AN ACTIONABLE RESEARCH AGENDA FOR INCLUSIVE LOW-CARBON TRANSITIONS FOR SUSTAINABLE DEVELOPMENT IN THE GLOBAL SOUTH

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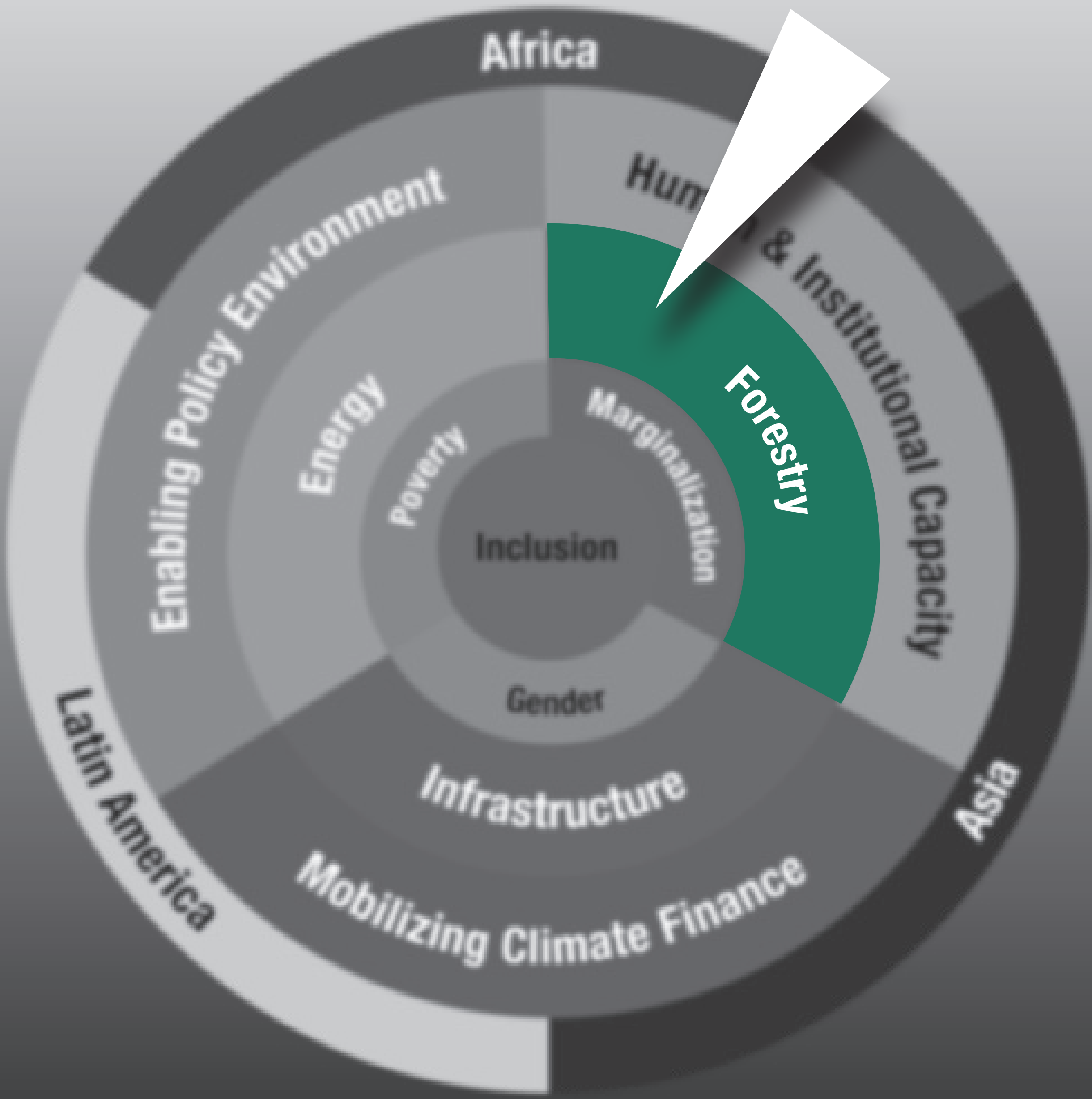

Contents

Preface

All countries now face enormous challenges posed by climate change. The consequences of continued greenhouse gas emissions are dire, particularly for countries in the Global South that are both more affected and more vulnerable to climate change at the same time as they have less capacity to adapt (AfDB, 2022). The realization that a low-carbon transition needs to be implemented also in countries in the Global South is well established and is also reflected in most countries' ratification of the Paris Agreement and in their Nationally Determined Contributions. In effect, most countries in the Global South are now confronted with the fastest and most dramatic transformation of their economies that they have ever experienced – or at least they would need to be.

The low-carbon transition in the Global South needs to be guided by research since such a transition is an inherently knowledge-intensive process. Therefore, the Sustainable Inclusive Economies (SIE) Division of the International Development Research Centre (IDRC) has identified this area as particularly important to support. This report is commissioned by SIE as part of a bigger initiative to develop an actionable research agenda that IDRC can support to achieve a low-carbon transition with gender equity in the Global South.

Forestry and Land Use is part of the Research Agenda for Low Carbon Transition and Gender Equity in the Global South series of papers. The consortium that is working on this series of papers is global and consists of 60 researchers from a multitude of universities and institutions. This particular paper was written by Yuanyuan Yi and Jintao Xu from Peking University, and Randall Bluffstone from Portland State University. Alejandro Lopez Feldman of the EfD Global Hub supported the authors.

This paper examines forestry and land use through its potential as a nature-based solution (NbS) to climate change mitigation and adaptation. After describing the concept of NbS in the context of climate change, the paper looks at the roles that forestry and land use can play in a low-carbon transition. We hope to receive constructive comments on this draft paper from IDRC, our networks and external scholars and practitioners. We will then revise the paper for validation by policy makers and senior civil servants in the Global South. Based on the reviews and validations we plan to prepare final versions of both the paper and the accompanying High-Level Research Agenda by March 2023. The ambition is that these papers will be useful both for donors and research institutions in supporting an even greater contribution by research to a much needed low-carbon transition with gender equity in the Global South in this crucial Decade of Action.

Gunnar Köhlin
Director, Environment for Development

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Forestry and Land Use

1.1 Motivation

Land provides the fundamental basis for the human being. The ecosystem services provided by land include the supply of food, fresh water, and a number other services such as the biodiversity needed for these ecosystem services. Also, land has a critical role for the earth's climate system. An estimated 23% of total anthropogenic greenhouse gas (GHG) emissions during 2007-2016 were derived from agriculture, forestry, and other land use (AFOLU) (IPCC, 2019a).

Forests cover 31% of the land area on our planet (WWF, 2015). They help people thrive and survive, for example, by purifying water and air and livelihood opportunities. Forests are responsible for much of the carbon removal by terrestrial ecosystems, which together remove 29% of annual CO2 emissions (~11.5 PgC; Friedlingstein et al., 2019). Tropical forests hold the greatest amount of aboveground biomass, and have one of the fastest carbon sequestration rates per unit land area (Harris et al., 2021), yet they face the greatest deforestation pressure (FAO, 2020). Globally, forest loss not only releases substantial amounts of carbon into the atmosphere, but also significantly diminishes a major pathway for carbon removal long into the future (Houghton and Nassikas, 2018).

Forests are home to more than three-quarters of the world's life on land (WWF, 2015). As such, land and nature-based approaches in the agroforestry and forestry sectors provide a unique opportunity to generate win-win outcomes toward achieving environmental goals and the Sustainable Development Goals (SDGs), especially SDG 15 (Elias et al., 2021). According to WWF (2015), some 13.2 million people across the world have jobs in the forest sector and another 41 million have jobs related to the sector. Many indigenous peoples and local communities (IPLCs) rely on forests for their survival and well-being, and as such, steward its resources.

In the past 15 years, a growing interest has been placed on the potential of nature-based solutions (NbS) to help and protect people from the impacts of climate change while slowing further warming and supporting biodiversity and securing ecosystem services (Cohen-Shacham et al., 2016; Nature, 2017). The International Union for Conservation of Nature (IUCN) has defined NbS as an umbrella concept that embraces several different ecosystem-based approaches and a set of general principles for any NbS intervention to fulfill its potential (Cohen-Shacham et al., 2016). The approaches can be placed into five categories: protection, management, infrastructure, restoration and issue-specific - such as ecosystem-based adaptation, mitigation, and disaster risk reduction, etc. The principles of NbS emphasize that these solutions should embrace nature conservation norms, cultural contexts, and be implemented in integration with other solutions to societal challenges. For instance, forest-based solutions should incorporate norms and rules of indigenous groups and pastoralist communities, who, in most contexts, are vulnerable with weak or insecure land and resource use rights.

Most importantly, NbS aims to recognize and address the trade-offs between the delivery of a few immediate economic benefits for development, and future options to produce the full range of ecosystem services.

1.1.1. The concept of NbS and its origin

The NbS concept was introduced towards the end of the 2000s by the World Bank (MacKinnon et al. 2008) and IUCN (2009) to highlight the importance of biodiversity conservation for climate change mitigation and adaptation. The NbS concept was promoted by IUCN in its 2009 position paper on the United Nations Framework Convention on Climate Change (UNFCCC) COP 15. In 2012, IUCN formally adopted NbS as a main work area within its 2013-2016 Programme.

In 2015 during the climate change negotiations in Paris, NbS was positioned by IUCN "as a way to mitigate and adapt to climate change, secure water, food and energy supplies, reduce poverty and drive economic growth" (IUCN 2014). IUCN defines the concept of NbS 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 et al., 2016). IUCN suggested seven principles as comprising the core of this concept, including cost efficiency, harnessing both public and private funding, ease of communication, and replicability of solutions (van Ham 2014). Notably, these principles highlight the role of NbS to address global challenges.

The NbS concept is increasingly being developed and applied by IUCN and other organizations. The European Commission includes NbS as a part of its Horizon 2020 Research and Innovation Programme and has invested in several projects to strengthen the evidence base for NbS (Maes and Jacobs, 2017). More broadly, the European Commission defines NbS as "solutions inspired by, continuously supported by and using nature designed to address various societal challenges in a resource efficient and adaptable manner and to provide simultaneously economic, social and environmental benefits" (EC, 2016).

The scope of NbS is broadly defined. The concept is rooted in climate change mitigation and adaptation and is understood as an umbrella term for simultaneously addressing several policy objectives. Among all the objectives, biodiversity conservation and enhancement of ecosystem services are considered as the basis for finding solutions to major challenges, including climate change and disaster risk reduction, as well as addressing poverty and promoting a green economy. Moreover, NbS can be cost-effective; the benefits range from environmental protection to creating jobs and stimulating innovation for a green economy. The goal of simultaneously furthering economic growth and sustainability via NbS has been particularly stressed by the European Commission (Maes and Jacobs 2017; EC 2016).

1.1.2. Applying NbS in the Context of Climate Change

To limit the increase in the global average temperature to 1.5°C and avoid the most serious consequences of climate change, it is necessary to achieve global net zero emissions by around 2050. The focus for emissions reduction has been placed on the energy, industry, and transportation sectors, which are accompanied by high costs and the need for rapid dissemination of technological innovation. Even in the most optimistic scenarios, relying solely on the reduction efforts of these industries will not be sufficient to achieve even the control target temperature of 2°C. On the contrary, according to current emission trends and the Intended Nationally Determined Contributions of countries, the global average temperature will increase by at least 3°C by the end of this century (UNEP, 2019).

Engineered solutions come at a very high cost; one of the distinctive advantages of using NbS to tackle climate change is its low cost, while delivering multiple additional benefits for people and nature, including biodiversity conservation, health benefits, etc. (Gómez-González et al., 2020). NbS can mitigate climate change through the protection, restoration, and sustainable management of ecosystems, including both land-based systems (agricultural land, woodland, grassland, wetland, and desert) and marine ecosystems. There are three main aspects in the mitigation effect of NbS in these ecosystems:

First, protecting forests, grasslands, and wetlands (including coastal wetlands and peatlands) from destruction or degradation can reduce the discharge into the atmosphere of the carbon that has been accumulated in the past decades or thousands of years.

Second, restoring degraded ecosystems can result in the absorption of carbon dioxide (CO2) from the atmosphere, both through photosynthesis and the storage of carbon in vegetation and soil, thereby increasing terrestrial carbon storage (i.e., carbon sink).

Third, the sustainable management of farmland, grassland and woodland reduces carbon emissions and increases terrestrial carbon sinks, as well as reducing non-CO2 greenhouse gases such as methane, nitrogen oxides, and so on, are related to land use and aquaculture.

In addition to the mitigation effect on carbon emissions, restoration of natural forests in upper catchments, for example, is an NbS that can help to protect communities downstream from flooding. Similarly, increasing carbon sequestration and protecting biodiversity through planting trees and increasing green space in cities can help with urban cooling and flood abatement, while storing carbon, mitigating against air pollution, and providing recreation and health benefits. More importantly, there is great potential to foster synergies among climate, biodiversity, and land degradation agendas as well as gender equity through nature-based approaches (Elias et al., 2021). In particular, NbS such as land uses and forestry programs that are responsive to gender issues pay attention to the gender quality in land access and user rights, and greater gains are usually accrued (Elias et al., 2021).

Consequently, NbS has increasingly been viewed not only as a way to reconcile economic development with the stewardship of ecosystems, but also to diversify and transform economies (Calliari et al. 2019). NbS has been endorsed by a number of climate action organizations – the IPBES Global Assessment (IPBES, 2019), the Climate Change and Land Report of the Intergovernmental Panel on Climate Change (IPCC, 2019), the Global Adaptation Commission Report (Global Commission on Adaptation, 2019) – and has been highlighted as one of nine key action tracks at the 2019 UN Climate Action Summit.[1] Meanwhile, the World Economic Forum's (WEF) Global Risks Report 2019 called for nature-positive business solutions and recognized the economic risks

1 See https://www.un.org/en/climatechange/climate-action-areas.shtml

posed by biodiversity loss and ecosystem collapse (WEF, 2019).

