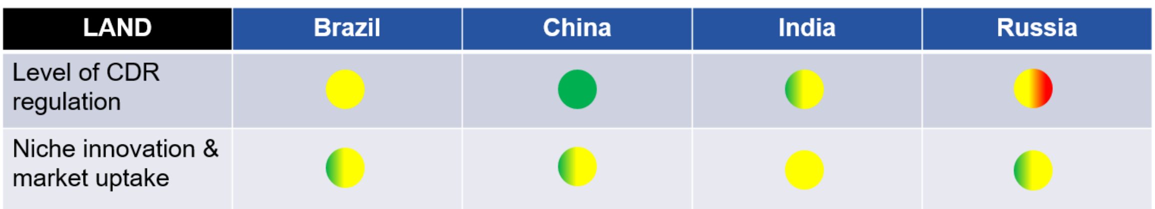
Table 4: Overview of key characteristics of four cases

Building block	Brazil	China	India	Russia
population (millions)	212.56	1,402.11	1,380.00	144.10
surface area (sq. km, thousands, 2018)	8,515.8	9,600.0	3,287.3	17,098.3
GDP (current US$, billions)	1,444.73	14,722.73	2,622.98	1,483.50
GDP/capita (current US$)	6,796.8	10,500.4	1,900.7	10,126.7
GHG emissions Global Carbon Project, 2019	465.71577	10174.6811	2616.44882	1678.36679
GHG emissions/ capita	2.206666	7.096385	1.914823	11.50573

Interim results of assessing "CDR-readiness" for land-based CDR

In order to provide a systematic assessment of each country, we first assessed the building blocks of CDR policymaking to identify the level of CDR-related regulation. We then assessed the stages of CDR innovation to explore the niche innovation and market uptake of CDR for land-based CDR in the four case study countries. The results of our analysis are summarized in Figure 3, which summarizes the coding (see Appendix 1) and translates it into a traffic light scheme, with green indicating higher CDR-readiness and red indicating lower readiness.

Figure 3: Assessment results for "CDR-readiness" for land-based CDR



In our initial assessment we identify quite substantial differences across the countries. The level of land-based CDR regulation is the highest in China, where the recently established emission trading scheme allows the use of 5% offsets for yearly compliance. For these offsets, only forestry-based Chinese Certified Emissions Reductions (CCER) can be used, other types of CDR methods are not yet applicable (Shrestha et al. 2021). China and India have in common that they have specific land-based removal targets in their first NDCs[1] and enacted policy instruments to enhance afforestation and reforestation in the past. The latter is also true for Brazil, where projects like Floresta+ produce forest carbon credits[2]. In Russia, the level of land-based CDR regulation is lower. While the issue has been increasingly taken up in recent policy initiatives in specific regions[3] and at higher political levels[4], concrete policy instruments do not yet exist.

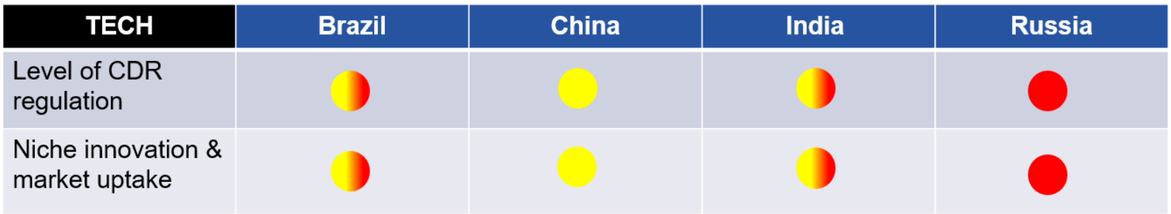
In terms of stages of innovation, the differences are less pronounced. Since afforestation and reforestation have been practiced for a long time, the differences in innovation levels are due to the variations in whether afforestation is certified as specific certificates and whether those are tradable in voluntary or niche markets. In Brazil and Russia voluntary markets are established[5]. The same is true in China (Zhou, Gong, and Gao 2017), but – as mentioned earlier – the ETS also allows for trading certified removals from forests. In China and India, where preparations to adopt net zero targets are traceable[6], observers from our expert consultation identify an increasing interest by private corporations in land-based removal credits. It is reasonable to assume that setting these targets would establish or strengthen a demand pull for land-based CDR.

