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TOPICAL REVIEW

What influences the implementation of natural climate solutions? A systematic map and review of the evidence

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Abstract

Emerging research points to large greenhouse gas mitigation opportunities for activities that are focused on the preservation and maintenance of ecosystems, also known as natural climate solutions (NCS). Despite large quantifications of the potential biophysical and carbon benefits of these activities, these estimates hold large uncertainties and few capture the socio-economic bounds. Furthermore, the uptake of NCS remains slow and information on the enabling factors needed for successful implementation, co-benefits, and trade-offs of these activities remain underrepresented at scale. As such, we present a systematic review that synthesizes and maps the bottom-up evidence on the contextual factors that influence the implementation of NCS in the peer-reviewed literature. Drawing from a large global collection of (primarily case study-based, $N = 211$) research, this study (1) clarifies the definition of NCS, including in the context of nature-based solutions and other ecosystem-based approaches to addressing climate change; (2) provides an overview of the current state of literature, including research trends, opportunities, gaps, and biases; and (3) critically reflects on factors that may affect implementation in different geographies. We find that the content of the reviewed studies overwhelmingly focuses on tropical regions and activities in forest landscapes. We observe that implementation of NCS rely, not on one factor, but a suite of interlinked enabling factors. Specifically, engagement of indigenous peoples and local communities, performance-based finance, and technical assistance are important drivers of NCS implementation. While the broad categories of factors mentioned in the literature are similar across regions, the combination of factors and how and for whom they are taken up remains heterogeneous globally, and even within countries. Thus our results highlight the need to better understand what trends may be generalizable to inform best practices in policy discussions and where more nuance may be needed for interpreting research findings and applying them outside of their study contexts.

1. Introduction

It is estimated that natural climate solutions (NCS)—carbon sequestration activities that focus on the 'protection, restoration and sustainable management of terrestrial and coastal ecosystems and landscapes'—have the potential to provide a third of emission reductions needed to keep global temperature rise below 2 °C (Griscom *et al* 2017). However, an understanding of how, if, and where these potentials can be met and with what trade-offs and co-benefits remains underresearched (IPCC 2019). As such, attention is shifting to the need for more information and data on the feasibility of NCS activities, in particular at the country-level and lower (Brancalion *et al* 2019, Chazdon *et al* 2020, Lamb *et al* 2021, Roe *et al* 2021).

In addition, the dynamics of implementation at scale remain unclear. Local stakeholders—including communities, companies, and governments—have an important role to play in protecting and restoring forests and natural ecosystems (Ostrom 2009, Mansourian 2016, Seymour 2020). For example, is there buy-in from these actors for these activities? What does the political economy look like? Even with stakeholder support—what kind of information and finance is needed, and is it accessible? Many questions regarding NCS are analogous to concerns that have been faced in Reducing Emissions from Deforestation and forest Degradation[4] (REDD+) efforts. Evidence from experiences implementing REDD+ provide a useful bridge for discussions regarding NCS. For example, research indicates that there has been some progress in advancing REDD+ objectives, but transformational change remains limited because necessary factors to operationalize REDD+, such as strong leadership and finance, remain weak (Korhonen-Kurki *et al* 2019). Communities are intended implementers and beneficiaries of REDD+, but this has not been reflected on the ground (Duchelle *et al* 2018, Skutsch and Turnhout 2018). Additionally, designing REDD+ with incentive-based conservation challenges and other environmental goals in mind has led to mixed results due to conflicts with political and societal priorities and, as such, low political and social feasibility (Rosa Da Conceição *et al* 2018)[5].

Furthermore, there has been a growing trend towards harnessing nature to implement the Sustainable Development Goals, including as a climate solution, while recognizing nature alone is not enough (Anderson *et al* 2019, Smith *et al* 2019). There is a clear need to understand the evidence base that exists around implementation, to more effectively communicate this information to decision makers and stakeholders, and to identify and address key knowledge gaps (Malhi *et al* 2020, Walsh *et al* 2021). In addition, it is important to understand how nature can realistically contribute to climate targets, including what types of activities lead to what outcomes (e.g. avoided emissions vs. removals). This is increasingly important given the urgency of climate change mitigation and as more attention is given to NCS in debates around voluntary carbon markets, emissions trading systems, and climate ambition[6].

This study contributes to the global assessments and evidence on the role of nature for climate change mitigation. Although individual studies and reviews have investigated implementation of NCS activities on local levels (Hoang *et al* 2019, Huang *et al* 2019, Uisso *et al* 2019), this synthesis is a first attempt to provide a broad assessment of implementation that can inform further research and policy directions. This is particularly valuable for informing meso-scale planning and designing non-quantitative indicators for monitoring NCS, such as when setting national targets and extrapolating insights from specific case studies may present biases due to heterogeneity within the country. Furthermore, this study contributes to an emerging research field to advance the implementation of NCS by complementing recent publications on the potentials, costs, and feasibility of NCS (Griscom *et al* 2020, Roe *et al* 2021). Finally, it develops a comprehensive and in-depth database that can facilitate a move towards more normative research (Nielsen *et al* 2019), for example, by highlighting key research questions and validating or challenging widely held assumptions and narratives around the potential of NCS, the current discourse and state of research, and the realities on-the-ground.

Specifically, we (1) clarify the definition of NCSs, including in the context of nature-based solutions (NbS) and other ecosystem-based approaches to addressing climate change; (2) present a systematic mapping and review of the literature on NCS implementation; and (3) reflect on characteristics of NCS that are relevant to designing and implementing socially just solutions and achieving long-term positive change.

2. Defining natural climate solutions

Researchers frequently encounter new terms and ideas. These are often integrated in policy, including high-level agreements and conventions. Translating these into action and ensuring they are implementable requires a common understanding of what these terms mean in science, policy, and practice (Star and Griesemer 1989, Brand and Jax 2007, Abson *et al* 2014).

'Natural climate solutions' is a subset of the umbrella concept of 'nature-based solutions'. NbS are defined by the International Union for Conservation of Nature as 'actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham

[4] The full definition of REDD+ is 'reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries.'

[5] REDD+ safeguards, also known as the Cancun safeguards, were introduced in 2010 at the 16th Conference of the Parties to the United Nations Framework Convention on Climate (COP16) to ensure that a broader set of issues (e.g. transparency, participation, biodiversity) are taken into account during REDD+ implementation.

[6] Responding to a call from over 70 countries, the United Nations has even proclaimed a 'Decade on Ecosystem Restoration' starting this year that will run through 2030 (UNGA 2019).

Table 1. Examples of references to natural climate solutions in policy and academia.

	Author	Source	Definition or reference
Policy briefs	The Nature Conservancy	Website	'Natural climate solutions are conservation, restoration and improved land management actions that increase carbon storage or avoid greenhouse gas emissions in landscapes and wetlands across the globe.'
	Conservation International	Website	'Any action that conserves, restores or improves the use or management of these ecosystems—*while*, and this is important, increasing carbon storage and/or avoiding greenhouse gas emissions—can be considered a 'natural' climate solution.'
	Nature4Climate	Website	'Approaches used to limit global warming by working with natural and managed forests, grasslands and agriculture, as well as wetlands systems to lower concentrations of greenhouse gasses in the atmosphere. This is accomplished by employing land use and management strategies that avoid greenhouse gas emissions and enhance carbon sequestration.'
	World Economic Forum	Website	'The Natural Climate Solutions (NCS) Alliance aims to scale up affordable natural climate mitigation solutions for achieving the goals of the Paris Agreement on climate change. These include; reforestation protection and conservation, livestock, animal and land management, and coastal wetland and peatland restoration, among a wide array of cost-effective solutions.'
	WBCSD	Proposal	'Nature-based Solutions can remove up to one-third of the necessary CO2 reductions. The Natural Climate Solutions initiative led by WBCSD seeks to make this possible by enabling private sector investment into these solutions.'
Academic literature	Griscom *et al* 2017	Article, *PNAS*	'Protection, restoration and sustainable management of terrestrial and coastal ecosystems and landscapes such as forests, grasslands, agricultural lands and wetlands' via 'conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands.'
	Anderson *et al* 2019	Policy Forum, *Science*	'Although analyses of NCS have some differences in the GHG fluxes they consider, all include emissions sources (such as deforestation, land-use change, and agricultural practices), emissions sinks (such as reforestation and restoring degraded lands), and non-carbon dioxide (CO2) agricultural emissions (such as methane from livestock).'
	Fargione *et al* 2018	Article, *Science Advances*	'Natural climate solutions (NCS), a portfolio of discrete land stewardship options, are the most mature approaches available for carbon conservation and uptake compared to nascent carbon capture technologies and could complement increases in zero-carbon energy production and energy efficiency to achieve needed climate change mitigation […] We consider 21 distinct NCS to provide a consistent and comprehensive exploration of the mitigation potential of conservation, restoration, and improved management in forests, grasslands, agricultural lands, and wetlands.'
	Griscom *et al* 2019	Letter to the editor, *Global Change Biology*	'Land-based options include natural climate solutions (NCS) which use ecosystems for removal and storage, and off-site storage using options like bioenergy with carbon capture and storage (BECCS).'
	Hohlwegler 2019	Article, *Advances in Geosciences*	'Mitigation efforts in line with efficient land management actions concerning, e.g. peats and soils, designated as 'natural climate solutions' […]'
	Griscom *et al* 2020	Article, *Philosophical Transactions Royal Society B*	'NCS can also be referred to as Nature-based Solutions (NbS), although this is a broader term which also refers to climate adaptation, food security, water security, human health, and social and economic development.'
	Baldocchi 2020	Article, *Global Change Biology*	'We are at the verge of capturing ecosystem scale trends in the breathing of a changing biosphere. Consequently, flux measurements need to continue to report on future conditions and responses and assess the efficacy of natural climate solutions.'

et al 2016). A second definition of NbS from the European Commission describes them as 'solutions inspired and supported by nature, designed to address societal challenges which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience' (Raymond et al 2017, European Commission 2021). NbS also include other 'nature-based' approaches such as ecosystem-based adaptation (EbA) and mitigation, green infrastructure, and eco-disaster risk reduction (Seddon et al 2020). These are just a few examples. Definitions of NbS are often adjusted depending on the context, initially raising concerns around the vagueness of the term NbS (Bennett et al 2009, Ring et al 2010, Nature 2017, Nesshöver et al 2017).