It is important to understand the circumstances under which NbS can transform business and enable sustainable development. As Calliari et al. (2019) noted when developing an NbS assessment framework, there is not yet enough evidence about the lessons and successes of how implementations of NbS can contribute to decarbonisation while achieving job creation, climate change mitigation effects, transition to a low-carbon economy, or poverty and inequality reduction effects.

1.1.3. The potential of NbS in global climate change mitigation

According to the IPCC synthesis (Masson-Delmotte et al., 2020), overall, Agriculture, Forestry and Other Land Use (AFOLU) activities accounted for around 13% of CO2, 44% of methane (CH4), and 81% of nitrous oxide (N2O) emissions from human activities globally during 2007-2016, representing 23% (12.0 ± 2.9 Gt CO2 eq yr-1) of total net anthropogenic greenhouse gas emissions. If emissions associated with pre- and post-production activities in the global food system are included, the emissions are estimated to be 21-37% of the total net anthropogenic greenhouse gas emissions. The natural response of land to human-induced environmental changes, such as increasing atmospheric CO2 concentration, nitrogen deposition, and climate change, resulted in global net removals of 11.2 ± 2.6 GtCO2 yr-1 (likely range) during 2007–2016 (Masson-Delmotte et al., 2020).

In other words, there exists immense potential to reduce emissions of AFOLU activities. It is estimated that, in 2030, 2050 and 2100, AFOLU activities can absorb 0-5, 1-11 and 1-5 GtCO2 yr-1, depending on the maturity, absorption capacity, cost, uncertainties, synergies and trade-offs (Griscom et al., 2017). In particular, the carbon sink potential of afforestation reaches 3.6 GtCO2 yr-1, among all the 20 common NbS pathways (see Figure 1).

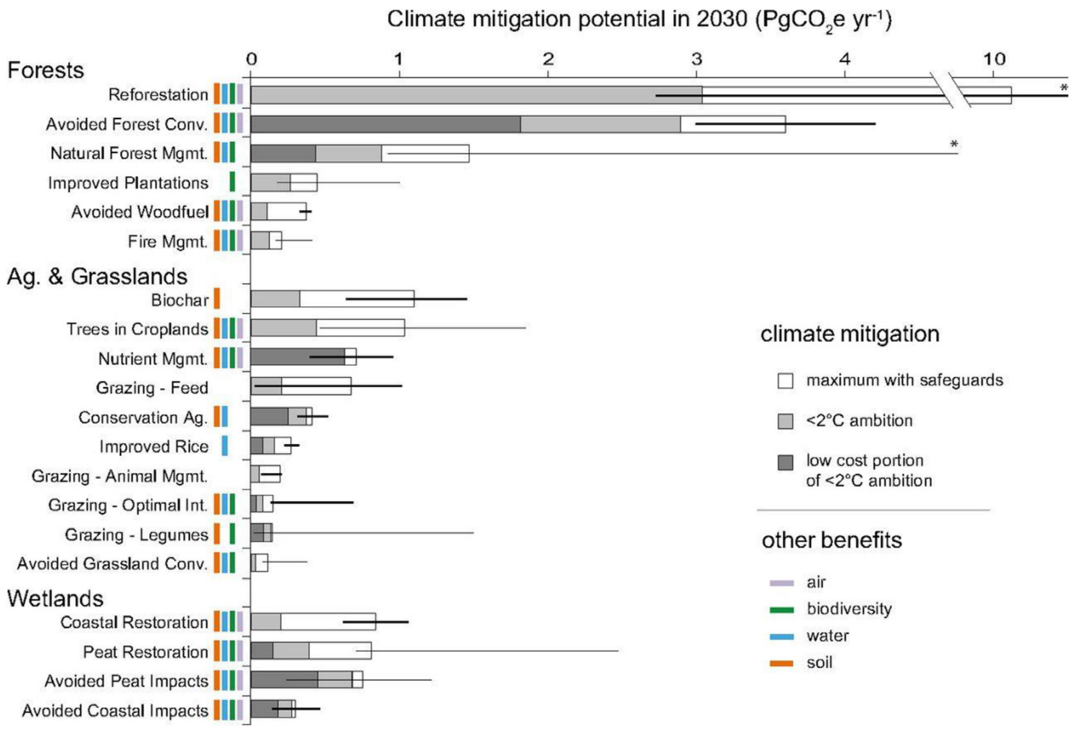

Figure 1. Climate mitigation potential of 20 natural pathways. Source: Griscom et al., 2017

The potential of land-based ecosystems is subject to the opportunity costs and constraints in land resources. It is estimated that the maximum potential of NbS—when constrained by considerations of food security, fiber security, and biodiversity conservation—is 23.8 $GtCO_2$ eq yr^{-1}(95% CI 20.3-37.4, Griscom et al., 2017). Of this potential, cost-effective climate mitigation represents about half, assuming the social cost of CO_2 pollution is no less than 100 USD tCO_2^{-1} by 2030 and that one-third of this can be delivered at or below 10 USD tCO_2^{-1}. More importantly, it has been shown that the aggregated cost-effective mitigation from the 20 pathways—as shown in the figure below—offer 37% of the needed amount through 2030, 29% at year 2030, 20% through 2050, and 9% through 2100 (Griscom et al., 2017).

Among the 20 pathways in Figure 1, reforestation is regarded as having the largest potential, followed by avoided forest conversion and degradation, natural forest management, avoided peat impacts, and peat restoration. The aggregate of the top five pathways accounts for 69.3% of the aggregated potential of all 20 pathways. Of this aggregate, the cost-effective mitigation and low-cost mitigation potential account for 67.8% and 88.8% of the total 20 pathways' potential, respectively. Under the low-cost scenario, the NbS pathway of avoiding deforestation and degradation has the largest potential, contributing to half of the total (Zhang et al., 2020).

To summarize, the "low-cost" and cost-effective NbS carbon sequestration opportunities compare favorably with cost estimates for emerging technologies, most notably bioenergy with carbon capture and storage (BECCS)—which range from ~40 to over 1,000 USD tCO_2^{-1}. Furthermore, large-scale BECCS is untested and likely to have significant impacts on water use, biodiversity, and other ecosystem services (Smith et al., 2016; Santangeli et al., 2016).

1.1.4. How NbS fits into inclusive low-carbon transitions and gender perspectives

Several governments are already considering how to design equitable and inclusive low-carbon development pathways that address the need to achieve emission targets, while taking into account any adverse impacts on low-income households, health and employment (OECD, 2020). For example, Canada, France, Germany, South Africa and Spain have developed or are working on transition plans that account for the social impacts on workers and communities of the transition away from coal. Costa Rica included social aspects in its decarbonisation plan. The Solidarity and Just Transition Silesia Declaration, adopted at COP 24 under the Presidency of Poland, reflects the need for an integrated approach that combines climate priorities, economic needs and social consequences. The declaration further recognises the specific needs and circumstances of developing countries, especially those most exposed to the adverse effects of climate change and most vulnerable to natural disasters and exogenous shocks.[2] It is of great importance that policies to address climate and environmental crises, such as forest and biodiversity loss/degradation, take growing inequality into account (Larson et al., 2021).

NbS can be inclusive through sustainable development, and reduces poverty and inequalities, due to its low-cost and supply of other co-benefits, such as income generating activities, health improvements, and increases in human capital. The degree to which NbS is inclusive depends on how solutions are designed and whether they incorporate inclusivity in addressing environmental problems. To fulfill the potential of NbS to deliver both inclusivity and climate change mitigation benefits, we need to better understand under what conditions NbS can be successful. Forests are the largest carbon pool in the terrestrial ecosystem, having low-cost and technological advantages as an NbS pathway, whilst facing challenges in scientific-based design on tree planting to meet the dual goals of mitigating CO_2 emissions and the long-term, deleterious impacts on biodiversity, landscapes and livelihoods (Di Sacco et al., 2021). However, studies quantifying this potential in low- and middle-income countries, and necessary institutional and policy support, have been scant (Osborne, 2021; Edwards et al., 2021).

More importantly, there are risks that if not gender responsive, NbS used for climate change mitigation can worsen gender equality (Elias, 2021). Women are in general disadvantaged in land and forest resources access and management rights, market access of production factors, education, health, poverty, care economy, compared to men; and rural women are much worse off than urban women in all these indicators (Jost et al., 2016). Women and men in forests and rural areas have different roles within the household and in their labor provision. While at home taking care of children, women are

2 he Solidarity and Just Transition Silesia Declaration, United Nations Climate Change Conference, COP24 Katowice, 2018 https://cop24.gov.pl/fileadmin/user_upload/Solidarity_and_Just_Transition_Silesia_Declaration_2_.pdf

usually responsible for harvesting biomass, collecting water, and household production, which may include subsistence agriculture, collecting non-timber forest products, and stall feeding of livestock (which may also graze in the forests) (Kristjanson et al., 2019). Women in rural areas have less ability to adapt or migrate in response to disasters due to discriminatory norms, mobility constraints and lower education and human capital which could otherwise increase their non-resource sector opportunities (Wong 2016). Women coming from minority ethnic groups (incl. indigenous groups) may confront further disadvantages compared to their counterparts from majority ethnic groups or urban areas (Torres et al., 2018). Though women play critical parts of forest economies, agriculture and textile manufacturing, the existing impact studies on these sectors rarely acknowledge the gender dimension.

1.2 Roles of forestry and land use in low-carbon transition

1.2.1. Carbon sequestration and offsetting CO2 emissions

Carbon dioxide removal cannot replace vital emissions cuts, but it can help to offset emissions that cannot be eliminated, and crucially, enable countries to achieve net-zero sooner. Making full use of the potential of NbS is an empowering opportunity in the sense that the poor get more access to land or improved tenure rights to land, especially in places where large shares of emissions come from the land sector (Anderson et al., 2019).

Due to the important roles of NbS in low-carbon transition, numerous studies have examined the quantification of carbon sequestration by NbS pathways. Although analyses of NbS have some differences in the Greenhouse Gas (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) (Anderson et al., 2019). According to the literature (Table 1), the global terrestrial C sink has been increasing over time (−0.2±0.9 Pg C yr−1 source in the 1960s to a sink of 1.9±1.1 Pg C yr−1 in the 2010s) (Friedlingstein et al., 2020). The C balance differs substantially among different land use types (Table 1 and Table 2): forest is the major C sink; farmland, shrubland and wetland soil act as C sinks; and whether grassland functions as a C sink or source remains unclear. The desert might be a C sink, but the magnitude and the associated mechanisms are still controversial (Yang et al., 2022).

The quantification of the potential for carbon sequestration of NbS is mostly estimated based on field surveys (Brown et al., 1984; Fang et al., 2001; Bastin et al., 2019). The International Biological Programme (IBP), implemented in the 1960s and 1970s, conducted many surveys on forest biomass in various countries. With the rapid development of information technology and the wide application of 3S technology, using remote sensing information and GIS technology to estimate carbon sequestration of NbS has become an important method. Many studies have used ecological models that combine remote sensing data with forest resource inventory data to more accurately estimate forest carbon reserves (Zheng et al., 2004; Piao et al., 2009; Gray et al., 2014; Babcock et al., 2016). Recent analyses demonstrate that NbS pathways of forests and land-related (incl. agricultural, grassland, and wetlands), including both decreasing sources and increasing sinks of GHGs in ecosystems and agriculture, could be deployed at the scale of billions of metric tons of CO2 equivalent (CO2e) per year, at costs below $100 per metric ton CO2e (Griscom et al., 2017).

In forestry, afforestation and reforestation are well-established approaches which can store carbon as well as enhance biodiversity (Catching carbon, 2022). However, the benefits of afforestation are constrained by land availability. Recent framing of the potential percentage of mitigation that can come from NbS, as opposed to energy and industry, has been interpreted to imply that climate mitigation in one arena will be offset by less reduction in others, implying that more mitigation in one sector leads to less mitigation effort required in another sector (Griscom et al., 2017). Successful implementation of any carbon dioxide removal approach will require careful consideration of other land-use needs.

About half of the world's habitable area is currently devoted to agriculture (Ritchie, 2019). Between 2004 and 2013, land-use change contributed to approximately 9% of global carbon dioxide emissions (Global Carbon Project, 2014). Between 1990 and 2007, the world's forests captured as much as 30% of the total yearly emissions of GHGs generated by fossil fuel combustion, cement production and land-use change (Pan et al., 2011). One way to expand capacity is through agroforestry, whereby trees are incorporated into agriculture such that the land can support food production, carbon uptake, and increased biodiversity (Catching carbon, 2022).