Interim results of assessing "CDR-readiness" for technology-based CDR

In a similar way, we assessed the CDR-readiness for technology-based CDR methods. Like for land-based CDR, Figure 4 summarizes our findings for technology-based CDR and translates them into a traffic light scheme (see Annex 1 for details).

[1] See UNFCCC NDC registry: https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx.
[2] For a description of the program and the voluntary market, see: https://www.biofilica.com.br/en/launch-programa-floresta-and-voluntary-carbon-markets/
[3] See brief description on UNFCCC website: https://unfccc.int/news/russia-s-far-east-in-race-to-net-zero-emissions and official statement (in Russian) here: https://economy.gov.ru/material/file/faf1abaae1e3f2be140971c9e934d0ab/dorozhnaya_karta.pdf.
[4] See analysis by BELLONA on the recent legislative initiative to adopt a law aiming at limiting greenhouse gases: https://bellona.org/news/climate-change/2021-06-russian-parliament-adopts-law-aimed-at-limiting-greenhouse-gasses.
[5] See: https://www.biofilica.com.br/en/launch-programa-floresta-and-voluntary-carbon-markets/ and https://unfccc.int/news/russia-s-far-east-in-race-to-net-zero-emissions.
[6] For China, see statement by Xi Jinping at UN General Assembly, 21.09.2021: https://estatements.unmeetings.org/estatements/10.0010/20210921/AT2JoAvm71nq/KaLk3d9ECB53_en.pdf; for India, see recent developments in 2021: https://www.hindustantimes.com/india-news/world-environment-day-what-we-know-about-india-s-net-zero-emissions-target-101622881384730.html.

Figure 4: Assessment results for "CDR-readiness" for technology-based CDR



In our initial assessment, we find that the level of technology-based CDR regulation, as well as market uptake and niche innovations, is significantly lower compared to land-based CDR. In terms of the level of regulation, we find that none of the countries have fully implemented carbon pricing that includes technology-based carbon removal, an explicit and legally binding removal target, or CDR-related regulatory mandates. It is notable that China has the highest CCS readiness and is the only country that shows some evidence of mitigation results-based subsidies/incentives to reduce emissions[7]. R&D activity oriented subsidies and incentives can be identified in Brazil, China, and India. In addition, recent developments in India, similar to China, indicate renewed attention to CCS and CCUS by the administration and industry. It remains to be seen to what extent these initiatives will lead to CDR-related developments, but we observe that the topic is also moving up the agenda in India[8]. Russia is the only country where we did not identify any relevant initiatives. In our initial assessment, we did not identify specific accounting rules for technology-based CDR; existing accounting focuses on land-based CDR. For the niche innovation and market adoption dimension, we did not identify demand-side, voluntary, or niche markets, nor scaled adoption of these CDR methods in a single country. China is the only country where we identified explicit technology-based CDR demonstrations. Russia is the only country where we found no evidence of related R&D.

Assessing explanatory factors and crafting hypothesis: A preliminary comparison across cases

Since we find significant differences across countries and across CDR methods, we now turn to the next step, the analysis of the explanatory factors identified above (see Section 3.4). It is important to note that the list of factors analyzed here is not intended to be a comprehensive set, but rather an initial attempt to approach the overarching question of the enabling and constraining conditions for CDR feasibility in different social and political contexts. To broaden the perspective beyond the geophysical potential for specific CDR methods, we also collected data on countries' overall net-zero ambition, their government capacity operationalized as government effectiveness and regulatory quality (World Bank 2020), and the Global Innovation Index to compare countries' overall innovation performance (GII 2021). As indicated in Section 3.4, each factor is subject to methodological pitfalls (see below). Therefore, the results should not be over-interpreted, but rather used as a hypothesis-generating practice that initiates future research on the specific cases. Table 5 summarizes the gathered data for the case studies.

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[7] See report on CCUS by the Chinese Academy of Environmental Planning, a branch of China's Ministry of Ecology and Environment: http://www.caep.org.cn/sy/dqhj/gh/202107/W020210726513427451694.pdf.