The concerns around the term NbS are valid and similarly applicable to NCS. Natural climate solutions is a relatively new term in environmental research and is quickly being adopted in the policy world (table 1). It was first defined in a 2017 study, referring to the 'conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands' (Griscom et al 2017). According to a follow up study, a key difference between NCS and NbS is that NCS focuses on climate mitigation while NbS also includes adaptation and non-climate objectives (Griscom et al 2020). In that regard, NCS can be understood as largely overlapping with the term 'land-based mitigation', as referred to in the IPCC (IPCC 2019)[7]. It is important to clarify these distinctions, as without clear definitions, parameters, and methodologies, NCS risks losing clout (Davis 2008, Brandt et al 2013, Hanson et al 2020, Lamb and Schmidt 2021). Furthermore, having a well-established NCS concept is essential to driving and evaluating the implementation of NCS activities.

To date, the academic research that uses the term NCS is limited but rapidly growing, increasing nearly eight-fold between November 2019 and September 2021 (see section 3.1). The general consensus from experts in the academic literature maintains the distinction that NCS focus on climate change mitigation activities (Hohlwegler 2019, Griscom et al 2020). As such, we adopt this definition of NCS for our study. However, we also recognize the important relationship between NCS and NbS in understanding biodiversity, livelihood, and adaptation impacts. These are captured as co-benefits in our study.

[7] Afforestation, a land-based mitigation measure, is handled differently in various studies on NCS and NbS. Griscom et al (2017) exclude it from their estimates of NCS potential to avoid adverse impacts to biodiversity but in Griscom et al (2020) they include it in forest eco-regions. Seddon et al (2020) and Chausson et al (2020) mention it in their studies on NbS although afforestation does not always seem to be recognized as an NbS by all parties to the debate. We follow the more recent literature and include afforestation in our study to capture the broadest set of possible NCS activities.

3. Methods

This study systematically maps the global evidence base on NCS implementation, with a focus on the enabling factors, in the scientific literature by reviewing ex-post studies. Here, we describe our approach to clarifying the definition of NCS; identifying, selecting, and reviewing the literature; and subsequently analyzing the data.

3.1. Scoping of terms

To prepare for this systematic review, we first conducted a quick scoping exercise to understand how the term 'natural climate solutions' appears in the academic literature. This was essential to developing a common understanding of the terminology among the author team and providing a clear framing for the review. We searched for the term 'natural climate solutions' on Scopus in November 2019 and found just eight peer-reviewed documents, two of which were led by the same author. Because much confusion surrounds the terms NCS and NbS, we also conducted a search for the term 'nature-based solutions', scanning primarily for literature that contained definitions of the term. The results include literature dating back to the emergence of term and caveats around it as well as more recent studies outlining current understandings of NbS. Finally, we also searched for definitions of NCSs on Google and relevant initiative websites we were aware of to observe how the terminology is used outside of the academic literature.

We conducted the same search of the term 'natural climate solutions' on Scopus in September 2021, at the time of submission of this review paper, and found 62 results[8]. The reason for this was to gain insight on how the research landscape on the topic had changed over the course of the review period.

3.2. Review criteria, search, and screening

Using 20 NCSs pathways derived from the IPCC as a starting point (Griscom et al 2017), we iteratively developed a search query to identify the body of literature for our review (see supplementary information available online at stacks.iop.org/ERL/17/013002/mmedia). These pathways build on the land-based—or Agriculture, Forestry, and Other Land Use (AFOLU)—climate solutions previously assessed by the United Nations' Intergovernmental Panel for Climate Change (IPCC 2018). In addition, they include activities in wetlands and other natural ecosystems not captured by AFOLU. Our search query thus encompasses the literature on forests, agricultural lands, grasslands (including savannahs), and wetlands (including peatlands) that also include reference to key terms and synonyms related to climate change mitigation and implementation. We limit our

[8] 27 new search results published in 2020 (one had already appeared in our November 2019 search) and 27 in 2021.

search to documents uploaded onto the Web of Science and Scopus platforms by November 1, 2019 or prior. As such, our search is limited to peer-reviewed literature and excludes grey literature.

Our search query provided us with 2939 initial results on Web of Science and Scopus. To limit the scope of our study to subject-relevant papers and evidence on activities that have already been implemented, we developed a set of inclusion/exclusion criteria to screen the abstracts of the initial search results (see supplementary information). The main criteria for inclusion were that studies focus on at least one activity that qualifies as an NCS and that they contain information on the implementation context, such as barriers and enablers. Studies on adaptation and technical aspects of implementation were excluded, as were systematic reviews and meta-analyses to avoid double counting. Similarly, studies that were simulations or models of possible activities and potentials were mostly excluded, with a few exceptions when a study still provided useful and relevant information on the implementation context.

Furthermore, we focus on studies in the English language that reference at least one enabling factor. These factors are broadly categorized into social, economic, political, institutional, financial, technical, and biophysical factors, building off the enabling conditions and barriers to AFOLU mitigation measures presented in the 5th IPCC Assessment Report (IPCC 2014). After screening the titles and abstracts of our initial 2939 search results using our inclusion/exclusion criteria, we narrowed our results to 345 papers. However, in the process of the full-text review, a further 134 papers were excluded, resulting in a final database of 211 studies (7% of the initial results) that met our review criteria. This demonstrates the thoroughness and selectivity of our search criteria to ensure our database captured experience-based evidence, rather than hypothetical or speculative. In addition, it indicates that while a large number of papers provide information on NCS activities, a relatively small number of papers provide detailed insights on specific contextual enabling factors and conditions around implementation.

3.3. Data extraction, coding, and analysis

Our review consisted of collecting two primary types of information: data for mapping the overall evidence base around NCS implementation and data for the analysis of the enabling factors related to implementation. To capture the descriptive data for the mapping, we extracted the metadata on each document (i.e. author, title, key words, journal year) as well as the study methods, geographical location(s), NCS activities and land types, any relevant programs (e.g. REDD+ or Clean Development Mechanism), and implementing institution(s), as applicable. For the data on the enabling factors, we developed a codebook detailing possible factors that was grouped into the same categories we considered in our literature screening (institutional, social, environmental, economic, technological, and financial), as well as possible co-benefits (see supplementary information). The database also allowed for the coder to provide comments on specific factors for each document, or general comments, to ensure that qualitative information or examples could be recorded as necessary. Note that we clustered together factors into simplified groups for the analysis. When we clustered, we just marked if any of the factors were mentioned to avoid double counting, however, we retained the original data for sub-sample analysis.

To test our codebook and approach, three coders initially coded sub-samples. The results of the test were discussed among the coders to ensure a common understanding of the codebook. Next, the codebook was applied to all the documents and data was extracted from the remaining documents by two coders. For documents where a coder was uncertain, they made a note and the results were discussed as a team.

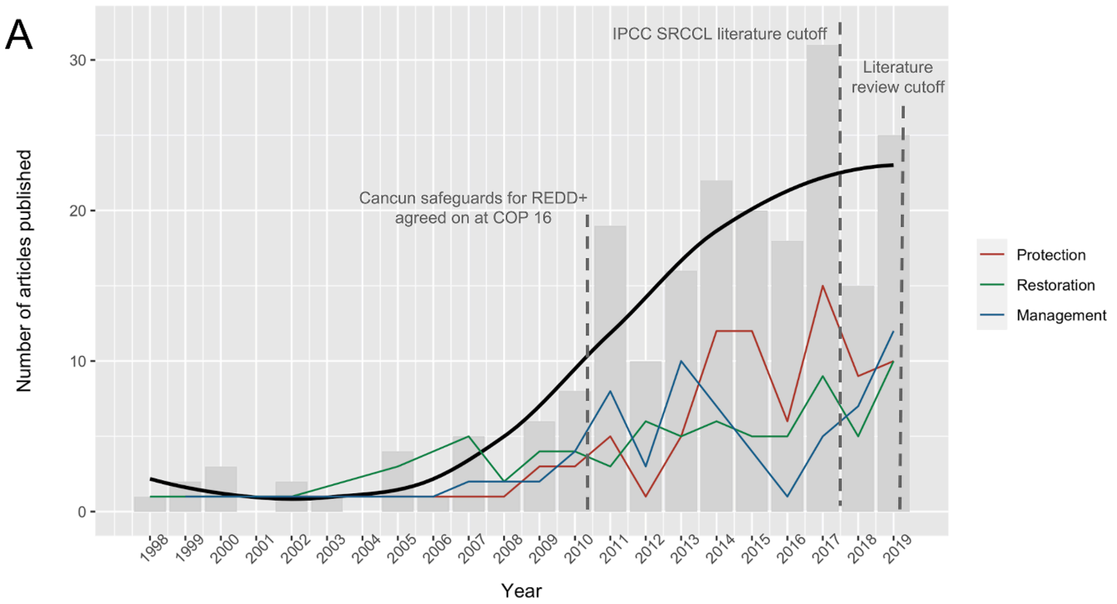
We cleaned and analyzed the coded data using R. We conducted analysis on the dataset as a whole, mapping out the overarching trends, geographical insights, and information on specific NCS activities. We then evaluated the enabling factors and co-benefits mentioned in the literature, providing examples for context where possible. We also categorized the NCS activities into protection, restoration, and management activities for some analyses, expanding on groupings from Griscom *et al* (2020) (figure 1).

4. Results and synthesis

Here we present the main findings and analysis of the reviewed literature. We synthesize these into two sections—an assessment of the overall literature on NCS activities and results on enabling factors for implementation. In the former, we outline historic trends, geographical coverage, and representation of different NCS activities in the literature. In the latter, we highlight important enabling factors and potential variations between geographies. We focus on providing information we have elicited from the dataset and key observations. These are expanded with further insights in the discussion (see section 5.1).