Table 1 The quantification of carbon sequestration by Nature-based Solution pathways

Land use type	Country/Region	Quantity of carbon emission (-) / sink (+)	Description	Source
Terrestrial ecosystems	Global	−0.2±0.9 Pg C yr^{-1}	in the 1960s	Friedlingstein et al., 2020
Terrestrial ecosystems	Global	1.9±1.1 Pg C yr^{-1}	in the 2010s, after deducting the C release induced by land use changes	Friedlingstein et al., 2020
Terrestrial ecosystems	Global	3.4±0.9 Pg C yr^{-1}	2010-2019	Friedlingstein et al., 2020
Terrestrial ecosystems	Global	3.1±1.2 Pg C yr^{-1}	2019	Friedlingstein et al., 2020
Terrestrial ecosystems	China	0.20–0.25 Pg C yr^{-1}	between 2001 and 2010, with forest accounting for about 80% of the sink, followed by cropland (12%) and shrubland (8%), and grassland being a C neutral or weak source	Fang et al., 2018; Tang et al., 2018
Terrestrial ecosystems	China	0.15–0.52 Pg C yr^{-1}	2060	Yang et al., 2022
Land use change, mainly deforestation	Global	-1.6 ± 0.7Pg C y^{-1}	2010-2019	Friedlingstein et al., 2020
Land use change, mainly deforestation	Global	-1.8±0.7Pg C y^{-1}	2019	Friedlingstein et al., 2020
Land use change	Southern China	0.11 ± 0.05 Pg C y^{-1}	2002-2017, increased standing aboveground carbon stocks; accounted for 33% of regional fossil CO2 emissions; newly established forests contributed 32%; forests already existing contributed 24%; forest growth in harvested forest areas contributed 16% and non-forest areas contributed 28% to the carbon sink	Tong et al., 2020
Forest, shrubland, and grassland	Region of China's six key national ecological restoration projects	132 Tg C y^{-1}	2001-2010, the total annual C sink in the project area (16% of the country's land area), 56% (74 Tg C y^{-1}) was attributed to the implementation of the projects	Lu et al., 2018
Forest	Global	−0.90 Pg C yr^{-1}	1987-1990, the C uptake by global temperate and cold temperate forest (0.7 Pg C yr^{-1}) due to forest growth and expansion could not compensate for the 1.6 Pg C yr^{-1} release caused by tropical deforestation	Dixon et al., 1994
Forest	Global	1.1 Pg C yr^{-1}	1990-2007, the global forest net C sink. The global forests accumulated C at the rate of 4.0 Pg C yr^{-1} and after deducting the C release (2.9 Pg C yr^{-1}) from tropical deforestation	Pan et al., 2011
Forest	Global	0.4 - 4.0 Mg C ha^{-1} yr^{-1}	?	Luyssaert et al., 2007
Forest	Global	8.95 Pg C yr^{-1}	1990s-2000s	Yu et al., 2014
Forest	Global	2.15 Pg C yr^{-1}	2001-2010	Pugh et al., 2019
Forest	Global	2.6 Mg C ha^{-1} y^{r-1}	?	Wang et al., 2017
Forest	Global	0.4 - 4.0 Mg C ha^{-1} yr^{-1}	?	Luyssaert et al., 2007
Forest	East Asian monsoon region between 20°N and 40°N	3.6 Mg C ha^{-1} yr^{-1}	1990-2010	Yu et al., 2014
Forest	North American	0.07-0.35 Pg C yr^{-1}	in the 1980s	Delcourt and Harris, 1980; Turner et al., 1995
Forest	North American	1.46 Mg C ha–1 yr–1	1991-2007	Schwalm et al., 2010

Forest	European	0.09–0.12 Pg C yr^{-1}	1971-1990	Kauppi et al., 1992
Forest	European	0.47 Pg C $yr^{-1.}$	2000s	Papale and Valentini, 2003
Forest	Amazon	0.54 Pg C yr^{-1}	1990s	Brienen et al., 2015
Forest	Amazon	0.38 Pg C yr^{-1}	1990s-2000s. The continuous increase in forest mortality led to a decline in C sink in the Amazon forests.	Brienen et al., 2015
Forest	Africa	0.66 Mg C ha^{-1} yr^{-1}	1990-2020	Hubau et al., 2020
Forest	East Asia	3.6±0.4 Mg C ha^{-1} yr^{-1}	1990-2010	Yu et al., 2014
Forest	China	0.15 Pg C yr^{-1}	1980s–2000s, offsetting about 15.6% of the fossil fuel C emissions	Zhu et al., 2017
Forest	China	0.08 Pg C yr^{-1}	1980-2000, Ecosystem C sink	Piao et al., 2009
Forest	China	0.18 Pg C yr^{-1}	1988-2008, Ecosystem C sink	Wang et al., 2007
Forest	China	0.12-0.17 Pg C yr^{-1}	1977-2013, Ecosystem C sink	Yang et al., 2017a
Forest	China	0.16 Pg C yr^{-1}	2001-2010, Ecosystem C sink	Fang et al., 2018
Forest	China	-0.022 Pg C yr^{-1}	1949-1980, Biomass C sink	Fang et al., 2001
Forest	China	0.015 Pg C yr^{-1}	1970s-1980s, Biomass C sink	Pan et al., 2004
Forest	China	0.021 Pg C yr^{-1}	1980-1998, Biomass C sink	Fang et al., 2001
Forest	China	0.05 Pg C yr^{-1}	1984-1998, Biomass C sink	Guo et al., 2013
Forest	China	0.068 Pg C yr^{-1}	1990s, Biomass C sink	Pan et al., 2004
Forest	China	0.109 Pg C yr^{-1}	1999-2008, Biomass C sink	Guo et al., 2013
Forest	China	1.9–3.4 Pg C	2020s-2040s, forest biomass, assuming no removals, mainly because of forest growth.	Tang et al., 2018
Boreal Forest	Global	0.50 Pg C yr^{-1}	1990-2007	Pan et al., 2011
Temperate Forest	Global	0.72 Pg C yr^{-1}	1990-2007	Pan et al., 2011
Tropical Forest	Global	–0.11 Pg C yr^{-1}	1990-2007	Pan et al., 2011
Grassland	Global	–1.9±0.1 Pg C yr^{-1}	1982-2001	Liang et al., 2020
Grassland	Global	0.37±0.19 Pg C yr^{-1}	1990–2007	Chang et al., 2021
Grassland	China	–3.4 Tg C y^{-1}	2001-2010, the grassland ecosystem served as a weak C source (vegetation biomass, dead organic matter, and soil organic carbon)	Fang et al., 2018
Cropland	Global	0.42 Pg C yr^{-1}	1961–2010	Karstens et al., 2020
Peatland	Global	0.48 Pg C yr^{-1}	1961–2014	Ren et al., 2020;
Cropland	Global	0.11 Pg C yr^{-1}	1975–2010	Wang et al., 2017
Cropland	China	140 kg C ha^{-1} y^{-1}	1980-2011, increased soil organic carbon (C) stock	Zhao et al., 2018
Peatland	Global	1.1-2.6 Pg C yr^{-1}	in 2030	Strack et al., 2022

Table 2 Quantification of carbon stock by Nature-based Solution pathways

Land use type	Country/Region	Quantity of carbon stock	Description	Resource
Terrestrial ecosystems	China	89.27 ± 1.05 Pg C.	All terrestrial ecosystems are considered	Tang et al., 2018
Forest	Global	1,146 Pg C	1987-1990, with biomass and soil C pools of 359 and 787 Pg C, respectively	Dixon et al., 1994
Forest	Global	861 Pg C	which was stored in biomass (363 Pg C, 42%), soil (383 Pg C, 44%), litter (43 Pg C, 5%) and dead wood (73 Pg C, 8%).	Pan et al., 2011
Forest	Europe	0.17–0.35 Gt C	in 1997, accounted for about 20%–40% of Europe countries' anthropogenic CO^2 emissions	Martin et al., 1998
Forests	China	30.83 ± 1.57 Pg C	of which 82.9% was stored in soil (to a depth of 1 m), 16.5% in biomass, and 0.60% in litter	Tang et al., 2018
Tropical Forest	Global	471 Pg C	consisting of 393 Pg C in intact tropical forest and 78 Pg C in re-growing tropical forest	Pan et al., 2011
Boreal Forest	Global	272 Pg C		Pan et al., 2011
Temperate Forest	Global	119 Pg C		Pan et al., 2011
Grassland	Global	634 Pg C	Vegetation 75 Pg C and soil 559 Pg C	Ajtay et al., 1979
Grassland	Global	633.6 Pg C	Vegetation 42.1Pg C and soil 591.5Pg C	Houghton et al., 1983
Grassland	Global	392.3 Pg C	Vegetation 51.8Pg C and soil 340.3 Pg C	King et al., 1997
Grassland	Global	525 Pg C	Vegetation 102 Pg C and soil 423 Pg C	Prentice et al., 2001
Grassland	Global	520 Pg C		Carvalhais et al., 2014
Grassland	China	58.4 Pg C	Vegetation 4.7 Pg C and soil 53.7 Pg C	Ni, 2001
Grassland	China	44.1 Pg C	Vegetation 3.1 Pg C and soil 41 Pg C	Ni, 2002
Grassland	China	17.3 Pg C	Vegetation 0.6 Pg C and soil 16.7 Pg C	Li et al., 2004
Grassland	China	59.5 Pg C	Vegetation 3.2 Pg C and soil 56.3 Pg C	Zhang et al., 2016
Grassland	China	25.40 ± 1.49 Pg C	Vegetation1.4 Pg C, soil 24 Pg C	Tang et al., 2018
Cropland	China	16.32 ± 0.41 Pg C	of which 82.9% was stored in soil (to a depth of 1 m), 16.5% in biomass, and 0.60% in litter	Tang *et al.*, 2018
Peatland	Global	600 Pg C	Peatlands cover ~ 400 million hectares (Mha), about 3% of the Earth's land area, yet are estimated to store up to 30% of all soil carbon	Strack *et al.*, 2022
Woodland and shrubland and desert scrub	Global	27.4 Pg C	Vegetation C stock in 1970s	Whittaker and Lik-ens,1973
xerophytic woods/scrub, warm grass/shrub, and cool grass/shrub	Global	306 Pg C	Vegetation 65 Pg C and soil 241 Pg C	Prentice *et al.*, 1993
xerophytic woods/scrub, warm grass/shrub, and cool grass/shrub	Global	310.3 Pg C	Vegetation 61.6 Pg C and soil 248.7 Pg C	Foley, 1995
dry grassland/shrubland, sclerophyll woodland, and shrub-tundra	Global	149 Pg C	Vegetation 14 Pg C and soil 135 Pg C	Prentice *et al.*, 2011
Scrub forest	China	0.4 Pg C	Vegetation C stock in 1990s	Fang *et al.*, 1996

Temperate dry scrubs, temperate semiarid scrubs, warm-temperate scrubs, tropical scrubs, and arid shrublands/ steppe	China	32.5 Pg C	Vegetation 8 Pg C and soil 24.5 Pg C	Ni, 2001
Scrubland	China	1.7 Pg C	Vegetation C stock in 2000s	Hu *et al.*, 2006
Scrubland	China	10 Pg C	Vegetation 0.9 Pg C and soil 9.1 Pg C	Yu *et al.*, 2010
shrubland	China	6.69 ± 0.32 Pg C	of which 82.9% was stored in soil (to a depth of 1 m), 16.5% in biomass, and 0.60% in litter	Tang *et al.*, 2018
Cropland	Global	157 Pg C	Soil C stock	Jobbágy and Jackson, 2000
Cropland	Global	165 Pg C	Soil C stock	Carter and Scholes, 2000
Cropland	Global	128–165 Pg C	Soil C stock	Lal, 2004
Cropland	Global	164 Pg C	Soil C stock	Global Soil Data Task,2014
Cropland	Global	194 Pg C	Soil C stock	Hengl *et al.*, 2014
Cropland	Global	140.3 Pg C	Soil C stock	Zomer *et al.*, 2017
Cropland	Global	115 Pg C	Soil C stock	Ren *et al.*, 2020
Cropland	China	12.2 Pg C	Soil C stock	Yu *et al.*, 2007
Cropland	China	13 Pg C	Soil C stock	Xie *et al.*, 2007
Cropland	China	4 Pg C	Soil C stock	Yan *et al.*, 2011
Cropland	China	5.1 Pg C	Soil C stock	Song *et al.*, 2005
Cropland	China	5.2 Pg C	Soil C stock	Qin *et al.*, 2013
Cropland	China	5.9 Pg C	Soil C stock	Li *et al.*, 2003
Cropland	China	4 Pg C	Soil C stock	Tang *et al.*, 2006
Cropland	China	11.8 Pg C	Soil C stock	Zhang *et al.*, 2017
Cropland	China	7.5 Pg C	Soil C stock	Tang et al., 2018

1.2.2. Forest policies relevant for a low-carbon transition at national level

Various jurisdictions worldwide have implemented, or are in the process of developing forest carbon mitigation strategies and policies to reduce their GHG emissions or increase carbon sequestration. There exists a significant gap in national-level forest-based approaches between the Global North and the Global South countries.

The Global North countries have started targeting this transition using forest policies that are still in relatively early stages. For example, the government of Finland has adopted climate change mitigation as one of its forest management goals (e.g., Ministry of Agriculture and Forestry, 2010; Ministry of Employment and the Economy, 2011), leading to the development of new, or modification of existing, policies associated with forest-related activities such as bioenergy, harvesting waste management, forest conservation and silviculture (Makkonen et al., 2015). Sweden has also implemented various forest carbon policies, notably in terms of bioenergy, waste management and carbon sequestration in harvested wood products (Lundmark et al., 2014).

In Poland, the issues of climate change and forest adaptation have been included as main themes in forest policy design. The "second" National Forest Policy (NFP 2), elaborated in 2012–2016, included creating a system for monitoring climate change impacts on forests, a substitute for energy-consuming materials and a renewable source of energy, and developing short-rotation forest plantations, which can complement and relieve ecosystem forestry (Kaliszewski 2018).

However, in the Global South, some countries have promulgated opposite forestry policies to conservation and sustainable use. In 2012, Brazil's National Congress altered the country's Forest Code, decreasing various environmental protections in the set of regulations governing forests. The consequences are increased deforestation and GHG emissions, and decreased protection of fragile ecosystems (Roriz et al., 2017).

