JOURNAL OF FOREST BUSINESS RESEARCH

Peer-reviewed research article

Journal of Forest Business Research 4(1), 37-72, 2025

Assessing conditions to scale up private investment in forest restoration

Jeffrey R. Vincent, [a,*] Yoshihiko Aga, [b] Marco Boscolo, [c] Kaichao Chang, [d] Zhuo Cheng, [c] John Dilger, [e] Daniel Guerrero Machado, [c] Diego Herrera, [f] David Kaczan, [f,g] Andrea McMahon, [e] Pierrick Rambaud, [c] Marija Spirovska Kono, [h] Karis Tenneson, [e] Mathieu Van Rijn, [i] Khalil Walji, [j] Yuanyuan Yi, [k] Yelena Finegold. [c]

a: Nicholas School of the Environment, Duke University, Durham, NC, USA.
b: Ministry of Agriculture, Forestry and Fisheries of Japan, Tokyo, Japan.
c: Forestry Division, Food and Agriculture Organization of the United Nations, Rome, Italy.
d: Department of Agricultural and Resource Economics, University of Maryland, College Park, MD, USA.
e: Spatial Informatics Group, Pleasanton, CA, USA.
f: Environment Department, The World Bank, Washington, DC, USA.
g: School of Business, University of South Australia, Adelaide, Australia.
h: International Programs and Trade, US Forest Service, Washington, DC, USA.
i: FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.
j: Centre for International Forestry Research and World Agroforestry, Nairobi, Kenya.
k: Environment for Development, University of Gothenburg, Göteborg, Sweden; and China Centre for Economic Research, National School of Development, Peking University.
[*] *Corresponding author: Jeff.Vincent@duke.edu*

ABSTRACT

Forest restoration (FR) in low- and middle-income countries (LMICs) requires private investment. We estimated the area of degraded forestland with investment conditions favoring private FR in 115 LMICs. We examined a base scenario, with FR driven by wood markets and influenced by seven investment conditions, and a "natural climate solutions" (NCS) scenario, with FR driven by carbon markets and influenced by six conditions. We have found that barely half of the restorable area in the base scenario, and barely a third in the NCS scenario, has at least four favorable investment conditions (i.e., at least half of the total number). In both scenarios, less than 1% of the restorable area has all conditions favorable. Locations with more favorable conditions tend to have greater potential to generate local livelihood benefits than global carbon or biodiversity benefits. Of the 59 LMICs that have made national commitments to restore forestland under the Bonn Challenge, which has a global goal to restore 350 million hectares by 2030, more than half have made a commitment whose area exceeds our estimate of the country's restorable area with at least four favorable investment conditions. This discrepancy implies that those countries cannot rely solely on private investment to achieve their commitments. Scaling up private FR in LMICs requires coordinated public-sector investments and policy interventions to improve investment conditions and ensure that private FR generates both local and global environmental benefits.

Keywords

afforestation, Bonn Challenge, carbon sequestration, forest restoration, low- and middle-income countries, natural climate solutions, private investment

Citation

Vincent JR, Aga Y, Boscolo M, Chang K, Cheng Z, Dilger J, Guerrero Machado D, Herrera D, Kaczan D, McMahon A, Rambaud P, Spirovska Kono M, Tenneson K, Van Rijn M, Walji K, Yi Y, Finegold Y. 2025. Assessing conditions to scale up private investment in forest restoration. J.For.Bus.Res. 4(1): 37-72. https://doi.org/10.62320/jfbr.v4i1.64

Received: 4 February 2025
Accepted: 22 April 2025
Published: 6 May 2025

INTRODUCTION

An estimated one trillion US dollars (USD) is needed to fund ambitious global forest restoration (FR) initiatives such as the 2011 Bonn Challenge's goal to restore 350 million hectares (Mha) by 2030 and the Kunming-Montreal Global Biodiversity Framework's target to restore 30% of degraded ecosystems by the same year (FAO and Global Mechanism of the UNCCD 2015, UNEP and FAO 2020, FAO, SCBD, and SER 2024). Recognition is growing that the private sector will need to be a primary funding source for FR initiatives (FAO and Global Mechanism of the UNCCD 2015, Brancalion et al. 2017, Ding et al. 2017, Löfqvist and Ghazoul 2019, World Bank 2022, 2024). Private investment is especially needed in low- and middle-income countries (LMICs), where government budget deficits are worsening (United Nations 2023) and official development assistance summed across all environmental activities, not only those related to forests, is equivalent to less than half of the annual FR funding need (OECD 2022). Inadequate finance is the most commonly mentioned barrier to scaling up ecosystem restoration (Meli et al. 2023). Yet, quantitative analyses of global and regional FR prospects have focused primarily on biophysical potential (WRI 2011, Griscom et al. 2017, Bastin et al. 2019, Crouzeilles et al. 2019, Walker et al. 2022) or general economic feasibility (Brancalion et al. 2019, Strassburg et al. 2020, Busch et al. 2024), not on the scope for private investment to fill the funding gap (Löfqvist and Ghazoul 2019, Löfqvist et al. 2023a).