4.1. Current state of the implementation literature

The majority (83%, $n = 176$) of the 211 studies in our final database were published after 2010 (figure 1). Eight studies were published in 2010 and since then the number has steadily increased each year. The historical development of REDD+ may somewhat explain this trend. REDD+ was formalized in 2007 and a number of new funding opportunities emerged



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	Protection	Restoration	Management
Forest	Avoided forest conversion	Natural regeneration Reforestation Afforestation	Improved forest management Avoided woodfuel
Agricultural land	---	Biochar	Trees in cropland Nutrient management Optimal grazing intensity Conservation agriculture Improved rice production
Grassland	Avoided grassland conversion	---	Improved fire management
Wetland	Avoided peat impacts Avoided coastal impacts	Peat restoration Coastal restoration River restoration Wetland restoration	---

Figure 1. (A) Growth in number of articles on natural climate solutions (NCS) published per year through November 2019, including number of mentions of activities falling into different categories of NCS (protection, restoration, or management) each year ($N = 211$). Some articles mention multiple categories of NCS (see supplementary information for analysis of articles mentioning just one category). (B) NCS activities broken down by category of NCS and land type (see supplementary information for icon image credits).

in 2009[9]. 43% ($n = 91$) of all the studies we reviewed were associated with REDD+, all but one of which were published in post-2010.

We observed small spikes in the number of studies published in 2011 and 2017. The former can again likely be due to the evolution of REDD+. A possible reason for the higher number in 2017 may be that the literature cut-off date for the IPCC Special Report on Climate Change and Land (SRCCL) was at the end of that year. Furthermore, until 2013 the number of articles published covering protection and management activities followed similar trajectories, likely because these activities were being discussed in articles on REDD+.

Our results also indicate a slow upward trend in the literature on restoration activities. This topic has recently begun to receive more attention in research and policy with the United Nations' Decade of Restoration that began after our literature cut-off date, so we anticipate this will continue. Literature on management activities experienced a lull and now is also increasing. This may also be linked to the interest in restoration. We categorize activities such as planting trees in croplands (including agroforestry) management practices, but by some definitions they may fall under restoration.

[9] REDD+ was formalized in Bali at the United Nations Framework Convention on Climate Change Conference of the Parties (COP) in 2007 (Norman and Nakhooda 2015). In subsequent years, a framework was negotiated in Copenhagen (COP15) and agreed on in Cancun (COP16). In addition, around this time large funding opportunities for REDD+ emerged. The World Bank's Forest Carbon Partnership Facility was established in 2007 and the Forest Investment Programme in 2009. Both provide channels of financial support for REDD+ planning and implementation. Furthermore, at the end of the Copenhagen negotiations six donor countries pledged USD 3.5 billion in fast-tracked funding to advance REDD+, signaling the optimism and momentum of the moment.

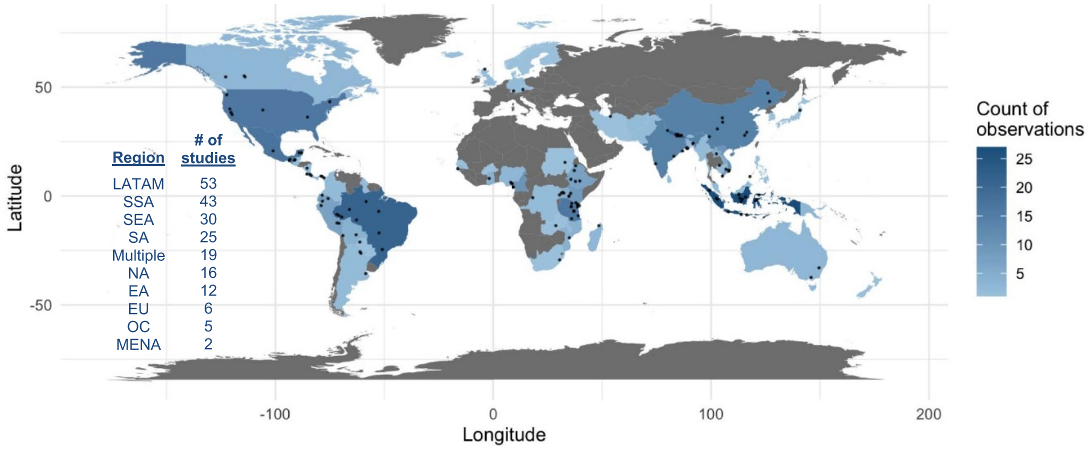


Figure 2. Geographical distribution of literature on natural climate solutions (NCS). Number of papers by country is depictured in blue ($N = 240$ observations in 211 studies). Black dots estimate specific study locations where sub-national information was available on the regional-level or lower ($n = 141$). Multiple locations were given and plotted for some observations.

4.1.1. Geographical coverage

The content of the reviewed studies overwhelmingly focused on tropical regions, specifically Latin America and the Caribbean (LATAM) (25%, $n = 53$), sub-Saharan Africa (SSA) (20%, $n = 43$), Southeast Asia (SEA) (14%, $n = 30$), and South Asia (SA) (12%, $n = 25$) (figure 2). Sixteen studies looked at North America (NA), 12 studies conducted research on East Asia (EA), five on Oceania (OC), and two on the Middle East and North African (MENA) region. Nineteen studies (9%) covered multiple regions. This distribution of geographies in the literature generally aligns with the NCS mitigation opportunities. 61% of the global NCS potential is in tropical countries (Griscom *et al* 2020), while there are few feasible NCS opportunities in the MENA region, which is primarily a desert landscape.

Countries with the most coverage in the studies in our database were Indonesia ($n = 27$), Brazil ($n = 21$), Nepal ($n = 20$), Mexico ($n = 17$), Tanzania ($n = 16$), USA ($n = 16$), China ($n = 14$), India ($n = 14$), Cameroon ($n = 10$), and Vietnam ($n = 10$), captured in ten or more articles each[10]. According to Griscom *et al* (2020), the top ten tropical countries with the highest technical mitigation potential are Indonesia, Brazil, the Democratic Republic of Congo (DRC), India, Malaysia, Mexico, Colombia, Sudan, Bolivia, and Myanmar. Half of these countries (DRC, Malaysia, Colombia, Sudan, and Myanmar) are strongly underrepresented in our database relative to their potential with two or less studies on each.

[10] Some studies in our review provided information on multiple countries. Where information for individual countries could be extracted, these were recorded as independent observations. Thus the total number of country observations in our database ($N = 240$) is slightly higher than the total number of studies ($N = 211$).

Our database contained a low count of literature on West Africa. We found nine observations on the sub-region in eight studies (14% of the Africa-focused literature) and covering just four countries, compared to 39 (70%), 11 (20%), and 6 (11%) studies mentioning East, Central, and Southern African countries, respectively. One possibility for this is that the NbS-relevant research in West Africa is primarily adaptation-focused (Chausson *et al* 2020).

We also found few studies (3%, $n = 6$) on NCS with a Europe (EU) focus. Four of these focused on a particular country. The other two studies evaluated the implementation of specific European Union-level policies. This does not necessarily mean that NbS activities are not taking place in the region, but those that are being pursued in the region may fall outside the scope of our study, as we limit our analysis to land-based mitigation measures. This is supported by research by Hanson *et al* (2020), which indicates that NbS in Europe may be taking the form of other activities such as green infrastructure development and ecosystem-based adaptation.

4.1.2. NCS activities

Our review assessed studies that implemented NCS activities on four types of landscapes: forests, agricultural lands, grasslands (including savannahs), and wetlands (including peatlands) (figure 3). Of 240 observations in 211 studies, activities in forests were a focus of the majority (85%, $n = 204$ observations). A fifth (20%, $n = 48$) of observations provided information on activities in agricultural lands. Few observations in the database are concerned with grassland (3%, $n = 8$) and wetland (10%, $n = 30$) activities, despite substantial theoretical mitigation potential (Griscom *et al* 2020). 18% ($n = 42$) of observations, including some of the aforementioned, discussed activities related to more than one land type.

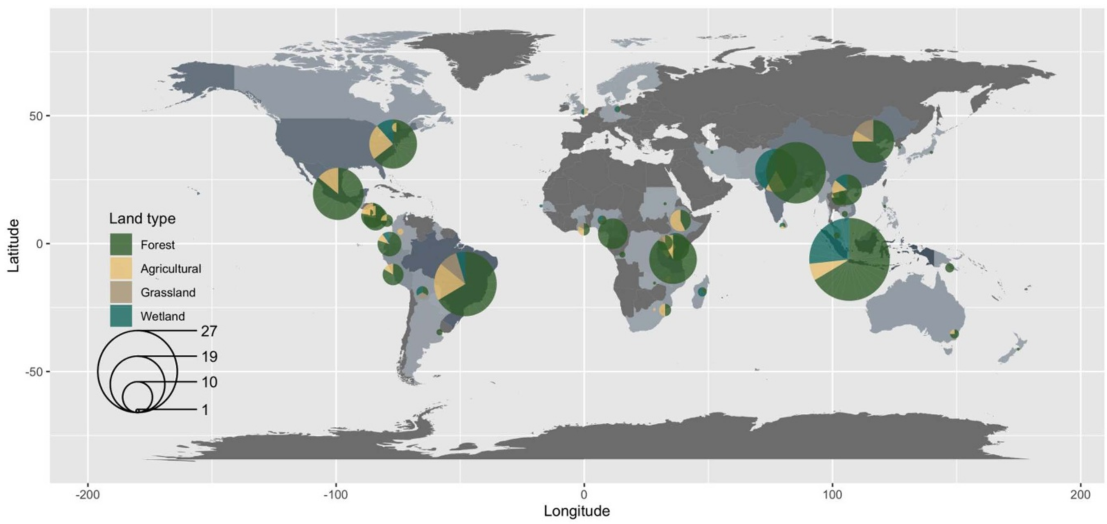


Figure 3. Number of mentions of natural climate solutions (NCS) activities in the literature by country and land type ($N = 240$ observations in 211 studies).