The Paris Agreement marked a historic turning point for global climate action, as world leaders came to a consensus on an accord comprised of commitments by 195 nations to combat climate change and adapt to its impacts. During 2015-2022, over 40 developing countries designated forestry policies to mitigate climate change (Table 3).

Carbon trading markets allow for forest carbon offsets and the trading of carbon credits. A similar gap exists between the Global North and the Global South countries. Carbon trading markets have been growing in many jurisdictions such as New Zealand (Manley and Maclaren, 2012), Australia (Buizer and Lawrence, 2014), and the USA (Kerchner and Keeton, 2015). Some developing countries have been involved in the climate mitigation mechanism of the United Nations known as reducing emissions from deforestation and forest degradation in developing countries (REDD+) (Angelsen et al., 2014). Mexico is currently the only country in the Global South which has successfully implemented an Emissions Trading System (ETS) up to 2022. Chile and Colombia, have intentions of implementing ETS, but this is either still under consideration, in legislative process, or in the public policy formulation stage (Carbon Pricing Dashboard, 2022). From the example of Mexico, one of the biggest challenges was the need for technical support and assistance. The design of this ETS program was supported by the German government and the World Bank (Gobierno de México, 2021). Another challenge is related to the companies and entities that make up part of the ETS, as there are several requisites needed. As ETS are a very new method for reducing carbon emissions, many companies do not understand the concept, the intentions, and the need to regulate these emissions, and therefore compliance levels may be low. Another limitation to the emergence of ETS in LAC is the lack of trust between institutions and their enforcement capacities due to asymmetric information between the companies and the ETS monitors (Cárdenas, M. et al, 2021).

Decentralized forest governance has been adopted by a growing number of countries (RRI, 2018; Agrawal et al., 2008); almost 30% of all developing countries' forests are now managed by local communities, well over twice the share for protected areas (RRI, 2020; Chape et al., 2005). Equally important, but largely ignored by researchers and policymakers in other low and middle income countries with rich forest resources, is evidence that reforms that decollectivize communal lands—i.e., reforms that convert communal farmland or forestland to private or quasi-private smallholdings—can boost investment in forest management and increase forest area through reforestation (Vincent et al., 2021). Vietnam (Quang et al., 2015; Nguyen et al., 2010) and China (Yi et al., 2014; Liu et al., 2017) provide leading examples of this effect.

Gender considerations have been incorporated into some countries of the Global South in the plans and strategies of using forest and land-based ecosystems for low-carbon development (RRI, 2017). For instance, Bangladesh in its Climate Change and Gender Action (ccGAP, 2013) has emphasized the role of women in the agricultural sector, creating an environment to lease land or water bodies to women and provide financial supports like crop insurance and training support such as improving capacity to take up alternative technologies. Cambodia's Climate Change Strategic Plan (2013) recognized that women are most vulnerable to climate change impacts because of their high dependence on agriculture and natural resources. Ethiopia, Gambia, Tanzania, and Uganda recognize this vulnerability too (Fisher and Mohun, 2015).

Women and men in the forests and rural areas have different roles within the household and in their labor provision. Women at home, taking care of children and livestock that may also graze in the forests, are responsible for harvesting biomass, collecting water, and household production, including production from non-forest products as well as agricultural subsistence (Kristjanson et al., 2019). Women in rural areas have less ability to adapt or migrate in response to disasters due to discriminatory norms, mobility constraints, and their lower education and human capital, which could increase their non-resource sector opportunities (Wong 2016). Women coming from minority ethnic groups may confront further disadvantages compared to their counterparts coming from the majority ethnic groups or urban areas (Torres et al., 2018).

Case studies offer lessons and success stories for the inclusivity of women in the process of low-carbon transition, climate change mitigation and adaptation. In Mozambique, Tanzania, and Nepal, community-based natural resource management and climate change adaptation plans took into account the needs of the local resource-dependent people and helped reduce pressure on fisheries, forests, and freshwater, which could help women – almost to the same extent as compared to their male counterparts – earn income, feed their families, and lifted themselves out of poverty (CARE-WWF Alliance, 2019). In India and Nepal, regulatory reforms introduced quotas and membership rules to increase local women's participation in community forest user groups, thereby opening spaces for women in community forestry (Wagle et al., 2017).

Given that REDD+ processes have highlighted the need for more secure rights to land and resources among women and marginalized groups of people as a precondition for more sustainable land management decisions, gender-responsive REDD+ can lead to inclusive low-carbon transitions (Larson et al., 2015; Chomba et al., 2016; Vallejos, 2020). A number of studies have provided positive links between tenure security – especially women's rights to land – and incentives and capacities to invest in sustainable land, soil, and environmental management (e.g., Etongo et al., 2018; Meinzen-Dick et al., 2019). Tseng et al. (2021), in their global review of 117 studies, found a positive relationship (in 32 cases studied) between improved land tenure security and environmental outcomes, including more sustainable agricultural practices, improved forest conditions, and investments in agroforestry and forest conservation. They further identify 'win-win' situations among human well-being and environmental outcomes, as well as trade-offs among outcomes. Specifically, they examine women's empowerment across nine countries (Ethiopia, Kenya, Rwanda, Tanzania, Zambia, India, Nepal, Vietnam and Peru), and the distribution of effects indicates strong support for the positive effects of enhanced land tenure security (72% positive). In Uganda, Ekesa et al. (2020) link improved tenure security for women and men with an increased diversity of species grown on those lands. However, the positive outcomes should not be taken for granted, and the necessity of the condition of secure land rights and/or other conditions is worthy of investigating (Holland et al., 2022), as well as the impacts on climate change mitigation.

To summarize this subsection, we use the note by IPCC (2019, p.31): "empowering women can bring synergies and co-benefits to household food security and sustainable land management." And the consequences facilitating low-carbon transition is worthy of rigorous study.

Table 3 Forest policies relevant for a low-carbon transition (2015-2022).

Laws and Policies	Country	Year	Description and sources
Strengthening the Nation's Forests, Communities, and Local Economies	United States of America	2022	This document updates the administration's forestry policies with a particular focus on federal lands. The document aims at reducing wildfire risk, strengthening local economies, and combating global deforestation. The objectives are stated as follows: 1) pursue science-based, sustainable forest and land management; 2) conserve America's mature and old-growth forests on federal lands; 3) invest in forest health and restoration; 4) support indigenous traditional ecological knowledge and cultural and subsistence practices; 5) honor tribal treaty rights; 6) and deploy climate-smart forestry practices and other nature-based solutions to improve the resilience of our lands, waters, wildlife, and communities in the face of increasing disturbances and chronic stress arising from climate impacts. The document stresses the importance of consulting with a range of local authorities and non-state actors, and of supporting local, collaborative initiatives. Link
Emissions Reduction Plan (ERP)	New Zealand	2022	The ERP contains strategies, policies, and actions for achieving the first emissions budget. Notable actions promoted by the ERP include establishing native forests at scale to develop long-term carbon sinks and improve biodiversity. Link
Conserve Global Forests: Critical Carbon Sinks	United States of America	2022	The plan sets forth the U.S. approach to conserving critical global terrestrial carbon sinks, deploying a range of diplomatic, policy, and finance mechanisms. It sets a restoration goal by 2030 with hopes of emulation. It outlines the initial approaches the United States intends to deploy to achieve four key objectives: incentivize forest and ecosystem conservation and forest landscape restoration; catalyze private sector investment, finance, and action to conserve critical carbon sinks; build long-term capacity and support the data and monitoring systems that enhance accountability; and increase ambition for climate and conservation action. The plan focuses primarily on the Amazon, the Congo, and Southeast Asian forests. Subject to Congressional appropriations, by 2030 the United States intends to dedicate up to $9 billion of international climate funding to support these objectives. Link.
National Forest Policy	Dominica	2022	The purpose of this National Forest Policy is to guide the sustainable management of the forest resources of the Commonwealth of Dominica, including the use of these resources, and the impacts and consequences of that use. It aims to keep the forests healthy, increase their cover and the ecological, economical, and socio-cultural benefits. It calls for a collaborative approach and the promotion of traditional knowledge. Link.
Framework Climate Law No. 98/2021	Portugal	2021	The objectives of this framework include protecting and promoting the regeneration of biodiversity, ecosystems, and services. Link.
Saudi Green Initiative and Green Middle East Initiative	Saudi Arabia	2021	The Saudi Green Initiative includes plans to generate 50% of Saudi Arabia's energy from renewables by 2030 and to plant 10 billion trees. The scheme is also reported to involve cooperation with other Middle Eastern leaders on a Green Middle East Initiative. Link.
Action Plan for Carbon Dioxide Peaking before 2030 ('1+N')	China	2021	This Action Plan aims to enable carbon dioxide peaking by 2030 and ultimately achieve carbon neutrality. It covers the 14th and 15th five-year plan periods. The plan mandates adopting systems thinking, with a holistic approach to the conservation of mountain, river, forest, farmland, lake, grassland, and desert ecosystems. Bolster the carbon sequestration capacity of ecosystems, including through large-scale protection and restoration of major ecosystems, afforestation, and increase of grassland resources. Strengthen the foundation for ecological system carbon sinks, notably by improving mechanisms for ecological compensation, measurement, and valuation of carbon sinks, and establish rules for carbon sink projects in the national carbon market. Promote carbon emissions reduction and carbon sequestration in agriculture and rural areas. Link.
The Gambia 2050 Climate Vision	Gambia	2021	This document sets out the government's strategy to meet commitments made under the Paris Agreement, and to move towards resilience and net zero carbon emissions by 2050. Strive to maintain 30% of the total land area of the Gambia under forest cover, with further efforts to implement afforestation actions which will contribute reductions of 275.4 GgCO2e in 2025 and 330.5 GgCO2e in 2030. Link.
Notification S.O. 4259(E) creating the Apex Committee for Implementation of Paris Agreement	India	2020	This document from the Ministry of Environment, Forest and Climate Change creates the Apex Committee for Implementation of the Paris Agreement (AIPA). It further sets its composition and missions. Climate targets in this law include creating more carbon sinks by creating more forests and tree cover by 2030. The creation of 2.5-3Bn T of carbon dioxide sinks. Link.

National Climate Change Learning Strategy of Zambia	Zambia	2020	This document systematically examines the country's learning and skills development needs to respond to the impacts of climate change. It aims to strengthen individual and institutional systemic capacities of the energy, health, forestry, agriculture, and education sectors to enable them deliver climate change learning and contribute to the implementation of the NDC and NAPs. Link.
Agriculture Act 2020	United Kingdom	2020	The Agriculture Act 2020 establishes a new system of agricultural subsidies, replacing the Common Agricultural Policy of the European Union following the UK's withdrawal from the European Union. Section 1(1) of the Act provides that financial assistance may be provided to those involved in agricultural, horticultural, or forestry activities for a number of purposes, including "managing land, water, or livestock in a way that mitigates or adapts to climate change." Link.
Green Jobs Initiative	Sweden	2020	This initiative aims at investing SEK 150 million into creating green jobs and helping the country against the adverse economic effects of the COVID-19 crisis. The policy seeks to strengthen nature conservation and forest management, as well as promote outdoor activities, cultural sites, recreation, and tourism. Link.
National Forestry Policy 2020	Solomon Islands	2020	This document has been identified in the country's updated NDC.
National Forest Policy 2020	Nigeria	2020	This document sets out the country's forest policy and replaces the National Forest Policy 2006. It seeks to improve sustainable management of the resource and increase total forest cover.
Dominica Climate Resilience and Recovery Plan 2020-2030	Dominica	2020	The plan confirms Dominica's commitment to becoming 'carbon neutral' by 2030. The description of this target in Annex 2 notes that carbon neutrality will be "achieved through 100% domestic renewable energy production, and increase of protected forest areas to 67% of Dominica's land mass." Link.
Enhanced National Greening Program (Executive Order 26 of 2011 and Executive Order 193 of 2015)	Philippines	2019	The program gives effect to Executive Orders No. 23 and 26 of 2011, which aim to address climate change, ensure the sustainable management of natural resources, and reduce poverty through forest management practices, and Executive Order No. 193 of 2015, which aims to rehabilitate all the remaining unproductive, denuded, and degraded forestlands, estimated at 7.1 million hectares, from 2016 to 2028.
Forests Act 12/2019	Nepal	2019	Forests Act 12/2019 was adopted to enable Nepal to meet its commitments to the Paris Agreement. This document notably states in chapter 13, article 44, on the management of environmental services that the government shall make provisions with regard to climate change adaptation and storage, mitigation of emissions of carbon, the management, and use and distribution of dividends. Link.
Brunei Darussalam National Climate Change Policy 2020	Brunei Darussalam	2019	This document is Brunei's framework policy to address climate change. It is devised in ten strategies focusing on industrial emissions, forest cover (planting 500,000 new trees by 2035), electric vehicles, renewable energy, power management, carbon pricing, waste management, climate resilience and adaptation, carbon inventory and awareness and education. Link.
Sudan National Forestry Policy Statement	Sudan	2019	The policy notably seeks to create a "greener Sudan" by countering deforestation and degradation of forest cover caused by illegal cutting, misuse and mismanagement of cutting permits, agricultural expansion, and demand for fuel energy. This goal is meant to reverse the trend of forest cover loss by facing and dealing with the deforestation, desertification and environmental degradation problems. The Sudan will in particular aim at identifying the detailed reasons for forest loss, and formulate and implement programs supported by the mid- and long-term national development and investment plans. Link.
Presidential Decree 7/2019 establishing the national policy of climate change mitigation and adaptation and creating the national response system to climate change	Nicaragua	2019	This decree establishes the national policy of climate change mitigation and adaptation and creates the national system of climate change response. The policy aims for the conservation, restoration and rational use of forests, as well as promoting forest plantations in areas of forest potential. Link.