[8] For a summary of recent developments see report by Council on Energy, Environment and Water: "From a Cameo to Supporting Role in the Nation's Low-Carbon Story": https://www.ceew.in/publications/strategy-for-carbon-capture-utilization-storage-technology-in-india.

Table 5: Explanatory factors by country

Building block	Brazil	China	India	Russia
Potential land-based CDR [in $MtCO_2e$/yr]	1697	1384	573	692
Potential technology-based CDR [CCS capacity Gt]	297-2087	403-2830	99-697	1234-8673
Net zero emissions ambition	low	medium	low	low
State capacity Government effectiveness (GE) Regulatory Quality (RQ) [rank, average 2016-2020]	GE: 41.25 RQ: 45.58	GE: 69.71 RQ: 46.54	GE: 60.58 RQ: 44.90	GE: 52.31 RQ: 34.90
Global Innovation Index [average reports from 2017-2021]	33.28	53.7	35.86	37.3

The comparison of the different CDR potentials shows significant differences between the countries. In absolute terms, Brazil has the highest potential for land-based CDR at 1697 $MtCO_2e$/year, almost three times that of India (573 $MtCO_2e$/year). China's potential (1384 $MtCO_2e$/year) is slightly lower than Brazil's, but about twice that of Russia (692 $MtCO_2e$/year). The potential for CCS is distributed differently: Russia has by far the highest potential in this category (1234-8673 $GtCO_2$), followed by China (403-2830 $GtCO_2$) and Brazil (297-2087 $GtCO_2$). India has much lower CCS potential (99-697 $GtCO_2$). Compared with our assessment of CDR-readiness, it seems evident tha the potentials alone are not sufficient to explain whether and to what extent countries are addressing relevant CDR methods politically and at what stage of innovation the methods are. Particularly striking here is that Russia, despite a large CCS potential, has not yet advanced any initiatives for technology-based CDR. In addition, it is worth noting the initiatives identified in India, which have been initiated despite a much lower potential.

Our comparison of net-zero pledges shows that China currently has the most ambitious net-zero pledge in this group of countries. Of course, this pledge alone is not a sufficient explanation for the comparatively high CDR-readiness. However, initial empirical material from the expert consultation shows that even signals from the administration to prepare for a net-zero target prompted corporations and sectors to think about ways to engage in CDR. Recent reports from India suggest similar dynamics in debates about CCS, CCUS, and CDR (Ankur and Vaibhav 2021). This observation is consistent with observations from OECD countries where net-zero targets as a new organizing principle of climate policy (Schenuit et al. 2021) are drawing attention to residual emissions and leading to evolving CDR debates. A hypothesis for future work would be that the more ambitious and credible net-zero targets are embedded in climate policy, the more specific CDR policymaking is expected to be. If this hypothesis can be confirmed in ongoing work, adopting and implementing ambitious net zero targets could be regarded as an enabling condition for CDR policymaking

World Bank data on government effectiveness and regulatory quality reveal another layer of differences between countries. China performs best on both indicators, with a substantial gap over all three other countries when it comes to government effectiveness. On the regulatory quality, China is about on par with Brazil and India. While Brazil scores significantly lower on government effectiveness, Russia is about substantially behind the other three countries. Given that Russia and Brazil also scored the lowest in our assessment of CDR-readiness, we should continue research in this direction and explore the question of whether higher state capacity also improves the extent to which states address CDR in climate policy and niche innovations.

A very similar hypothesis arises from what is currently the last explanatory factor: China performs significantly better than all three other countries in the Global Innovation Index. Since China is also the country with the highest CDR-readiness, future work should also focus on whether and how effective CDR policies are enabled or constrained by the innovation ecosystem in specific countries. As noted above, this initial and cursory assessment does not claim to be comprehensive. At this stage, we cannot say much about how the various contextual conditions captured here affect CDR-readiness. However, the generation of new hypotheses and the identification of new research questions help to structure the ongoing work in this project and could spur new research on the socio-political and institutional feasibility of effective CDR policies, as well as on their constraining and enabling conditions.