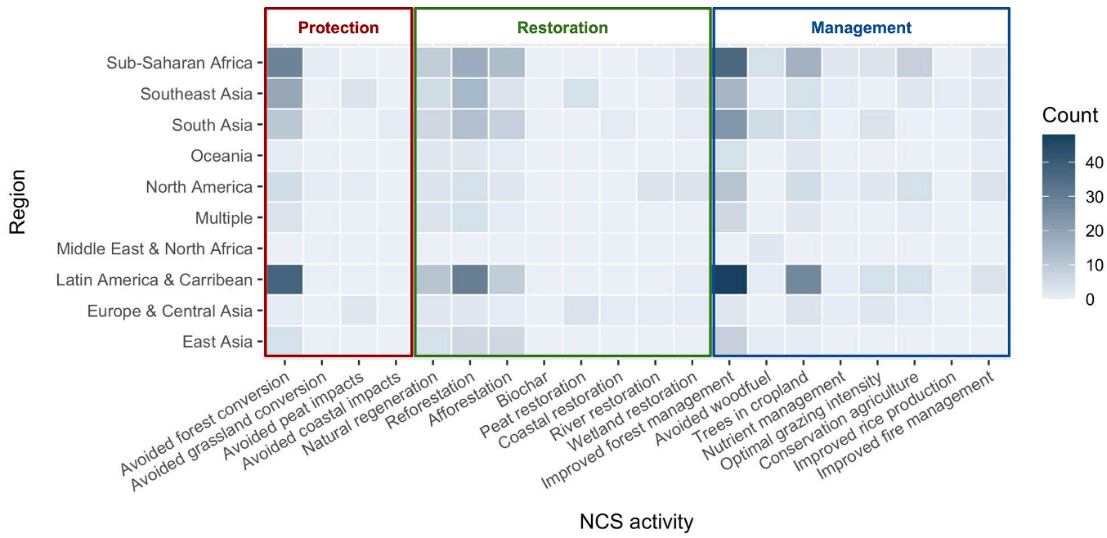


Figure 4. Number of mentions of natural climate solutions (NCS) activities in the literature by region and NCS category ($N = 240$ observations in 211 studies).

Regions that had the most observations on land types besides forests were LATAM and SSA with agricultural lands ($n = 16$ and $n = 13$, respectively) and grasslands ($n = 3$ and $n = 2$, respectively). Observations with wetlands were observed most frequently in SEA and SA ($n = 9$ and $n = 6$, respectively).

The majority of observations (63%, $n = 150$) mentioned NCS activities in the management category. This was followed by restoration ($n = 135$) and protection ($n = 117$). As mentioned previously, however, many articles touched on NCS activities across multiple categories. Just 6% ($n = 15$) of observations focused solely on protection activities, 7% ($n = 16$) on restoration, and 12% ($n = 28$) on management activities alone.

We provide more detailed results on specific NCS activities and geographic distribution—organized by land type—in the remainder of the section (figure 4).

4.1.2.1. Forest

Avoided forest conversion and improved forest management activities, which include natural, plantation, and community forest management practices were identified in nearly half of all observations (46%, $n = 110$ and 51%, $n = 122$, respectively) and received more mentions than any other activity in the reviewed literature. These were closely followed by forest restoration activities—broken down into reforestation, natural regeneration, and afforestation, which we identified separately (in 38%, 18%, and 19% of observations, respectively). Avoided wood fuel was identified in 6% ($n = 14$) observations and fire management in 5% ($n = 13$), though there is some overlap in that activity with grasslands. Forest activities were often mentioned together, in particular in the REDD+ literature. 61% of forest activity observations ($n = 125$) were identified with more than one activity. A REDD+ project or program was associated with 37% of the observations mentioning forest activities in our database ($n = 75$ of 204). This again points to the strong influence of the REDD+ framework in both the design of activities and research.

The literature encompassing forest activities was distributed across global regions. Outside the tropics, the most mentions of forest activities were in observations on the United States ($n = 12$) and China ($n = 10$). Literature on forest activities in the United States focused on both public policies (Cheng *et al* 2016) and incentivizing private landowners (Kim and Langpap 2015, Tian *et al* 2015), while the literature on China skewed towards large-scale government-led afforestation projects under national initiatives such as the Grain to Green Program (i.e. Return Farmland to Forest Program) and National Forest Conservation Program (Liu *et al* 2008, Zinda *et al* 2017, Gong and Zeng 2019).

4.1.2.2. Agricultural land

The addition of trees to cropland (i.e. agroforestry, silvopasture) was identified in 23% ($n = 54$) of the observations in our dataset[11]. Conservation agriculture was identified in 8% ($n = 20$) and optimized grazing practices in 6% ($n = 14$). Nutrient management was identified in six observations and improved rice production in just one. Strikingly, none (0%, $n = 0$) of the reviewed studies mention biochar. This may be related to the fact that most of the literature on biochar focuses on technical aspects of implementation, such as the application and effects, and thus would have been excluded in our literature screening.

Observations of NCS activities related to agriculture were concentrated on the LATAM ($n = 29$) and SSA ($n = 16$) regions, in particular Brazil ($n = 7$), Costa Rica ($n = 5$), Mexico ($n = 5$), and Indonesia ($n = 5$). These regions are the largest producers of some of the 'big four' commodities (beef, soybeans, palm oil, and wood products) driving ecosystem conversion (Henders *et al* 2015). Agricultural activities were also mentioned in five observations on the United States and four on Tanzania.

4.1.2.3. Grassland

We considered two activities, fire management and avoided grassland conversion, as possible NCS activities related to grasslands, which we understood to include savannahs. The results on fire management were already reported in the forest section, however, as the activity cuts across both land types and the studies we reviewed only mentioned on wildfires as a source of forest degradation. None of the studies in our dataset looked at fire management in the context of grasslands. Avoided grassland conversion was identified in less than 1% of observations ($n = 2$). Neither study mentioning avoided grassland conversion provides in-depth information on implementation. One study is an article from a decade ago on the role of the United States agriculture sector in climate change (Johnson 2010). The article touches on the value of grasslands as one ecosystem that can hold carbon in the soil and aboveground biomass when undisturbed. The other is on REDD+ in Ghana, and describes the expansion of the program to a savannah area (Asiyanbi *et al* 2017).

Other literature mentioning grasslands and savannahs such as the Chaco and Cerrado in Latin America focus on forest and agriculture-related NCS activities (Alves-Pinto *et al* 2015, Nolte *et al* 2017, Milmanda Fernández and Garay 2019). This may be because these areas are active agriculture frontiers in the region located amid forests. Furthermore, savannahs are often described as tropical dry forests. While EA (i.e. China and Mongolia) is home to large grasslands as well, most of the literature on grasslands in that area did not meet our review inclusion criteria because they were scenarios or model projections and did not contain relevant information on the implementation context.

4.1.2.4. Wetland

We identified NCS activities related to wetlands—including coastal lands, peatlands, and rivers—in 8% of our observations ($n = 20$). Half of these included mentions of wetland restoration generally ($n = 10$). Three of these observations were from the same study on blue carbon that provided information on multiple countries (Wylie *et al* 2016). Eight observations were identified for peatlands (avoided impacts, restoration, or both), five for river restoration (e.g. riparian and catchment areas), and two for coasts (avoided impacts, restoration, or both).

Four of the observations on river and wetland restoration were on the United States. Other countries captured in the observations for those activities were Costa Rica, Ethiopia, India, Kenya, Vietnam, Madagascar, and Indonesia with one each. In addition, half of the observations on peatland activities were on Indonesia ($n = 4$), one on the United Kingdom, and one on Germany. The other two had regional foci on the EU and NA. The studies on the developed countries centered more on peat restoration and management than the Indonesia literature, which also acknowledge efforts to avoid conversion of new peatland areas (Whitfield *et al* 2011, Hagen *et al* 2013, Mulyani and Jepson 2017). Regarding the coastal activities, one observation was in the same

[11] We coded agricultural lands as the land type for fewer observations ($n = 48$) than there are observations on agricultural land NCS activities ($n = 72$) because for some of the observations on agroforestry the land type was coded as forest. This does not affect the analysis as it is based on all observations in the dataset ($n = 240$).

study on the EU that also mentioned peatland activities, while the other observation was on Sri Lanka. The latter is one of the few observations on mangroves (Tanaka 2009).

4.2. What are important enabling factors & where?

In our global dataset, social and political enabling factors were mentioned most frequently on aggregate. These were closely followed by financial, institutional, and technical factors (figures 5 and 6). Specifically, the engagement of indigenous peoples and local communities (IPLC), performance-based finance, and technical assistance are important drivers of NCS implementation. These factors are often overarching and interact with others, creating feedback effects (Dawson *et al* 2018, Rosa Da Conceição *et al* 2018, Aganyira *et al* 2019). Details for each NCS category and examples are provided in the subsequent subsections to help illustrate our results.

Enabling factors appearing within each NCS category parallel the general trends in our dataset (figure 6). The management literature had the most mentions for many factors and the protection literature the least, likely reflecting the difference in the number of observations between the two. Interestingly, free, prior, and informed consent (FPIC), stakeholder consultation, acceptance from leadership, and realistic requirements were factors that came up more often in the protection literature than other categories. This may possibly be because of the politicized nature of REDD+ or the tensions of setting legal destinations for conservation. For instance, many protected areas overlap with land traditionally used by local peoples for livelihoods. NCS in these areas has not led to positive outcomes, in particular when IPLCs do not have secure rights or access to grievance mechanisms (Tauli-Corpuz *et al* 2020).