The National Environment Act	Uganda	2019	This document repeals, replaces and reforms the law relating to environmental management in Uganda. It aims to provide a legal framework to environmental issues including climate change. Art. 69 on the management of climate change impacts on ecosystems states that a lead agency may put in place guidelines and prescribe measures to 1) address the impacts of climate change on ecosystems, including by improving the resilience of ecosystems, promoting low-carbon development and reducing emissions from deforestation and forest degradation, sustainable management of forests and conservation of forest carbon stock, and 2) advise institutions, firms, sectors or individuals on strategies to address the impacts of climate change, including those related to the use of natural resources, 3) take measures and issue guidelines to address the impacts of climate change, including measures for mitigating and adapting to the effects of climate change, and 4) liaise with other lead agencies to put in place strategies and action plans to address climate change and its effects. Link.
Strategic Investment Framework for Environment and Natural Resources Management (CSIGERN)	Togo	2018	The framework seeks an inclusion of environmental concerns, including climate change mitigation and adaptation aspects, into sectoral policies, and sets a budget to finance actions in forestry and other environments.
Zambia's Climate Change Gender Action Plan (ccGAP)	Zambia	2018	The ccGAP is an intersectional document aiming at advancing women's empowerment and enabling gender equality while setting climate change response plans. Climate targets in this law include reducing the share of wood fuel in the energy sector to 40% by 2030. Link.
Framework Law No. 30754 on Climate Change	Peru	2018	Article 16 of the Framework Law details how mitigation efforts should be pursued, via carbon sequestration and the increase of sinks; prioritizing the protection, conservation and sustainable management of forests; afforestation and reforestation; controlling land use and change of land use; etc. Link.
National Policy and Response Strategy on Climate Change	Liberia	2018	This document defines the overarching climate mitigation and adaptation strategy of Liberia, sectoral implications, and cross-cutting issues. It notably assesses the country's vulnerabilities to climate change regarding poverty and forest management. Mitigation policies include the enhancement of the country's potential for carbon sequestration by promoting conservation, sustainable forest management, and community forestry, and curbing key drivers of deforestation and forest degradation, which in turn will contribute to sustainable wildlife management. Link.
General Law for Sustainable Forest Development	Mexico	2018	Specific objectives of this law (stated at art. 3) include: 1) the promotion of sustainable forest management in order to help maintain and increase carbon stocks and reduce emissions from deforestation and forest degradation, as well as reduce vulnerability and strengthen resilience and adaptation to climate change, and 2) the design of strategies, policies, measures and actions to transition to a zero percent carbon loss rate in the original ecosystems, in terms of the General Law on Climate Change and the National Climate Change Strategy, for incorporation into the instruments of forest policy planning, taking into consideration the sustainable economic development of forest regions and community forest management. Art. 10 states that the federal state has the prerogative of designing strategies, policies, measures and actions to avoid loss and increase carbon stocks in forest ecosystems, taking into account sustainable rural development. Art. 32 states that the contribution to carbon fixation is one of the mandatory criteria for forestry policy of an environmental and forestry nature. Link.
Climate Investment Programme - Operational Framework for Managing and Accessing Climate Finance in the Kyrgyz Republic	Kyrgyzstan	2018	This programme aims to finance a range of climate resilient projects that are aligned with climate-related national policies. The programme identifies a key action to enhancing the climate resilience of forestry and biodiversity. Link.
National Policy for Climate Change	Uruguay	2017	The National Policy on Climate Change promotes adaptation and mitigation in the country. It sets objectives over the short, medium and long term up to 2050. It further seeks to improve the carbon sequestration function of national forests. Link.
National Strategy to Combat Climate Change in Change	Chad	2017	This document aims to sustainably integrate climate change adaptation and mitigation issues into national development policies, and to effectively coordinate the convergence of climate initiatives in the country. It sets five goals; the first goal is strengthening the resilience of agro-sylvo-pastoral production systems. Link.

Policy Development Plan 2017-2021	Suriname	2017	This document lays out the country's development plan for the period 2017-2021. The plan notably seeks to increase resilience capabilities, including protecting forests. Link.
Decree No. 8.972 Creating the National Policy for the Recovery of Native Vegetation	Brazil	2017	This decree creates the National Policy for the Recovery of Native Vegetation -Proveg. Proveg has within its main objectives to articulate, integrate and promote policies, programmes and actions that encourage the recovery of forests and other forms of native vegetation; and to promote the environmental regulation of Brazilian rural properties, under the terms of Law 12.651 of 25 May 2011. Its guidelines are: 1) promoting adaptation to climate change and mitigating its effects; 2) prevention of natural disasters; 3) protection of water resources and soil conservation; 4) encouraging the conservation and restoration of biodiversity and ecosystems services; 5) provide incentives for the recovery of the Permanent Preservation Areas, Legal Reserve Areas and Areas of Restricted Use; 6) stimulus of native vegetation. Link.
National Mitigation Plan	Ireland	2017	The plan outlines the emissions profiles, policy frameworks and strategies to achieve climate change mitigation at the national level, in each of the following sectors: 1) electricity generation, 2) the built environment, 3) transport, and 4) agriculture, forestry and land use. It further quantifies costs and emissions reductions potentials. Link.
Regulation No. 40464-MINAE for the Implementation of the National REDD + Strategy	Costa Rica	2017	This regulation defines the National REDD + Strategy. This strategy will be part of the Forest and Rural Development Program of the National System of Conservation Areas, which will be an instrument that contributes to the fulfilment of the goals of the National Development Plan, Nationally Determined Contributions and current climate policies (National Climate Change Strategy and Action Plan), as well as the National Forest Development Plan 2011-2020, through actions that help prevent deforestation and degradation of forests, favouring their conservation and sustainable management, and an increase in carbon stocks.
National Greenhouse Gas Emissions Reporting Regulations, 2016	South Africa	2017	The purpose of the National Greenhouse Gas Emissions Reporting Regulations is to introduce a single national reporting system for the transparent reporting of greenhouse gas emissions, which will be used to maintain a National Greenhouse Gas Inventory, allow South Africa to meet its UNFCCC reporting obligations, and inform the formulation and implementation of legislation and policy. The sectors covered include energy, transport, industry, agriculture and forestry. Link.
Regulation No.70/2017 Implementing REDD+ and Sustainable Management of Forests	Indonesia	2017	The Ministerial Regulation No.70 is a guideline for the implementation of REDD + (Reducing Emissions from Deforestation and Forest Degradation, Role of Conservation, Sustainable Management of Forest and Enhancement of Forest Carbon Stocks) for the person in charge of the National, Sub-National REDD + management agency and REDD + implementer. This Ministerial Regulation aims to achieve REDD + implementation that is in accordance with the requirements of the UNFCCC COP Decree on REDD + and is consistent with national policies, as well as encouraging REDD + implementers to achieve full REDD + implementation, to support the achievement of targets for Nationally Determined Contribution (NDC) implementation in the forestry sector. The scope of this Ministerial Regulation includes: 1) REDD + locations, approaches and tools; 2) monitoring, evaluation and guidance. The implementation of REDD + includes the following activities: 1) increasing institutional capacity and human resources; 2) strengthening REDD + policies and tools; 3) research and development. Link.
National Climate Change Policy for Grenada, Carriacou and Petite Martinique (2017-2021)	Grenada	2017	The policy objectives for 2017-2021 include building climate resilience in the area of biodiversity and ecosystems. Link.
Second National Biodiversity Strategy and Action Plan 2017-2026	Sierra Leone	2017	The 2017 version of this document focuses on wildlife, forest biodiversity, agricultural biodiversity, freshwater, marine and coastal biodiversity. It notably aims to reduce and better organise fuel wood production. Link.
The National Development Plan 11 (2017-2023)	Botswana	2017	The plan lists several climate change relevant initiatives and programmes in the forestry and energy sectors, including: the Community-Based Natural Resource Management Programme and the Renewable Energy-Based Rural Electrification Programme.
PM Decision 2044/2016 approving the Climate Change Policy Framework	Vietnam	2016	This approves the Climate Change Policy Framework 2016 and 2017 and the document of Support Program to Respond to Climate Change (SP-RCC) for the period 2016-2020. The main objectives of the Climate Change Policy Framework 2016 and 2017 include sustainable forest management and development. Link.

Growth and Sustainable Development Strategy	Belize	2016	The document notably seeks to increase understanding of resilience, promote low-carbon energy sources and strengthen sustainable forest management. Link.
Action Plan on Gender and Climate Change and Executive Decree No. 012-2016-MINAM	Peru	2016	The policy analyzes gender disparities in eight areas affected by climate change: forests, water resources, food security, energy, solid waste, education, health and well-being and disaster risk management. Link. Link2.
National Climate Change Management Policy	Malawi	2016	The document focuses on reducing emissions from deforestation and forest degradation and fostering carbon sinks. Link.
Pan-Canadian Framework on Clean Growth and Climate Change	Canada	2016	Specific policies include: carbon pricing, with a federal benchmark calling a price starting at $10/tonne in 2018 and a $10/year increase until it reaches $50/tonne in 2022; increased stored carbon in forests, use of wood for construction, bioenergy and bio products. Link.
National Policy on Climate Finance	Kenya	2016	This policy outlines the role that climate financing could play in each of Kenya's most important economic sectors (agriculture, forestry, energy, transport, trade, tourism, manufacturing, water and sanitation, disaster risk management, and research and innovation). Link.
National Agricultural Sector Strategy (2017-2022)	Palestine	2016	The document notably seeks to increase resilience to climate change, by 1) developing resources and policies for the Risk Prevention and Agricultural Insurance Fund and 2) promoting innovation and adaptive solutions. Further specific objectives include intensifying efforts of research and official institutions, local authorities and centers to protect forests and natural reserves, as well as organizing and developing pastures and protecting agricultural biodiversity in all environmental areas in Palestine. Link.
National Five-Year Development Plan 2016/17 - 2020/21	Tanzania	2016	Climate targets in this plan include 130,000 ha increased national forest cover by 2020 against a 2015 baseline. Link.
Tonga Climate Change Policy	Tonga	2016	This policy intends to make Tonga climate-resilient by 2035 and enhance mitigation efforts. It seeks to improve governance and participatory actions, and lists a number of specific targets, including 30 percent of land in Tonga utilized for agroforestry or forestry. Link.
Forestry Sector Strategy (2016-2025)	Nepal	2016	The Forestry Sector Strategy (FSS) provides guidance for the long-term development of forestry sector of the country. The FSS has identified eight pillars: 1) Sustainably managed resources and ecosystem services; 2) Conducive policy process and operational environment; 3) Responsive and transparent organizations and partnerships; 4) Improved governance and effective service delivery; 5) Security of resource use by the community; 6) Private sector engagement and economic development; 7) Gender equality, social inclusion, and poverty reduction; 8) Climate change mitigation and resilience. The vision of the FSS is to ensure sustainable management of the forest ecosystem, biodiversity, and watersheds for national prosperity. Link.
Priorities for Adaptation to Climate Change in the Kyrgyz Republic till 2017 (updated to 2020)	Kyrgyzstan	2015	This plan was approved by a governmental resolution. It sets the government's adaptation priorities to 2020, and charges executive bodies, notably the State Agency for Environmental Protection and Forestry, to develop sectoral programs accordingly. Link.
National Forest Program (NFP) 2015-2025	Lebanon	2015	The NFP's goals include 1) establishing restoration and rehabilitation plans in degraded lands to counteract soil erosion and desertification, 2) enhancing ecosystem resilience in forestland to mitigate the impact of climate change and other natural hazards, and 3) carbon sequestration. Link.
National Strategy in the Field of Climate Change by 2030	Montenegro	2015	This strategy aims at assessing the institutional framework in place and the technological needs that Montenegro must build for mitigation and adaptation purposes. It includes the National Forest Strategy (which recognizes climate change as an important factor affecting national forest protection measures). Link.
National Adaptation Plan for Climate Change (NAP)	Burkina Faso	2015	The plan stresses that new administrative capacities are needed to respond satisfactorily to the sectoral objectives it lists (forestry, agriculture, health, energy, infrastructure, livestock, housing). Link.
Framework Act on Agriculture, Rural Community and Food Industry	South Korea	2015	This act outlines a general framework for the sustainable development of South Korea's agricultural sector. In particular, it requires promotion and Information Service in Food, Agriculture, Forestry and Fisheries. Link.

Decree 119/2016/ND-CP and PM Decision 120/2015 on Sustainable Management, Protection and Development of Coastal Forests	Vietnam	2015	The decree sets out policies to manage, protect and ensure a sustainable development of coastal forests to cope with climate change. The policies are as following: 1) localities must review and convert the coastal land areas planned for production forests that are eroded or affected by sand to coastal protection forests; 2) localities have to relocate construction works that affect protected coastal forests; 3) investment projects have to respect the regulations of the law on forest protection and development. PM Decision No.120/2015 approved the project on protection and development of coastal forests to cope with climate change in the 2014-2020 period. The objectives are the following: 1) to promote the protection of coastal forests to cope with climate change and rising sea; 2) to alleviate natural disasters, protect sea dikes and infrastructure; 3) to conserve biodiversity; 4) to ensure socio-economic development and reinforce national defense and security. Link.
National Action Programme to Combat Deforestation and Land Degradation	Equatorial Guinea	2015	The National Action Program to Combat Deforestation and Land Degradation in Equatorial Guinea aims to achieve the neutrality of land degradation at the national level and as one of the essential programs for the fulfilment of the Sustainable Development Goals. The programme further seeks to maintain the carbon storage properties of the country's forests, and develop international financing schemes accordingly. Link.
Law No. 2015-537 (Agricultural Guidance of Cote d'Ivoire)	Côte d'Ivoire	2015	This law addresses the national agricultural development policy of Ivory Coast. Art. 55 states that the State constitutes a reserve of pre-basic and basic seeds for each of the vegetable, animal, fishery, aquaculture and forestry productions that are seriously threatened by climatic hazards. Link.
National Climate Change Policy	Uganda	2015	The policy adopts the climate change strategies that address the impact of climate change and promotes sustainable activities in the sectors of agriculture and livestock, fishery production, water management, forestry, wetland, biodiversity and ecosystem services and tourism, which are identified as important needs to develop Uganda's approach to adaption to climate change. Link.