Interim conclusions and next steps

Since the adoption of the Paris Agreement, the role of CDR in international and national climate policymaking changed considerably. Together with the adoption of net zero pledges, countries as well as corporations have started to address land-based and technology-based CDR as a new tool in the mitigation toolbox. From being a technical issue discussed in small science circles CDR struggled onto the climate policy agenda rapidly.

A new model intercomparison project clearly illustrates that the amount of CDR expected to be deployed in decarbonization pathways requires a rapid scale-up of removing capacities. According to the net zero scenarios with a 600Gt CO_2 budget, many regions would have to ramp up land-based CDR in this decade and technology-based starting in 2030. Our assessment of CDR-readiness in Brazil, China, India and Russia, a group of countries that has so far not been studied in the emerging literature on CDR governance and policymaking but is expected to deploy large-scale CDR in the future, reveals that comprehensive CDR policymaking and governance is lacking, for land-based and technology-based.

Our preliminary findings suggest that all countries already regulate land-based CDR to some extent. However, most of the initiatives identified in the case studies address CDR implicitly rather than as part of an explicit mitigation strategy integrated into climate policy. For technology-based methods, we observe very limited efforts to regulate CDR. However, evolving net-zero emissions targets in China and India are spurring new initiatives for these options. These initiatives often relate to CCS and CCUS, not necessarily CDR options in itself. But in this context, national modeling efforts, other scientific reports, and policy initiatives are starting to address key elements of CDR technologies such as direct air capture and the combination of bioenergy and CCS. Despite these recent developments, we generally find that the policy feasibility of CDR has been very limited to date. To implement CDR at scales anticipated in IAMs, countries would need to increase their efforts to develop effective CDR policies substantially.

Our exploration of possible explanatory factors showed that geological potential alone is not sufficient to explain how and to what extent CDR is addressed politically. Discussion of net-zero ambition, state capacity, and innovation performance helped to hypothesize the role these contextual factors might play in constraining or enabling higher levels of CDR-readiness. Thus, by linking our initial findings to the broader academic literature on the feasibility of decarbonization pathways, we can support that a closer look and better understanding of context-specific political and institutional feasibility is key to the discussion on scaling up CDR and achieving climate goals.

However, in order to obtain robust and well-founded results, the research project will be continued. In particular, the results of the expert consultation are to be integrated more systematically into the empirical findings. In addition, the analysis of the explanatory factors needs to be deepened, among other things by refining the operationalization of the individual factors, checking for possible overlaps and investigating further relevant factors that could help explain the differences between the countries.

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Annexes

Overview binary codings of CDR-readiness

Land-based

level of CDR-related policymaking

LAND	Brazil	China	India	Russia
(1) CDR-relevant accounting practices	y	y	y	y
(2) R&D activity-oriented subsidies/incentives	n	y	y	n
(3) Mitigation results-oriented subsidies/incentives	y	n	n	y
(4) CDR-related regulatory mandates	y	y	n	n
(5) explicit and legally-binding removal target	n	n	y	n
(6) fully-fledged carbon pricing incl. removals	n	y	n	n

stages of innovation

LAND	Brazil	China	India	Russia
(1) R&D	y	y	y	y
(2) Demonstrations	y	y	y	y
(3) Scale-up: deployment of CDR projects	y	y	y	y
(4) Voluntary/niche markets	y	y	n	y
(5) Demand-pull	n	n	n	n

Technology-based

level of CDR-related policymaking				
TECH	**Brazil**	**China**	**India**	**Russia**
(1) CDR-relevant accounting practices	n	n	n	n
(2) R&D activity-oriented subsidies/incentives	y	y	y	n
(3) Mitigation results-oriented subsidies/incentives	n	y	n	n
(4) CDR-related regulatory mandates	n	n	n	n
(4a) CCS-readiness	medium (43)	medium (54)	low (26)	low (30)
(5) explicit and legally-binding removal target	n	n	n	n
(6) fully-fledged carbon pricing incl. removals	n	n	n	n

stags of innovation				
TECH	**Brazil**	**China**	**India**	**Russia**
(1) R&D	y	y	y	n
(2) Demonstrations	n	y	n	n
(3) Scale-up: deployment of CDR projects	n	n	n	n
(4) Voluntary/niche markets	n	n	n	n
(5) Demand-pull	n	n	n	n