Factors such as delivery of benefits, labor availability, technical assistance, and performance-based finance were mentioned more in the restoration and management literature, even compared to other factors within those categories. Local acceptance and IPLC engagement were mentioned often in the management literature in particular. This may highlight on the one hand, the implementation costs and capacities needed to transition to sustainable land use practices but also the tradeoffs that may make the willingness to participate in NCS activities from local actors challenging. Secure funding was mentioned most frequently in the restoration literature, which makes sense given that restoration activities may take more time to get off the ground and produce tangible results.

4.2.1. Social

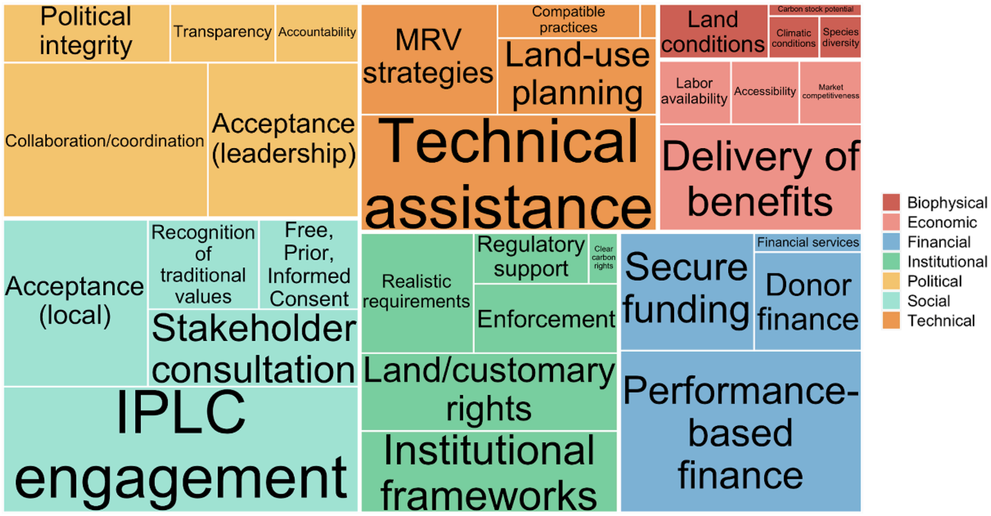
Of all the enabling factors identified in the literature, IPLC engagement was by far the factor that appeared in the most observations, present in 60% ($n = 144$). Nearly half (48%, $n = 69$ of 144) of these observations that mentioned IPLC engagement as an important factor included REDD+ projects or programs as a focus. Social safeguards, including the full and effective participation of IPLCs, are a requirement for REDD+ eligibility. A sub-sample analysis of this factor shows mentions of 'participation of IPLCs' ($n = 115$), 'local awareness' ($n = 59$), and 'education' ($n = 50$). In some observations, two or three of these were mentioned together. However, it is important to recognize the differences in each of these terms of engagement and how they relate to each other (see section 5.1).

Local acceptance, where a consistent quality of life is ensured, community needs and benefits are aligned, and there is support for NCS activities, was another social factor we coded for. It was mentioned in 33% of observations ($n = 78$). FPIC, another concept along the line of participation but more complex, appeared in 12% of observations ($n = 29$). It sets out principles for engaging indigenous peoples that have been adopted by many international organizations, including the United Nations during recent climate negotiations (Wallbott and Florian-Rivero 2018). The element of consent is fundamental, as this is what sets FPIC apart from other consultation processes. It also goes beyond general stakeholder consultation, which we understood to also include outreach to different actor groups such as government, academia, and civil society ($n = 52$). Nevertheless, these processes and inclusion criteria are meaningless if they do not account for local ways of life (Dawson *et al* 2018, Duker *et al* 2018). This recognition of traditional values and local norms was discussed in 13% of observations ($n = 32$).

4.2.2. Economic

The most mentioned economic factor in our review was the delivery of benefits ($n = 70$). In observations on Ethiopia and Indonesia, for example, researchers noted that project implementation was hampered due to a mismatch or insufficient benefits (Duker *et al* 2018). In the latter, while people earned wages from tree planting and received training to support forest conservation, these did not compensate for losses on banned agricultural activities or meet farmers' livelihoods needs. In Vietnam, on the other hand, increased mangrove cover positively impacted farmers' shrimp production and income, making participating in restoration activities an attractive option (Wylie *et al* 2016).

Labor availability, accessibility, and market competitiveness were also mentioned in a handful of observations ($n = 15$, $n = 14$, $n = 13$, respectively). Some observations described limitations to implementation due to lack of qualified labor, in particular within project or program offices or responsible government ministries (Aganyira *et al* 2019, Wurtzebach *et al* 2019). Hein *et al* (2018) highlight these shortages as a disconnect between priorities and resource allocation at district and national levels. In addition, A



B

Social

IPLC engagement	60%
Acceptance (local)	33%
Stakeholder consultation	22%
Recognition of traditional values	13%
Free, prior, informed, consent (FPIC)	12%

Economic

Delivery of benefits	29%
Accessibility	6%
Labor availability	6%
Market competitiveness	5%

Political

Collaboration/coordination	43%
Acceptance (leadership)	31%
Political integrity	13%
Transparency	8%
Accountability	7%

Institutional

Institutional frameworks	28%
Land/customary rights	27%
Realistic requirements	18%
Enforcement	13%
Regulatory support	8%
Clear carbon rights	2%

Financial

Performance-based finance	53%
Secure funding	21%
Donor finance	14%
Financial services	3%

Technical

Technical assistance	46%
Monitoring, reporting, verification	20%
Land-use planning	16%
Compatible practices	7%
Research	1%

Biophysical

Land conditions	8%
Climatic conditions	3%
Species diversity	3%
Carbon stock potential	2%

Figure 5. (A) Treemap illustrating the distribution of enabling factors for natural climate solutions (NCS) extracted from the literature ($N = 1396$ mentions in 240 observations). (B) Enabling factors by mentions in percent of the literature ($N = 240$ observations in 211 studies) (see supplementary information for icon image credits).

difficulty accessing an activity site and weak demand for sustainable products posed barriers (Bastos Lima *et al* 2017, Huang *et al* 2019, Muttaqin *et al* 2019).

4.2.3. Political

Collaboration and coordination were mentioned as enabling factors for NCS implementation in 43% of observations ($n = 102$). We understood this factor to include measures such as policy coordination between sectors or within a sector and alignment between standards and laws or laws at different levels, among others. This was followed by acceptance from leadership, i.e. political will, in a third of observations (31%, $n = 75$), and integrity, accountability, and transparency ($n = 32$, $n = 20$, $n = 16$, respectively). We included measures like lack of corruption and proper management under integrity, while having clearly designated responsibilities and authorities as well as access to justice were included under accountability.

4.2.4. Institutional

Strong frameworks to support NCS implementation were discussed as an enabling factor in 28% ($n = 68$) of observations. Regulatory support, specifically, came up in 8% ($n = 19$). Equally as important as these frameworks was clarity on land and customary rights (27%, $n = 64$). Carbon rights were explicitly mentioned in just 2% of observations ($n = 5$). We included various forms of security, recognition, and property types under the land and customary rights factor, such as both traditionally and legally-held ownership. These were, however, not always aligned with each other (Dawson *et al* 2018). Availability and access to conflict resolution mechanisms for tenure can help ease these tensions (Holmes *et al* 2017). Access to justice and grievance mechanisms are essential for ensuring equity and representation of IPLC perspectives in NCS activities.

Realistic program or project requirements were also mentioned as an enabling factor in 18% of observations ($n = 44$) and enforcement in 13% ($n = 32$). Overly complex regulations, for example, tended to increase costs and be technically infeasible (Chia *et al* 2019). Inadequate enforcement was cited as one reason for slow progress in some programs and projects. The ability to properly enforce policies and laws was often contingent on labor availability and technical capacity (Schroth *et al* 2016, Ngendakumana *et al* 2017, Aganyira *et al* 2019, Wurtzebach *et al* 2019).