1.2.3. Forest restoration: co-benefits beyond mitigating climate change

A major attraction of NbS is the potential for co-benefits beyond climate change mitigation, including improved forests, croplands, grazing lands, and wetlands that support human health and well-being. Actions to protect, enhance, or restore carbon stocks can improve habitat, reduce the risk of catastrophic wildfires, increase soil fertility and water-holding capacity, and decrease air and water pollution. In some places, especially in rural areas of low and middle-income countries, the co-benefits of NbS may be more valuable than carbon mitigation benefits. The prospect for alignment between climate and other goals increases the attractiveness of NbS and the motivation for rapid deployment, especially where policy and governance frameworks support inclusive and participatory NbS approaches and a reasonable level of monitoring (Anderson et al., 2019).

Forest restoration in agricultural and degraded lands is emphasized by international initiatives such as the UN Decade on Ecosystem Restoration ("UN Decade on Restoration," n.d.), the Bonn Challenge to restore 350 million hectares of degraded landscapes by 2030 ("The Bonn Challenge | Bonchallenge," n.d.), and nationally determined contributions (NDC) to the Paris Agreement. Prior forest restoration studies are at global or tropical scales (Bastin et al., 2019; Brancalion et al., 2019; Busch et al., 2019; Griscom et al., 2020, 2017; Strassburg et al., 2020), and have neglected inclusivity – the potential importance of restoration by smallholders and the potential impacts on women or ethnicity disadvantaged populations.

Focusing on smallholders and inclusion of women and ethnicity disadvantaged population groups in designing and implementing forest restoration projects provides a vital opportunity to the objectives of inclusive low-carbon transitions – i.e., in the pursuit of sustainable development goals. These groups of people live in highly biodiverse and threatened landscapes (Cottrell, 2022; Erbaugh et al., 2020; Samberg et al., 2016) and are exposed to multiple hazards, including climate change (Cohn et al., 2017). Women farmers are particularly vulnerable because of prevailing discriminatory norms and institutions (Isgren et al. 2020; Jost et al. 2016). Their demographic strength, role in rural land-use decisions, limited market/technology knowledge, and exposure to poverty and food insecurity make them key stakeholders in determining where and how to restore tree cover, as well as the success of forest restoration projects.

Forest restoration activities can have tremendous effects on community economics by generating regional employment, income, and other economic impacts, often in places that have experienced widespread reductions in logging and milling infrastructure over the last three decades (Hibbard and Karle 2002; Hjerpe et al., 2021). For example, ecological restoration is an alternative in Latin América and Argentina not only to revert the ecological degradation trend, but to promote a socioeconomic development better integrated with nature (Echeverría et al. 2015; Zuleta et al., 2015). Despite the opportunity costs, forestry is typically a lower-income activity than agriculture. Forest restoration also yields community benefits in terms of reducing catastrophic wildfire risk, protecting local water supplies, and enhancing a broad set of ecosystem services (Dubay et al. 2013).

Forest restoration influences and is also influenced by human population dynamics, particularly migration (Vincent et al., 2021). Forest restoration projects may lead to human migration; it can also be true that people migrate so that there is more space for forest expansion. There is an emerging recognition that outmigration from origin communities might change demand for land, and lead to forest restoration (Oldekop et al., 2018) and government investments in forest restoration projects which have displaced populations (Leblond et al., 2014). China's Sloping Land Conversion Program (SLCP) was launched in 1999 in response to catastrophic flooding and is found to have induced households in many locations to shift their income sources first from crops to livestock, and then to off-farm work (Gutiérrez et al., 2016). Impact-evaluation studies in two provinces, Anhui and Ningxia, report large, significant impacts on increasing outmigration (Treacy et al., 2018; Démurger et al., 2012). Large-scale forest restoration driven by carbon pricing has raised concerns about negative impacts on food security (Vincent et al., 2021).

Successful restoration relies on funding and selection of seedlings (e.g., many programs are successful because of their own native trees), support in soil and forest health, protection of wildlife corridors, and management of land sustainability (Gustafson, 2020). Restoration efforts do not always result in net benefits, either locally or globally (Reyes-Garcia et al. 2019; Coleman 2021). Whether driven by global agreements, national policies or market needs, a restoration project can lead to conflicting visions of land use, power grabs and authoritarian actions that can hurt disadvantaged populations if they are not responsive to these population groups (Shyamsundar et al. 2021; Fleischman et al. 2020). Additionally, depending on how it impacts crop composition, forest restoration could have general equilibrium effects that may impose costs by raising food prices, e.g., with warming limited to 2°C instead of 1.5°C. The Global Trade Analysis Project (GTAP) model predicted that the conversion of agricultural land to forest would raise food prices by 3-4 times in most regions (Peña-Lévano et al., 2019), or create conditions that increase farmer poverty, as evidenced in Chile (Hofflinger et al., 2021; Nelson et al., 2019). It warned that such large food-price increases could make forest restoration socially and politically unacceptable as a climate mitigation strategy (Peña-Lévano et al., 2019). Scientific enquiry and global restoration efforts must invest in understanding and reducing any such negative outcomes of restoration.

1.2.4. Investment and finance to incorporate NbS into inclusive low-carbon transition

Recent years have brought renewed focus to international challenges, such as climate change and sustainable development, with the ratification of the Paris Agreement and adoption of the Sustainable Development Goals (SDGs). These international agreements have, in turn, piqued the interest and involvement of financiers. With greater attention on these global challenges, discourse on how to achieve and finance these goals has been at the forefront of international discussions.

The past decade has seen a bourgeoning interest in scaling up private investment to address low-carbon transition (Clark et al., 2018). Funds such as the World Bank Bio Carbon Fund, the Clean Development Mechanism, the Global Environment Facility, and the Green Climate Fund have also emerged to support the low-carbon transition. In general, capital obtained from philanthropic and government sources dominates this space (Shames et al., 2014). Recently, investment aiming to integrate NbS and traditional "built" infrastructure such as dams or other energy systems, has the potential to make the infrastructures more resilient to climate change. An interesting and successful example in Latin America is the restoration of natural ecosystems upstream of hydropower plants. Such restoration improves water flows, help energy companies generate more power and enrich upstream communities by means of ecotourism or sustainable, organic food businesses (Ozment et al., 2021).

These sources can only fulfil a small fraction of the overall finance required to meet the sustainable development and climate agendas (Clark et al., 2018). As such, calls for the upscaling of finance can be directed at all levels of government and international funding agencies, accompanied by a recent focus on the private sector, which is identified as the important sector to bridge the gap between the levels of finance required and the level currently invested.

There are several barriers to bridging finance gaps between private investment and public sectors, including: reliance on voluntary commitments, market failures, information gaps, short-termism, undervaluation of natural capital as well as inconsistent and often counterintuitive policies that have created market environments that disincentivize wide-scale private investment in sustainable development (Schuyt 2005; Stein et al., 2010; Clark et al., 2018). To facilitate forestry and land-based approaches to fit into low-carbon transitions, ex-ante assessments, including choice experiments, randomized controlled trials (RCTs), and return-on-investment analyses allow for better planning based on better understanding of the preferences of potential investors (Richards et al., 2020; Vincent et al., 2021).

Gaps in financing need to be addressed through innovative payment schemes and supply chain improvements. For instance, payments for ecosystem services, which can increase the competitiveness of restoration with alternative land uses, are becoming available to create a bundle of revenue streams for smallholders and women or other disadvantaged populations through multiple financing mechanisms (Duguma et al., 2020). These mechanisms include climate-related public funds, forest carbon offset markets, institutional investors such as pension funds, and impact investments (Binkley et al. 2020; Löfqvist and Ghazoul, 2019; Shyamsundar et al., 2021; Vincent et al., 2021). Modifications in market supply chains, for example, through out-grower schemes, companies that offer technical advice, financing, or guaranteed market access to disadvantaged people (Väth et al., 2019; Vincent et al., 2021), and producer associations that help increase smallholder knowledge and political and market power (Bettles et al., 2021; FAO and AgriCord, 2016), can also make tree planting more attractive to them. For these market-based strategies, it is essential for successful implementation that policy and institutional reforms support incentives for carbon offsets and the market demand for wood and tree products is steady.

Specifically, climate finance helps mobilize funding to reduce GHG emissions and assist local communities as they adapt to a changing climate. Concerns have been increasingly raised about the negative implications of climate finance on gender equity (Wong 2016), which raises questions as to whether, and how, climate finance helps achieve gender equity. To improve gender equity, climate finance needs to create a level playing field as women and men decide how climate resources are used and whether climate funds can challenge gender discrimination (Wong 2016). Women are adopting changes less frequently than men, due to financial and resource limitations; when new tasks are labor intensive, women tend to lack financial resources to change agricultural or agroforestry practices (Jost et al., 2016).

Given that little or no credit to women for forest-related activities and enterprises is the norm (which is difficult to change in the short run) (Haverhals et al., 2014), interventions which strengthen equitable access to credit targeting women and other traditionally less empowered groups are needed. These interventions include loans or subsidies to tree nurseries, and opportunities to enhance women's roles in forest-related value chains for forest-related activities and enterprises (Kristjanson et al., 2019). If insufficient attention is paid to existing gender gaps and differences in climate financing in the sectors where the finances are used, then without challenges to structural inequalities they risk reinforcing, rather than challenging, women's subordination in access to land and public participation (Wong 2016).

1.3 Identifying the gaps in research.

1.3.1. Systematic understanding of social and economic costs, benefits, risks and uncertainties of land-based NbS

The critical potential of climate change mitigation by land-based ecosystems is subject to a systematic understanding and quantifications of social, economic costs, benefits, risks and uncertainties of the uses of these approaches. For example, Griscom et al. (2017), Busch et al. (2019) and Bastin et al. (2019) have found the huge potential of reforestation as a large-scale nature-based strategy for removing carbon dioxide from the atmosphere, but many gaps remain in understanding how to reforest to meet climate goals through inclusive community-oriented processes.

One of the research gaps is not knowing the opportunity cost of land and other constraints – including risks and uncertainties about land resources (Vincent et al., 2021). There is a need for cost-benefit studies that assess the value of land if restored to forests (including for wood production) versus the opportunity cost of the land. Specifically, the land's opportunity cost means the value of its alternative use, typically agriculture such as cropland, or being allocated to some other use with the highest value. There is also a need for establishing models that predict the set of locations where afforestation/reforestation or forest restoration can maximize carbon sequestration for a given level of budgetary resources. Furthermore, models that enable users to investigate the impacts of different benefits, costs and risk factors of the socio-economic viability of afforestation/reforestation or forest restoration, can thereby deepen their understanding of the importance of these factors and how they interact.

Investors weigh expected benefits against opportunity and establishment costs, and assessments of risks and uncertainties when deciding whether to adopt an NbS. For land-based ecosystem approaches, case studies uncovering precise data and investigating relationships between successes and failures of a land-based NbS will have important value for future planning of forest and land-based programs for inclusive low-carbon transitions in different contexts. These factors will include the costs, benefits, risks and uncertainties, as well as the distributional patterns of these factors –by location, context, culture, or population group (e.g. youth/poor/women/indigenous) will be especially important for low and middle income countries.

1.3.2. Roles of different forest policies in low-carbon transition

Any forest policy must elicit impacts on climate change mitigation through human activities. Of special importance are the following three potentially inter-related areas, all of which have significant implications for the welfare of women and youth and other vulnerable groups, we find scant studies:

- Sustainable forestry through better forest institutions.
- Constructing markets and pricing that support climate change mitigation.
- Forest policy with gender dimension.

1. ***Sustainable forestry through better forest institutions.***

In principle, forest sector reforms can improve forest management—and as a result, forest ecological health, potentially carbon sequestration and local livelihoods. Drivers of such improvements include empowering users who may have the best understanding of local conditions and constraints and who are accountable forest users: strengthening these actors' incentives to manage forests for long-term returns; and facilitating the flow of technical assistance to local levels (Blackman et al., 2017; Somanathan et al., 2009; Ribot, 2008). Chhatre and Agrawal (2009) find that community forests with more autonomy supply more carbon sequestration while also supporting local livelihoods. Forest access and resource rights determine the success of community forestry management (CFM) in 51 countries (Hajjar et al., 2021). Meanwhile, CFM differs from a forest institution which has been supported by national, legal systems. Therefore, there is a strong need for research that identifies the conditions and forest institutions in which devolution of forest management produces positive outcomes in terms of both environmental and societal scopes.

The impacts on women and youth are scant in these studies. Statistics from Google Scholar show that after 2000 there have been 379,123 records of studies on forest institutions and sustainable forestry whilst only 21,700 of them (less than 6%) incorporate a gender perspective. For example, Zambia's Climate Change Gender Action Plan (ccGAP) in 2018 explicitly aims at advancing women's empowerment and enabling gender equality in setting climate change response plans – with a climate target of a 40% share of wood fuel in the energy sector by 2030. As earlier discussed, women are in general disadvantaged in land and forest resources access and management rights, market access of production factors, education, health, poverty, and care economy compared to men; women at home need to take care of children, and stall feeding of livestock that may also graze in the forests; they are also responsible for harvesting biomass, collecting water, and household production including those from non-forest products as well as agricultural subsistence. Also, it has been found that women in rural areas have less ability to adapt or migrate in response to disasters due to discriminatory norms, mobility constraints, their lower education and human capital – option that could increase their opportunities for working in non-resource sectors.