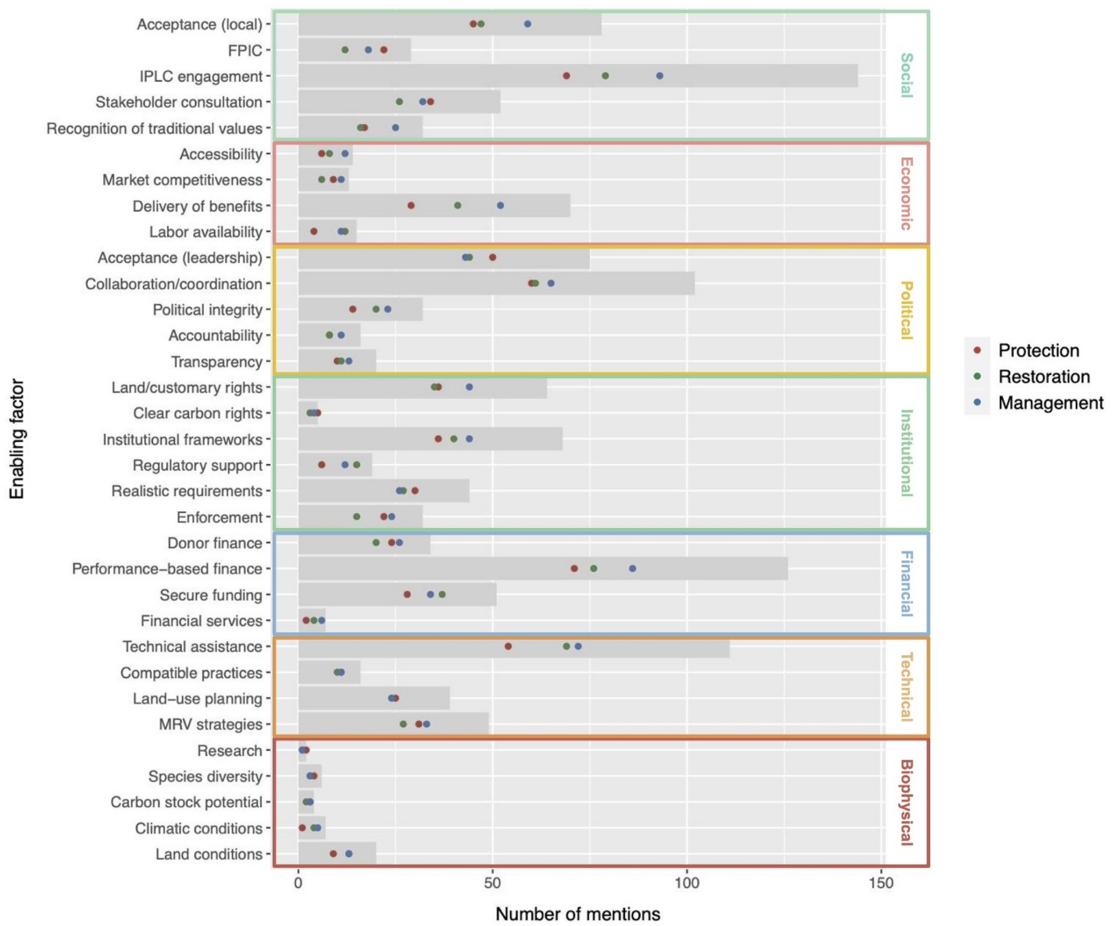


Figure 6. Mentions of enabling factors for natural climate solutions (NCS), including total number of mentions across all articles (in grey) and number of times mentioned in the literature on each category of NCS (protection, restoration, or management) ($N = 240$ observations in 211 studies). Some articles mention multiple categories of NCS, thus there may be overlap in the mentions noted for the literature by NCS category.

4.2.5. Financial

Over half of our observations (53%, $n = 126$) mention the role performance-based finance, or finance paid for demonstrated results, in many NCS programs or projects. This can take the form of payments for ecosystem services (PES) ($n = 65$), where 'providers' of clean air, water, and other healthy ecosystem services are compensated for their actions; benefits-sharing mechanisms ($n = 24$), which aim to ensure that benefits received are equitably distributed to participating groups of people or communities; or results-based finance ($n = 23$), in which program or project participants are paid for emissions reductions. The caveat was often that the incentives need to be appropriate to the local context ($n = 68$) and payments have to be enough to maintain a consistent quality of life for IPLCs changing their practices and engaging in new NCS activities (Duker *et al* 2018).

There are also concerns about the lack of secure funding surrounding NCS activities. Ensuring a source of secure, long-term finance was mentioned as an important factor for successful, lasting, implementation in 21% of observations ($n = 51$). Access to other financial services, such as local crediting schemes, received less attention in our dataset ($n = 7$). Subsidies for NCS activities in many countries remain less than those to drivers of land use change (Regina *et al* 2016, Bastos Lima *et al* 2017). Tensions may also arise from external finance being uncertain, temporary, or acting as a competing investment. Some payment schemes also only support community projects rather than individuals, which was not well-received by community members in an example from Ethiopia (Duker *et al* 2018).

4.2.6. Technical

Technical assistance was mentioned as an enabling factor in nearly half of the observations in our dataset (46%, $n = 111$). Of these, 67% specifically include training, 31% information provision, 15% availability of seeds and seedlings, 12% adequate capacities, and 7% technology accessibility ($n = 74$ of 111, $n = 35$, $n = 17$, $n = 13$, $n = 8$, respectively). Studies either described a lack of this assistance as a challenge, or found that farmers receiving technical support were more likely to move forward with implementation (Korhonen-Kurki *et al* 2016, Wang *et al* 2019). In China, this also provided a better understanding

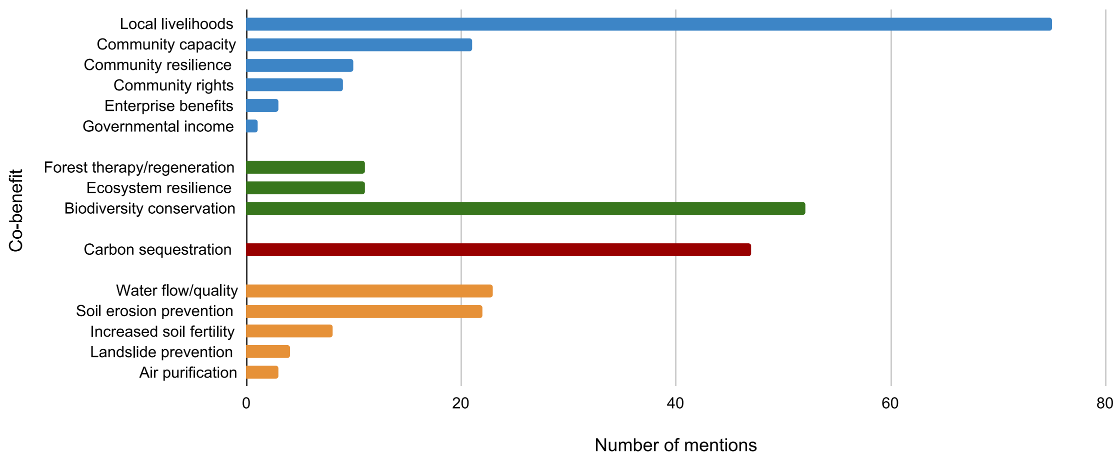


Figure 7. Number of mentions of co-benefits in the literature ($N = 240$ observations in 211 studies). Co-benefits were discussed in the literature as potential outcomes of natural climate solutions (NCS) activities, as opposed to pre-conditions for implementation, which were coded as enabling factors.

of the structure and composition of natural forest, which enabled better project design (Jiang *et al* 2018). Training local people also filled labor needs.

Monitoring, reporting, and verification (MRV) was discussed in 20% of observations ($n = 49$). Good MRV was contingent on available resources, such as technological or labor capacities. Community-based monitoring approaches also were used to build participation and ownership for projects among IPLCs (Newton *et al* 2015, Rosa Da Conceição *et al* 2018). Land-use planning—mapping, identification of land-use drivers, and assessment of ecological conditions—came up almost as often as MRV ($n = 39$). Planning prior to project or program activities can aid implementation, in particular in the long-term (Blomley *et al* 2017, Mulyani and Jepson 2017). Ensuring compatible practices or adoption of integrated approaches were a consideration in 7% of observations ($n = 16$). Only two observations included research as a potential enabling factor.

With technical factors, there were also distributional imbalances reported. An analysis of participatory forest management in Tanzania found that training and information provision is given only to a certain number of people, who do not always pass this knowledge onto the community because they perceive there is no benefit to them or they can not afford to (Mustalahti and Tassa 2012). A study on payments for environmental services in Costa Rica also notes a lack of an effective monitoring system and that the design did not include small properties and some of the poorest households (Wallbott *et al* 2019).

4.2.7. Biophysical

Few biophysical factors were discussed as enabling factors in the literature reviewed. This is likely due to our exclusion criteria, which removed any studies that focused on more technical and ecological aspects of how to do implementation. In our dataset, which really emphasized the enabling context for NCS activities, land conditions appeared the most, in 8% of observations ($n = 20$). For example, where and what NCS activity was implemented could depend on the size of a project area or nature reserve, the surrounding land use, or the forest or land yield (Nolte *et al* 2017, Shrestha *et al* 2017). Climatic conditions (i.e. rainfall, adequate soil) were a factor in seven observations, species diversity in six, and the potential for increasing carbon stocks in four.

4.2.8. Co-benefits

The multiple potential outcomes of NCS activities are reflected in the co-benefits mentioned in the literature (figure 7). Supporting local livelihoods was an important co-benefit and additional motivation for adopting NCS in 31% of observations ($n = 75$). The value to biodiversity conservation was recognized in 22% ($n = 52$) and carbon sequestration in 20% ($n = 47$), the latter while also being a primary objective of NCS. Other co-benefits, such as community capacity building ($n = 21$) and community rights ($n = 9$), did not often explicitly appear as such in the literature. They are also more strongly represented in the dataset as enabling factors, or pre-conditions for implementation rather than outcomes.

4.2.9. By geography

The overall distribution of enabling factors synthesized by region is similar to the global results. To add nuance, we looked at the distribution of enabling factors by category in the ten countries with the highest number of observations in our dataset (figure 8). Social factors were most prominently mentioned in India, Nepal, China, Indonesia, Vietnam and Tanzania. In China, political factors comprised an equal share of mentions. The categories of factors mentioned in the United States were relatively evenly distributed, with biophysical and economic factors

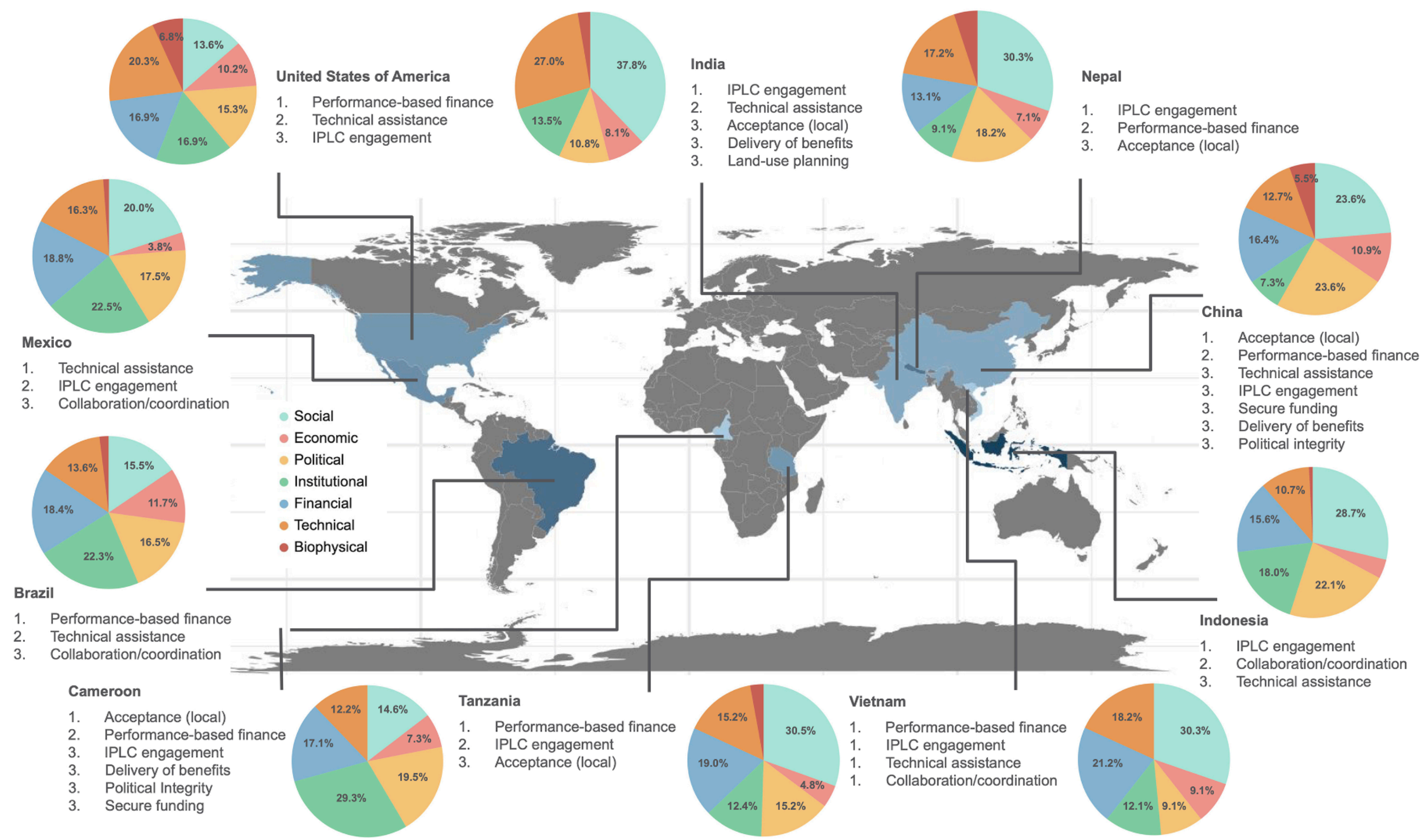


Figure 8. Shares of types of enabling factors for natural climate solutions (NCS) and top three enabling factors mentioned in the literature on the ten countries with highest number of observations. More than three enabling factors are listed for countries where multiple factors are tied for a position. The position is indicated by the numbering.

being mentioned the least. These categories, however, also had less factors than the others. In Mexico, Brazil, and Cameroon, institutional factors comprised the largest share of mentions. At the same time, the number one enabling factor mentioned in almost all ten countries was either performance-based finance or IPLC engagement. The exceptions were China and Cameroon, where local acceptance was mentioned the most, closely followed by performance-based finance; and Mexico, where technical assistance was first followed by IPLC engagement. Other factors that received within the three highest mentions in these ten countries included collaboration and coordination, delivery of benefits, secure funding, and political integrity[12].

5. Discussion

This section consists of four subsections: a short summary of our results and additional insights on the findings; building on our results; a discussion on how different enabling factors may fit together, or be 'bundled'; a critical reflection on the current state of evidence and knowledge production for implementation of NCS; and concluding thoughts.

5.1. Summary and insights

This review provides an overview of the evidence base surrounding the implementation of NCS activities. We find the coverage of the studies skews towards tropical regions and activities in forest landscapes. Nevertheless, much can be learned about the enabling factors for implementation of NCS from the available data. These factors are often interlinked across categories (e.g. social, political, etc) with engagement of IPLC, performance-based finance, and technical assistance being most frequently mentioned in the literature.

We also observe that there remain challenges to ensuring enabling factors in practice. Projects sometimes take years to get off the ground or provide tangible benefits due to insecure finance or poor governance, leaving some communities feeling abandoned or skeptical of future promises (Enrici and Hubacek 2019). Public perception is also a critical part of the implementation context (Wang *et al* 2019). Lack of trust and confidence in project developers can amplify conflicts (Duker *et al* 2018). In a case in India, local leaders were elected by the community and committees democratically decided what sustainable livelihood activities to support (Chowdhury *et al* 2016). This type of approach is particularly relevant to community forest management and participatory forest management activities where better integration of IPLCs is needed (Cronkleton *et al* 2011, Mustalahti and Tassa 2012).

The findings of the reviewed literature also suggest that participation can not be effective without awareness. Awareness can come about through education, dialogue, or an existing connection to the land. The latter was the case with farmers living in earthquake stricken areas of China, where their experiences made them more aware of the importance of ecological protection (Gong and Zeng 2019). Furthermore, awareness can strengthen the longevity of NCS activities by promoting buy-in among IPLCs. Evidence on the United States, for example, indicates that forest owners who were aware of climate change were more willing to participate in NCS activities (Charnley *et al* 2010, Tian *et al* 2015). Additionally, research from Costa Rica and Cambodia found wealthier households and farmers were more willing to participate in NCS activities, raising questions about equity (Cole 2010, Pasgaard 2015). This is supported by a study on the Asia-Pacific region that notes that REDD+ participation is limited and exclusion of the poor and insecure tenure rights remain a problem (Barr and Sayer 2012).

Many studies in the reviewed literature also discussed the role of regulatory support for implementation and how it could be streamlined. For example, REDD+ frameworks or any new institutional arrangements need to either be consistent with existing laws or embedded into them (Korhonen-Kurki *et al* 2016). If there are too many institutions, this also risks regulations and tenure overlapping, conflicting government priorities, and confusion over laws (Enrici and Hubacek 2019).

Political factors often appeared together in the literature, together with institutional factors. Poor leadership often resulted in poor coordination between vertically and horizontally, unclear authority, weak enforcement, lack of policy consistency, and overlapping or misaligned regulations (Korhonen-Kurki *et al* 2016, Rosa Da Conceição *et al* 2018, Chia *et al* 2019). Implementation was also limited with NCS activities where not a priority for those in power, where decisions were made with short-term objectives in mind, or those in power did not have the technical expertise needed to participate fully in the REDD+ process, but continued to do so for political reasons. This is also seen with international actors who often control national processes due either financial or political influence (Dawson *et al* 2018).

In addition, interventions such as PESs can also be difficult to implement if other enabling factors, such as clear land tenure, are not in place (Cortner *et al* 2019). Results-based payments and benefit-sharing, for example in connection to REDD+, have been touted for their potential to provide long-term funding through access to markets for carbon credits. These programs often depend on donor finance

[12] We also conducted exploratory analyses on the differences between factors in different regions using correlation plots (see supplementary information).

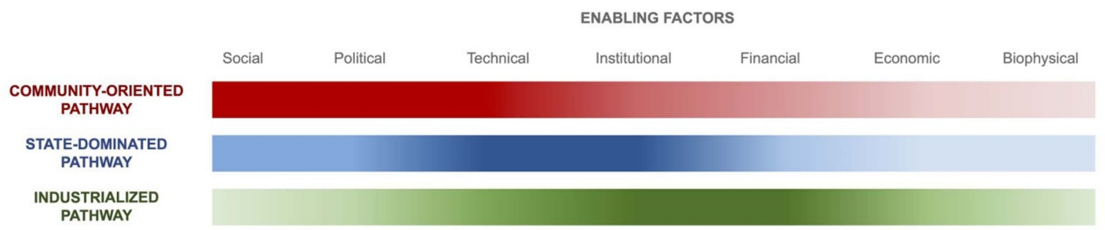


Figure 9. Illustrative implementation pathways for natural climate solutions (NCS). Darker colors indicate categories of enabling factors that may play a larger role in implementation for each pathway. These pathways are meant to serve as examples to show that there are different combinations of factors that may influence implementation, and these are highly context dependent. Implementation trajectories are not limited to these pathways and they are not mutually exclusive.

($n = 34$) to be set up, however. Governments are also major driving forces behind REDD+ and other PES programs, but effectiveness can be low due to political obstacles (Rosa Da Conceição *et al* 2018).

5.2. Bundling enabling factors

Our review results highlight that the successful implementation of NCS rely, not on one factor, but a suite of enabling factors. Individual factors may also open doors to capitalize on other enabling factors along implementation pathways. For example, recognition of traditional values may lead to greater acceptance of NCS activities by local communities. Based on the evidence in our review synthesis, we present three illustrative pathways by considering enabling factors that may interact with each other in different contexts (figure 9). We outline our proposed pathways below and describe characteristics of each. While implementation trajectories are not limited to these pathways and they are not mutually exclusive, we see these as a useful heuristic for thinking holistically about the conditionality and variability of NCS implementation and informing policy discussions.

5.2.1. State-dominated pathway

Countries or geographies falling into the state-dominated pathway may include those where governments hold strong influence and control, but experience weak governance due to lack of leadership, corruption, and conflicting priorities between decision makers. Land use planning and consideration of NCS is a top-down process. At the same time, these countries have large local and vulnerable populations that depend on natural ecosystems for their livelihoods but face difficulties in having their needs met. Certain activities, such as cattle ranching, may also be socially and culturally embedded adding extra complexity (Cortner *et al* 2019). Examples include case studies from parts of Brazil, China, Vietnam, and Uganda (Dawson *et al* 2018, Cortner *et al* 2019, Wang *et al* 2019, Wurtzebach *et al* 2019).

In the state-dominated pathway, we argue that social and political factors represent particularly foundational stepping stones for implementing NCS potential. This may be due to bottlenecks posed by political insecurity and changing priorities, which can lead to mistrust of the government among farmers and local communities (Cortner *et al* 2019). The politics of the moment may also drive institutional and financial decisions that may have trickle down effects on NCS implementation. For instance, in Ecuador electoral interests led to prioritization of non-environmental concerns and overall low conservation effectiveness in the national sustainable forest management program (Rosa Da Conceição *et al* 2018).