Community forest benefits have proven elusive. For example, decentralization initiatives sometimes fail to spur meaningful shifts in power, and even when they do, can lead to recentralization (Koch, 2017). There have also been concerns about distributional issues such as those relating to income (Adhikari, 2005; Adhikari and Di Falco, 2009) and gender (Agarwal, 2001). There is also an important debate regarding whether more women in forest user groups improve outcomes (Agarwal, 2009; Mwangi et al., 2011). Women's presence in better conservation outcomes is attributable to women's contributions to improved forest protection and rule compliance, more opportunities for women to use their knowledge of plant species and methods of product extraction, and greater cooperation among women in India and Nepal (Agarwal, 2009). On the contrary, Mwangi et al. (2011) found that a higher share of females in forest user groups result in worse forest outcomes in East Africa and Latin America, and this mostly attributes to gender biases in technology access and discrimination, labor constraint faced by women and limitation to women's sanctioning authority.

Methodologically, to date, there has been relatively limited rigorous impact evaluation on distributional issues, including fairness and equity for exclusively female-headed households (Luintel et al., 2017), and relatively little attention to privatization or quasi-privatization as a second land reform option besides decentralization of communities. Research is needed, using rigorous impact evaluation methods to assess the causal relationships between policy and outcomes to understand whether, and under what conditions, do decentralization, devolution, and privatization improve ecological and socioeconomic outcomes for women. There is also a need to look beyond the static issue of the impact of land tenure reforms on existing forestland resources, with attention focused on the risk of deforestation and degradation of those resources, toward the more fully dynamic issue of the impact of land reforms on the creation of new forests through tree planting and natural forest regeneration on marginal agricultural lands.

2. ***Constructing markets and pricing that support climate change mitigation.***

There is also a need to understand the potential contributions of forest carbon pricing and carbon market creation for the low-carbon transition, as well as the effects on forest-dependent people and especially women. Most researchers have found that within the context of carbon pricing schemes such as REDD+, the costs of sequestering carbon are well below contemporary estimates of the social cost of carbon (e.g., Bellassen and Gitz, 2008; Yang and Li, 2018; Fischer et al., 2011). Evidence from devolved forests, however, suggests that while REDD+ sequesters carbon (Pandey et al., 2016), it may cost more than the social cost of carbon (e.g., Marseni et al., 2014; Pandit et al., 2017; Dissanayake et al., 2018), may require important modifications of user groups (Newton et al., 2015), and may have differential effects by income group (Ickowitz et al., 2017). Some researchers also caution that REDD+ can upset fragile collective action equilibria (Luintel et al., 2017). These findings suggest important linkages between forest decentralization and devolution and carbon sequestration policies (Agrawal and Angelsen, 2009; Bluffstone et al., 2013).

People in rural areas of low- and middle-income countries are very dependent on a variety of products from forests, perhaps the most important being biomass fuels, which are used daily by over 1 billion people worldwide and often collected by women (Jeuland et al., 2015; Cooke et al., 2008). This dependence is expected to decline relatively little in the coming decades (IEA, 2020). While biomass fuel demand has traditionally been viewed as environmentally negative, this perception is partly due to researchers' focus on deforestation instead of reforestation. From the standpoint of reforestation, biomass fuel demand is potentially environmentally positive, as it creates an economic incentive to increase forest area and invest more in forest management (Favero et al., 2020; Vincent et al. 2021). A necessary condition to the positive environmental outcomes is that market demand increases – i.e., timber prices or prices of other wood and non-wood products increase at rapid rates, combined with policies that reward forest carbon sequestration, could propel scaling-up substantial forest restoration in low- and middle-income countries (Vincent et al. 2021).

The main channel is economic incentives provided to landholders, investors, and policymakers in the given contexts where continued competition for land with agriculture and constrained governmental budgets in these countries and aid agencies. Case studies and quantitative evidence focusing on this necessary condition and the supply- and demand-side incentives in specific Global South countries and other important conditions – such as technological innovation in extending lives of wood products and industrial policies for replacing energy-intensive materials by wood products – are currently scant and worthwhile to understand.

3. ***Forest policy with gender dimension.***

The literature has a lack of focus on the elements of identity on top of gender such as age, race, social condition (migrant, income level, working status). In the past two decades, several studies have examined the links between forests and rural livelihoods (de Sherbinin et al., 2008, Hogarth et al., 2013, Porro et al., 2015, Sunderlin et al., 2005, Thanh et al., 2015, Yemiru et al., 2010, Zenteno et al., 2013), but few have examined how these factors affect success or failure of forest-related adaptation policies on these people. They are of crucial value to investigate because they may need special market or social incentives to adapt or change their living strategy in the process of low-carbon transitions. For example, ethnicity and wealth levels in terms of physical asset holdings determine rural households' forest-based living strategies among indigenous and migrant settler populations in the Ecuadorian Amazon (Torres et al., 2018).

It is quite natural that age, race, social conditions such as migrant status, income level, working status could be determining rural households' consumption preferences and constraints in time/labor supply, access to markets for factors of production including land, labor, and capital. Case studies focusing on distributional patterns of impacts of forest-related policies – and, their willingness to transition to a low-carbon economy – of these population groups will inevitably help and inform policymakers. Without understanding how impacts may be distributed, considering various intersectionalities, we will not be able to facilitate an inclusive transition.

1.3.3. Gender equality and inter-generational assessment of the relationship between land use changes and low-carbon transition

A growing literature focuses on gender equality and low-carbon transition. This builds on key issues such as energy access and land use change (often deforestation) (Bowen and Fankhauser, 2009). However, there is a lack of awareness at the institutional level – such as forest policy – not enough attention has been paid to women and/or youth in a particular role in forestry and land-based solutions to low-carbon transition. As Table 3 suggests, only Zambia explicitly aims at women's empowerment and gender equality in setting the national climate target (i.e., the ccGAP in 2018). Specifically, on restoration of degraded ecosystems, poor institutional choices have negative impacts on conservation and land uses. Five case studies from Africa (Burkina Faso, Senegal, Tanzania, and two from Ghana) show that negative consequences for social outcomes are due to poor institutional choices that lack active interventions and local knowledge across several sets of actors, and the lack of dynamics of restoration as a long-term process (Walters et al. 2021).

It is tempting to assume that climate change equally influences the lives of women and men, because the most visible effects occur on societal scales (Eastin, 2018). Yet, most of the literature suggests that gender disparities in climate change vulnerability not only reflect pre-existing gender inequalities, but also reinforce them (Panitchpakdi, 2008). It has largely been recognized that women's lack of ownership and control of household assets and their rising familial burdens in the cases when the males migrate out or work outside; in such situations, declining food supply and water access, and increased disaster exposure would make it it more difficult for women to achieve economic independence, enhance their human capital, or even maintain health and wellbeing (Eastin, 2018). It is thus not surprising that such negative impacts are most salient in places that are relatively less democratic or developed, and with greater dependence on agriculture.

There are high research needs in understanding whether land-based policies in meeting climate change mitigation and adaptation targets have reinforced gender inequality and what lessons could be learned. There exists the base of studies in this area – some work has been done (see Chomba et al, 2016 for example), further investigations relying on rigorous methodology in providing causal impact estimates are crucial for policymakers to make appropriate decisions. This type of research outcome will offer critical evidence and more knowledge of the necessary conditions for inclusive low-carbon transitions to be gender-responsive.

Some work suggests that women can be beneficiaries of low-carbon or green growth interventions, which can support gender equality (Fisher and Mohun, 2015). Clean energy and forestry are two key areas of low-carbon development that have clear gendered dimensions. Several existing clean energy projects, such as the introduction of clean cookstoves, and the provision and use of micro-hydro and solar energy projects, have been targeted at women as a means of ensuring success. Ethiopia introduced the cookstoves as a flagship programme, and these can make significant contributions to reducing carbon emissions whilst reducing indoor air pollution and bringing health benefits for women and children (Terry 2009). FAO has published a guide to make sure that officers working on forest-related issues will be able to identify concrete actions to ensure that gender issues are integral components of projects and programs (Lauren, 2016). Given the current scant studies on including gender-dimension in low-carbon transition strategies and the expected outcomes, it is important to obtain more evidence and draw lessons from it to understand the conditions for success.

1.3.4. Investment and financing in scaling-up forest and land-based NbS

Over the past decade, international initiatives led by the Bonn Challenge and the U.N. Decade on Ecosystem Restoration have declared ambitious goals for restoring global forest cover, with the goals of mitigating climate change and achieving other sustainable development goals. A widely reported study in Science identified nearly a billion hectares of the Earth's surface as having the biophysical conditions necessary for forest restoration and afforestation (Bastin et al., 2019). The cost of restoring such a vast area, or even the smaller, but still large area of the Bonn Challenge and U.N. Decade on Ecosystem Restoration, exceeds the financial resources available from governments and international development organizations. Scaling-up restoration will require engaging the private sector as a source of capital, labor, and land. In turn, private-sector participation will require restoration investments to earn a return from timber harvests, carbon payments, and other revenue streams (e.g., in terms of payments for ecosystem services), and the return must exceed the return from competing land uses (i.e., the opportunity cost of the land). Otherwise, landholders will have insufficient incentive to invest in restoration.

From a global perspective, historically, forestry has long provided opportunities for institutional investors and almost all the investment has come from institutions in OECD countries (Binkley et al., 2020). In the past two decades, forestry investment has shown that it can offer financial, environmental, social, and governance benefits due to its nature as a truly long-term asset and being able to provide cash-flow in the long run. But these markets are merely emerging, and challenges exist in understanding the details for the establishment of such markets–i.e., how careful reforestation, afforestation, and sustainable management activities are planned, conducted, and maintained. The functioning relies on internationally accepted, longstanding third-party certification standards, which have largely been effective at mitigating negative social and environmental impacts of the projects (Cashore, et. al., 2004).

Forest bonds, pension fund plans investing in forestry, and timberland investment have been studied in a few countries – mostly limited to OECD countries such as the United States, Canada, Australia, New Zealand, and several countries in Europe – and shown to have attractive risk-adjusted total returns that can be used as an effective hedge against inflation (Binkley et al., 2020).

1.4. Proposal of an applicable research agenda

Table 4 summarizes a research agenda based on the research gaps discussed in the previous section, followed by further discussions on specific research issues.

Research agenda	Specific research issues
Cost-effectiveness of using land-related NbS for low-carbon transitions (LCTs) at global, national, & regional scales	Scientific assessment estimates of carbon sequestration potential of land-based pathways of NbS. 1.2 Estimates of co-benefits land-based NbS pathways, incl. wood fuel harvest, forest employment and taking inclusivity into account. Opportunity cost estimates of land and labor for land-based NbS pathways. Estimates of constraints of risks and uncertainties for land-based NbS pathways, incl. risk of deforestation, population change, exchange rate fluctuations, conflicts, accessibility to cities, etc.
Evidence of impact evaluation of forest policies targeting LCT, accounting for heterogeneous impacts across population groups	2.1 Examples of various policy instruments aimed at development and LCTs with successes and lessons from low- and middle-income countries. Gender-heterogeneous and intersectional impacts of using forestry and land-based ecosystems to contribute to LCTs in low- and middle-income countries
Forest carbon pricing & market creation for inclusive LCTs, between & within Global South countries	Research comparing pricing instruments with other climate policy instruments: e.g., carbon trading markets or carbon taxes vs. standards for carbon emissions or renewable energy portfolios, which are policies designed to increase renewable energy use Impact evaluations on the interaction or comparison between pricing and other command-and-control instruments focusing on environmental effectiveness, economic efficiency, market outcomes, revenue generation, and stakeholder engagement
Forest restoration & impacts in Global South countries	Forest restoration and value of socioeconomic benefits (e.g., job creation) and ecosystem service benefits (e.g., woody biomass supply, wood products) Research on how forest restoration can be balanced with food production, income generation and development, integrating systematic understanding of competing forms of land-use. Research on the uses of forest and other land-based solutions, like using marginal agricultural land for forest restoration, to support mitigation of climate change and population migration
Investment & financing forest restoration	5.1 Country-specific studies on private investments and financing in promoting forest restoration to unlock the potential of forestry and land use change in LCTs

1.4.1. Cost-effectiveness of using land-based ecosystems as NbS to mitigate climate change and promote low-carbon transition based on opportunity cost of land and other constraints, risks, and uncertainties

In this section, we take forest as a starting point to propose applicable research focusing on the cost-effectiveness of using land-based ecosystems as NbS to mitigate climate change and promote low-carbon transition. Specifically, there are research needs to systematically quantify the costs, risks and uncertainties based on estimates of the carbon sequestration potential of forest-related approaches. We propose a research agenda grouped into the following four aspects: 1) on carbon sequestration potential, 2) on other co-benefits in addition to carbon sinks, 3) on opportunity cost of land, and 4) on other constraints of risks and uncertainties. Studies of both global and regional scales based on empirical data will be valuable and help inform policymakers for better planning because of the estimates out of empirical data and rigorous analyzing methods. These studies and estimates will help identify locations where the benefits of land- and forest-based approaches are high relative to costs, subject to biophysical and socioeconomic constraints that any policymaker or stakeholder impose to define the areas is allowable and ready as the planning area.