Various other challenges are also described in the literature, such as pro-environment and IPLC policies being anchored in laws, but often ignored (Baez 2011). In Peru, officials disregarded a consultation process because they felt it was more important to get the program deployed quickly, leading to adverse outcomes (Rosa Da Conceição *et al* 2018). As such, coordination and collaboration between different levels of government and stakeholders, as well as integrity, accountability, transparency and enforcement mechanisms are essential. These factors are also necessary to close gaps and increase communication between policy makers and local people (Wang *et al* 2019). At the same time, leveraging existing policies and institutions are a first step in realizing them and improving learning (Wurtzebach *et al* 2019).

5.2.2. Community-oriented pathway

The community-oriented pathway is characterized by a strong political and social interest in participatory land management approaches. Underlying these approaches, however, are financial and technical considerations that are often the limiting factors for implementation. Also important are social factors, in particular acceptance of NCS activities by the local communities and people that are expected to partake. Examples of places employing community or social forestry and land management programs include cases from Indonesia, Nepal, Ethiopia, Panama, and Tanzania, but also Brazil highlighting overlaps between and the fluidity of our proposed pathways (Cronkleton *et al* 2011, Newton *et al* 2015, Holmes *et al* 2017, Duker *et al* 2018, Wood *et al* 2019).

Duker *et al* (2018) describe how the lack of engagement of smallholder farmers in the development of climate forestry projects in Ethiopia and Indonesia led to distrust, which was amplified by insufficient and unreliable incentives for farmers to participate in conservation. An additional study in Ethiopia observed a community forest management approach with overall positive impacts on the land, carbon and biodiversity; however, this took place over a longer period (Wood *et al* 2019). Collaboration between communities and the government and reaching a common understanding, for example, took ten years to establish. In other cases, discourses are still shaped by a small group of powerful actors in practice (Bushley 2014).

In this pathway, institutional factors remain relevant and strongly interact with social and political factors. Local support for an NCS activity, for example, is often linked to clear land or forest rights for communities (Wood *et al* 2019). In Tanzania and Nepal, an important reason for success in their community-based forestry programs was that they had existing institutional structures and laws in place which they could build on through REDD+ readiness activities, so the frameworks and political will for implementation were already present (Newton *et al* 2015).

5.2.3. Industrialized pathway

The industrialized pathway reflects a way forward for developed countries or geographies that may have the institutional structures already in place to support NCS implementation, but still face challenges in meeting diverse stakeholder needs and providing sufficient incentives for actors to shift away from their potentially unsustainable business-as-usual practices. Examples of such countries from the literature include the United States, Germany, and the United Kingdom (Schaich and Plieninger 2013, Feliciano *et al* 2014, Schmitz and Kelly 2016).

In particular in the context of emerging carbon markets, countries may struggle to balance diverging land management approaches from vested-interest actor groups aiming to maximize carbon sequestration versus conservation-minded stakeholders concerned that 'carbon farming' may result in tradeoffs for ecological integrity (Schmitz and Kelly 2016). Similar to in the other pathways, performance-based finance and technical assistance also are relevant to sustainable land management. Land in these countries is often under a combination of public and private ownership that demands diverse approaches for shifting the behavior of land users (Schaich and Plieninger 2013). In addition to market mechanisms, incentives may take the form of direct public PESs or tax subsidies and exemptions (Tian *et al* 2015). Attitudes of private landowners towards these incentives may vary based on their interests and experiences with them.

5.3. Critical reflection & implications for the future

Our review results and illustrative pathways (see section 5.2) highlight that there is not a one-size fits all approach for implementing NCS. While the broad categories of factors mentioned in the literature are similar across regions, the combination of factors and how and for whom they are taken up remains heterogeneous globally, and even within countries. This points to the importance and need to reflect critically on current policy discourses and narratives. This is relevant to the identification of research and knowledge gaps as well as deciding how to implement activities and measure if they are effective. Below, we discuss these gaps as well as considerations for future knowledge production.

5.3.1. Research gaps

While our study focuses on NCS, taking climate mitigation as the primary objective, it is important that NCS activities not be designed with only this objective in mind. Based on the evidence in our review, we observe that local livelihoods and biodiversity are mentioned most frequently as co-benefits. In line with Girardin *et al* (2021), recognizing these factors not only as co-benefits, but co-objectives from the outset, is central to the long term, ethical, and equitable implementation of NCS. More interdisciplinary research is needed here to avoid silos, but these were clearly lacking within our database. We were able to capture projects that did not mention climate or carbon as the explicit focus, but where it could be understood as an important co-objective (e.g. projects with a community-based conservation frame), due to the nature of our search query. However, few articles reported on carbon and other greenhouse gas outcomes together with social outcomes.

The bias in the literature towards forest landscapes also demonstrates the difficulty of providing a representative set of information on NCS to policymakers. Generally, there was a lack of on the ground research on different ecosystems. There were a number of papers on grasslands in China and Mongolia that we excluded because they projected scenario outcomes of NCS activities but did not provide evidence on implementation drivers. While our review results between landscapes were similar enough to indicate we can learn about the implementation context of NCS across ecosystems from others, this lack of balanced evidence on different types of NCS can have other implications. One risk is that it unintentionally trickles down in project and research funding decisions, influencing the direction of future workstreams. Lack of information may also slow or hamper implementation all together. The opposite can also occur, as demonstrated by the development of REDD+, subsequent policy and financing mechanisms, and the publications that followed.

There were also major research gaps on particular geographies. We found few publications on OC, for example. Though a small region, it is a vulnerable area and uptake of NCS, including wetland protection and restoration, could improve resilience to future climate events by providing both climate mitigation and adaptation benefits. More research, however, is needed on countries in the area to determine the feasibility and approach for implementing such activities. Other areas may be underresearched because they are challenging to access due to political tensions, civil unrest, lack of established contacts, or difficult terrain. In practice, research locations are often determined by the scope of funding schemes or network entry points. We also acknowledge that a limitation of our study is that it excluded publications outside the English language. It is possible that we would find more information on regions such as West Africa and EA if we ran our search query in the French or Chinese languages. More exploration of virtual research methods could be useful for eliciting broader input and negating some of these structural biases. These limitations do not diminish our results, but are important to highlight for the sake of transparency and identifying future research opportunities.

In addition, our review did not include information from project databases or grey literature. These may provide further information on NCS implementation, but may come with their own biases if only certain information is included to meet reporting requirements or selection of project areas is influenced by donor interests. At the same, the IPCC is also limited to peer-reviewed literature and coverage of social sciences remains patchy. Social science studies, in particular of qualitative nature, have historically faced difficulties finding a home in the IPCC process due to concerns about them being too interpretive (Victor 2015, Minx *et al* 2017). This is slowly changing, and systematic methods and reviews such as ours are one channel for ensuring rigorous assessment of the available evidence. While synthesizing information from a diverse set of case studies is challenging and some interpretation by individual reviewers in the coding is unavoidable, having a clear protocol helps reduce those arbitrary decisions. In addition, it allows for future work to improve NCS activities to easily expand on our study. The literature on NCS is growing at a rapid pace and a large number of new articles on NCS activities have been published since initiating this review two years ago. This new body of literature could be evaluated against our results to potentially address some of the gaps we have raised.

5.3.2. Considerations for knowledge production

Finally, it is important to critically reflect on who is creating the evidence we are assessing and for whom. Western scientists and economists are the dominant influence in climate change research and policy processes, though with NCS much action is projected in non-Western countries. Our review can help us identify enablers of implementation in different places, but what is effective or successful implementation may depend on the activity, how well it is implemented, and how long it is implemented, and who sets the criteria for determining this. Recent evidence from Indonesia reinforces that current land use scenarios and policy development do not yet provide the benefits or income needed to support livelihoods while placing more burden on local actors to contribute to climate change mitigation, as was the case for many studies in our review dataset (Merten *et al* 2021). While there was a range in the duration of the projects in the reviewed literature, many did have longer timeframes due to our focus on NCS activities that were underway or had already been implemented.

Thus, a different set of enabling factors may matter more when thinking about implementation from an alternative perspective, such as a social justice or equity angle, than purely a mitigation objective. These could include more focus on capacities of communities and smallholders, local land use rights, and participatory decision-making processes. These factors are typically excluded from the modelling projections that determine the potential for NCS to begin with because they are complex to integrate or data, if available, is considered to be inadequate. While it is difficult to ensure representativeness in research, applying the concept of 'unlearning', or letting go of preconceived notions to allow for new knowledge to be created, may also be useful to explore within this framing and existing meta-narratives (Becker 2005, Downes *et al* 2015).

This raises the question, who informs and decides on the global NCS agenda. Similarly, who determines who should bear the costs of implementation? Undeniably, the positionality of researchers plays a role in the formation of the evidence base, the messaging of the results, and to whom it is disseminated. While beyond the scope of this paper, a mapping of authors and funding sources driving the research in our database would be valuable in identifying possible systemic biases and power imbalances.

5.4. Conclusion

This review and dataset have allowed us to go beyond the analysis of individual enabling factors to provide a larger picture of how these factors fit together. While this is a first step, it points to the need to think more systematically about this topic. Moving forward, more inclusive (and systematic) methodologies for considering underlying drivers of change in technical and economic studies of potential for enhancing decision making could be explored.

Finally, our results indicate that implementation is contingent on interactions between factors, among the most prevalent being social and political. It is likely that the goals of NCS will not be achieved without broadening them to recognize that the dimensions and impacts of climate change vary across the globe, and successful mitigation solutions will be those that include different strategies targeted at a range of actor groups. Climate change is taking place in diverse social, economic, political, institutional, financial, technical and biophysical contexts and we must make understanding and balancing the enabling factors within these realms a priority in research and policy.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Author contributions

I S conceived of the study. I S, S F, and J E screened and coded the papers included in the study. I S performed the analysis, formulated the figures, and wrote the manuscript. I S, S F, and J O N discussed the results and contributed to the final manuscript. S F supervised the project.

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