1) On carbon sequestration potential, we propose scientific assessment-based estimates that consist of three aspects: First, through newly planted trees and replanting trees on land that has long been fallowed after felling, the "Afforestation/ Reforestation" pathway offers a carbon sink effect as tree cover increases and more CO2 from the atmosphere is absorbed. Second, the "Avoiding Deforestation and Forest Degradation" pathway prevents the carbon stored in trees from releasing to the atmosphere. Third, the "Sustainable Forest Management" pathway holds huge potential that has not been paid enough attention (Cohen-Shacham et al., 2016; IPCC, 2019). To put it differently, forest-management techniques that prioritize the increase of both the amount of wood produced—with the increased vegetation volume—and the carbon stock retained in the forest increase the carbon density of existing forests.

Importantly, the "Sustainable Forest Management" pathway offers mitigation in two ways. Firstly, if policy permits, when regenerating mature and over-mature forests and planting with young trees, more carbon is absorbed from the atmosphere than the old forests release, in the cases where they were over-protected and degraded. Harvesting old forests according to the sustainable yield rule and regenerating with new trees will add incremental carbon sequestration, compared to the status quo of letting the old trees die and release carbon.

Second, the harvested timber used to produce wood products exerts the substitution effect that reduces CO2 emissions from the use of higher-carbon energy and materials (Jin et al., 2020). For example, wood products can substitute for steel, cement, aluminum, plastics, bricks, etc., so that the amount of CO2 emitted in the production processes of these energy-intensive materials is avoided. Moreover, wood fuel is a renewable green energy, so that substituting for fossil fuels reduces CO2 emissions. However, the carbon sink estimate of the above-mentioned two categories of uses has not yet been paid enough attention, nor considered by the existing literature.

2) Other co-benefits include wood fuel harvest based on accurate estimates of plantation growth rate referring to potential annual production of woody biomass by different species, and forest employment in terms of the existing number of forest-related jobs per hectare of forestland due to afforestation/reforestation activities. A higher level of forest employment implies attractive business conditions for labor-intensive wood harvesting and processing industries, which tends to make FR more feasible when income for local households is a desired benefit. Forest employment can be the sum of jobs across three economic activities: 1. forestry, logging and related service activities; 2. manufacture of wood and of products of wood and cork, except furniture; and 3. manufacture of paper and paper products. This of course varies by country and, for countries with sufficient data, by first-level administrative subdivision (e.g., state or province).

Studies on distributional aspects of the above co-benefits of forest-based approaches are necessary as an inclusive element of low-carbon transitions. Interested groups include women vs. men, youth vs. the rest, indigenous vs. migrant (or minority ethnic group vs. the majority group), smallholders vs. the medium/large-scale landholders, etc.

3) On opportunity cost of land, the benefits of afforestation are constrained by land availability and accurate estimates of the opportunity cost of land. Successful implementation of any carbon dioxide removal approach will require careful consideration of other land-use needs, in addition to the establishment and implementation cost for any afforestation/ reforestation or forest carbon project associated with the assessment of possible uncertainty and risks.

About half of the world's habitable area is currently devoted to agriculture (Ritchie, 2019). One way to expand capacity in terms of the increase in land area that is allowable for forest carbon projects is through agroforestry, whereby trees are incorporated into agriculture such that the land can support food production, carbon uptake, and increased biodiversity (Catching carbon, 2022).

Global and regional studies are needed with the aim of providing accurate estimates of the value of land if it is not used for the planned project (i.e., the land's opportunity cost). Social and economic data collection, empirical studies, and expanded use of statistical, econometric methods will be important for this type of research.

4) Other constraints of risks and uncertainties include the risk of deforestation, declining population, exchange rate fluctuations, conflicts, and accessibility to cities, as well as the uncertainties due to rule of law and probability of natural regeneration success. Institutions that help deal with ecological risks and other risks to ecosystem services are necessary for inclusive low-carbon development. Evidence from existing forest reforms could be very important, for example, in China and the Global South countries.

To be specific, a higher deforestation rate tends to make afforestation/reforestation projects less feasible as it increases the risk that restored forests will be converted back to non-forest land uses. Declining populations tend to make an afforestation/reforestation project more feasible, as it decreases the risk that human pressure will cause restored forests to be converted back to non-forest land uses.

The effect of accessibility to cities on the feasibility of afforestation/reforestation plans depends on local conditions. Greater accessibility can make afforestation/reforestation more feasible by increasing the return earned by forest products sold in urban markets, but it can also make afforestation/reforestation less feasible because the return earned by products from non-forest land uses may also increase as the access to cities becomes easier.

Fluctuations in exchange rates directly link with the global wood products market and financial markets and affect the prices of wood products. Hence, these fluctuations affect the incentive of landholders and investors to increase land area for forests.

Rule of Law is a governance indicator developed by the World Bank that is often interpreted as an indicator of property rights. Stronger property rights tend to make afforestation/reforestation more feasible by reducing risks associated with afforestation/reforestation investments.

Finally, natural regeneration is more likely to succeed when restoration sites are closer to remaining natural forests, which are an essential seed source.

1.4.2. Forest policy needs for low-carbon transition using land-based ecosystems, with concerns on distributional impacts, gender-heterogeneous effects, and inter-generational differences.

Here we propose a research agenda for mainstreaming the gender focus in using forestry and land-based ecosystems for low-carbon transition:

The first is to analyse examples of instruments aimed at the development of policies designed to contribute to the low-carbon transition addressing gender and other inequalities. Research questions can be as specific as: How to mainstream gender in forestry? Why do gender issues matter in land projects? In addition, what roles can women play in forest policy and decision making – e.g., deciding on methods and periods of product extraction based on their knowledge of plant species and care, deciding on rule compliance, arranging forest protection, cooperating, etc.?

On the one hand, there are instances where forests have grown healthier, where the poor enjoy greater access to forest products and increased income, and where decision-making about these landscapes has become more democratic, as we discussed earlier and showed in a number of existing studies. In most places, however, increases in forest cover and quality have occurred at the cost of forest uses that supported the livelihoods of the poor, and where women are more vulnerable to the negative impacts. Therefore, an insightful understanding of the driving factors of the positive contribution of forest and land-based ecosystems to low-carbon transition – in terms of forest growth and better livelihoods, for example, is necessary.

On the other hand, the role of women on forest policy and decision making, or any forest policy that ensures gender issues are integral components of policies, projects, and programmes, are important for the success of the implementation of such policies. Based on considerable empirical research in other fields such as agriculture, better understanding of the importance of the differing priorities, needs, activities and responsibilities of men and women, boys and girls at multiple levels in using forestry to meet livelihood needs and contribute to climate change mitigation is necessary.

The second research agenda is to analyse the gender-heterogeneous effects of the impacts of using forestry and land-based ecosystems to contribute to low-carbon transition in the Global South countries. The overall objective is to provide generalizable economic evidence and policy implications for the Global South. To investigate this, data availability for disaggregated groups, individual data, and collection of such data is necessary. An important methodological future issue and research need is expanded use of impact evaluation methods to generate unbiased estimates of these heterogeneous social and environmental effects of existing forest-based policies. For similar reasons and using similar empirical strategies, it is equally important to have research unravelling the ethnicity-heterogeneous effects, inter-generational differences, religious differences, heterogeneous effects by social status, and other factors.

1.4.3. The potential contributions of forest carbon pricing and carbon market creation for inclusive low-carbon transitions, both international and within any of the Global South countries

Given the context that since the 2015 Paris Agreement prompted governments to consider stronger policies to achieve decarbonisation, the most economically efficient way to reduce greenhouse gas emissions is using carbon pricing policy instruments (Aldy, 2015; Edenhofer et al., 2015; Metcalf and Weisbach, 2009; Schmalensee and Stavins, 2015). Carbon pricing mechanisms fall into three main categories: cap-and-trade (i.e., emissions trading systems (ETS)), carbon taxation, or hybrid mechanisms that combine elements of both.

Recent implementation of ETSs is mostly in OECD countries including the USA (California), Québec and South Korea, and the existing implementations show significant institutional learning from prior systems, especially the EU ETS, with these regions implementing more robust administrative and regulatory structures suitable for handling unique national and sub-national opportunities and constraints. Evidence also shows that there is potential for a 'double dividend' in emissions reductions even with a modest carbon price, provided the cap tightens over time and a portion of the auctioned revenues are reinvested in other emissions-reduction activities.

Policy instruments available for climate policies can be grouped into two categories – market-based and non-market-based. Market-based instruments include charges, subsidies, fees and taxes, and tradable markets for carbon emission rights or "emission reduction" credits: in other words, pricing-based instruments. Non-market instruments are command-and-controls including regulations and standards that restrict input uses, emissions, and productions. However, knowledge gaps exist in understanding the interaction of pricing instruments with other climate policy instruments and how governments manage these policies to achieve optimum emissions reductions with lower administrative costs.

Therefore, a future research agenda can focus on the comparison between pricing instruments and other climate policy instruments, for instance, carbon trading markets or carbon tax versus carbon emissions standards or renewable portfolio standards (renewable electricity standards), which are policies designed to increase the use of renewable energy sources for electricity generation.

This research agenda has important implications for the Global South countries in their low-carbon transition in meeting their own climate change mitigation targets. We propose five main criteria for the evaluation of the interaction or comparison between pricing and other types of policy instruments: environmental effectiveness, economic efficiency, market, revenue, and stakeholder engagement.

1.4.4. Forest restoration in low- and middle-income countries

1) ***Value of job creation, woody biomass supply, wood products***

Specifically, research on questions about the relationship between forest restoration and the values of the co-benefits that contribute to climate mitigation will be insightful for policy design at the initial stage of any national forest restoration programme. These co-benefits include job creation, and other economic values such as woody biomass supply and wood products substituting for carbon-intensive materials – all these values are important for low-carbon transition.

The forestry sector accounts for an estimated total of 45.15 million jobs and an income of more than of US$580 billion per year (FAO, 2018). Estimates (FAO, 2014, Agrawal et al., 2013) further suggest that around 40 to 60 million people are involved informally in the forest sector. While varying significantly between locations, FAO (2014) estimated that globally, on average, edible plant-based non-wood forest products provide 16.5 kcal per person per day. As one of the most affordable and reliable energy sources, wood fuel is used by an estimated 2.4 billion people worldwide (FAO, 2018). Especially in rural communities in developing countries, forests provide a valuable additional source of food (and nutritional diversity), fuel, and income. We call for more evidence and estimates of these values coming from low- and middle-income countries as a further step for research and based on rigorous analysis using impact evaluation methods to identify the causal relationship between forest restoration and the outcomes.

2) ***Food security concerns***

In addition, evaluation research has shown that streams flowing from tropical forests are more efficient in cleaning pollutants than less biodiverse streams (Cardinale, 2011), and this finding is attributed to the enormous positive impact and significance of REDD+. More importantly, how forest restoration can be balanced with food production, income generation and development, needs to be based on a systematic understanding of the competition for land with food production and other land uses. The Global South countries are facing huge challenges to improve the standard of living while also conserving the remaining forests and other natural resources. There needs to be further research in the question of investigating the potential negative impact of large-scale forest restoration on food security. This type of research requires the development of economic models of global and regional wood and food markets that are based on higher resolution, frequent, and/or micro-level data, as well as greater spatial variation in the effects of forestry, agricultural returns on land-use change, and should incorporate migration's effects on land use.

3) ***Migration***

Another pursuit of the intersectional research is on the uses of forest and other land-related solutions like marginal agricultural land for forest restoration in contributing to climate mitigation and population migration. With liberalization of the labor market and urbanization in most of the Global South in the past decades, rigorous research on this topic is necessary. Designing the necessary research program requires a systematic review of the literature on migration and forest recovery. A special focus on the gender, ethnicity and age differences in the interrelationships will help inform the policy makers about the distributional effects of using forest restoration instruments in climate mitigation and welfare development. Equally important is to account for the full array of types of migration, from permanent moves to temporary or seasonal ones, sequential moves, and circular migration, and the entire gradient from immobility to mobility, given that far more people stay in place than move (Vincent et al., 2021).

The rationale is that the amount of marginal agricultural land or land available for forest restoration is not fixed. Economic development is usually accompanied with urbanization, which draws populations out of rural areas, and this in turn reduces the returns to labor-intensive agricultural systems. Consequently, forestry, as a less labor-intensive economic activity, becomes relatively more attractive to landholders. Followingly, globalization of labor markets will amplify this effect, in the cases where rural laborers can move freely and seek employment outside their hometowns or countries. Currently, only a few studies on forest restoration at global or regional scales (for example, tropical regions) have considered land opportunity costs, demography, or other socioeconomic factors, as we discussed in the earlier sections. Due to data limitations, they have measured opportunity costs using gross agricultural revenue instead of the net income that matters to landholders, sometimes using decades-old data from simulation models instead of current data related more directly to on-the-ground observations.

1.4.5. Country-specific studies on private investments and financing in promoting forest restoration to exert the huge potential of forestry and land use change in low-carbon transition.

As earlier mentioned, in several OECD countries, forest bonds, pension fund plans invested in forestry, and timberland investment have been studied in a few countries – such as the United States, Canada, Australia, New Zealand, and several countries in Europe (Binkley et al., 2020). These country studies have shown that private investments have attractive risk-adjusted total returns and can be used as an effective hedge against inflation because of forests' natural characteristics of storing wealth. Future research is called for studying forest bonds or pension fund plans or similar financing instruments investing in forestry in low- and middle-income countries.

Low and middle-income countries are important and worthwhile for this research because of the need for advancement in their financial institutions and market development. Expected outcomes include lessons and success that could help understand which conditions can shape the valuation of the potential of these options.

In terms of exerting the huge potential of forest restoration on mitigating climate change in the Global South, more knowledge is needed from private sector investments and finances in these areas on the associated conditions for success, to promote increased private investment in forestland in low- and middle-income countries. It is important to learn from case studies to inform and facilitate the development of investment strategy and portfolio management for the mechanical design of investing in forestry by the governments of the Global South.

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