A lack of information on feasible locations for private FR investment in LMICs—i.e., the spatial overlap between locations where degraded forestland exists and locations with favorable conditions for private investment—is an important impediment to such investment (World Bank 2022). In this study, we use a medium-resolution spatial dataset (30-arcsecond pixels, ~1 km at the Equator) spanning 115 LMICs to estimate the area of degraded forestland with favorable conditions for private FR investment. Our working definition of forest degradation is straightforward: a pixel includes degraded forestland if current (= 2019) tree cover (Buchhorn et al. 2020) is less than potential tree cover (Bastin et al. 2019). We use the relative share of "missing" tree cover to estimate the potentially restorable fraction of a pixel's area. We limit our analysis to rural land in ecological zones where forests naturally occur (FAO 2012) and can attain more than 10% canopy cover under natural conditions (FAO 2018). We exclude higher-value agricultural land, where private investment in forest restoration is less likely to be financially viable, and land inside protected areas (PAs), where FR is more likely to be financed by governments, aid agencies, and conservation organizations than by the private sector. Our purpose is to investigate landscapes that evidently provide promising opportunities for private FR investments, not to identify specific locations for FR projects.

The UN Decade on Ecosystem Restoration, which launched in 2021 (United Nations General Assembly 2019), accepts that restoration "can happen in many ways" and that restoring an ecosystem to its original state "is not always possible – or desirable" (UNEP and FAO n.d.). Studies commonly consider forest restoration to encompass various types of tree systems in addition to natural forests of native species, including timber plantations, farm woodlots, and agroforestry systems (IUCN and WRI 2014, Brancalion et al. 2017, Löfqvist et al. 2023b). Our analysis implicitly includes all these types of tree systems but not orchards, which definitions of "forest" typically exclude (FAO 2018).

Prospective private FR investors in LMICs are heterogeneous (FAO and Global Mechanism of the UNCCD 2015, Ding et al. 2017, Löfqvist and Ghazoul 2019, World Bank 2022, Löfqvist et al. 2023a). At one end of the spectrum, they include local landholders within LMICs, where agricultural land (i.e., cropland and pastureland) comprises most of the area that offers low-cost carbon sequestration via FR (Shyamsundar et al. 2022) and is mostly managed by smallholders (IUCN and WRI 2014, Shyamsundar et al. 2022). At the other end, they include financial institutions, corporations, and impact investors, which are headquartered mostly in high-income countries. A commonality across these diverse actors is that they place heavy, but not necessarily exclusive, weight on the expected financial returns earned by FR investments (IUCN and WRI 2014, Ding et al. 2017, Löfqvist and Ghazoul 2019, Martin et al. 2021, World Bank 2022, Löfqvist et al. 2023a, Ashton et al. 2024).

Wood harvests and carbon credits are the most commonly cited sources of monetary returns for private FR investors (Brancalion et al. 2017, Binkley et al. 2020, Löfqvist et al. 2023a, World Bank 2024, Wellspring Development Capital Limited 2024, Cubbage et al. 2025). We therefore focus our analysis on two scenarios: a base scenario, which refers to wood-driven FR investment; and a "natural climate solutions" (NCS) scenario, which refers to carbon-driven FR investment. We include the NCS scenario for a second reason, too: the UN Decade on Ecosystem Restoration emphasizes achieving Sustainable Development Goal 13, Climate Action (UNEP and FAO 2020).

We treat the base and NCS scenarios as alternatives, but we recognize that wood production and carbon sequestration are commonly combined in practice. Although wood harvests reduce carbon stored in forests, solid wood products can store carbon for extended periods, and income from wood harvests can reduce the net cost of carbon sequestration (Busch et al. 2024). The NCS scenario's relevance for forest-based climate change mitigation refers more to afforestation, reforestation, and revegetation (ARR) projects than to projects in the UN Programme on Reduced Emissions from Deforestation and Degradation in Developing Countries (REDD+) (Forest Trends' Ecosystem Marketplace 2024). Despite the "+" in the acronym, REDD+ projects have tended to aim at reducing deforestation and degradation, not at promoting ARR.

The expected financial return on any investment has three primary components: revenues, costs, and risks. Many conditions affect these three components for both wood-driven and carbon-driven FR investments. In our primary analysis, we develop a list of conditions—seven in the base scenario, and six in the NCS scenario—that are associated with higher revenues, lower costs, or lower risks. We describe these conditions and their data sources in the Methods section. We estimate the value of each condition in every pixel with restorable forestland, and we rank the pixels from highest to lowest according to the favorability of the condition for private investment. For example, we rank a pixel with lower FR costs as more favorable than one with higher FR costs. We then classify the pixels into two halves for each condition: the half with relatively more favorable values of the condition, and the half with relatively less favorable values. Next, we tally the number of times each pixel is in the more favorable half of the full set of six or seven conditions. Finally, we aggregate restorable forestland area according to the number of favorable conditions thus determined, and we consider pixels that have a larger number of favorable conditions to be more attractive for private investment.

We recognize that actual FR investors do not assess investment conditions in this simple, unweighted, additive way, especially given their heterogeneous characteristics. We nevertheless view our findings as offering novel, large-scale insights into the *relative* attractiveness of restorable forestland in LIMCs for private FR investment. In the Conclusions section, we describe a way that future research could incorporate investor-specific weights into the type of spatially disaggregated assessment of investment opportunities presented here.[1]

---

[1] We thank an editor at the *Journal of Forest Business Research* for suggesting this idea.

We present our results differentiated by three World Bank country groups (World Bank n.d. (a)): low income (LI), lower middle income (lower MI), and upper middle income (upper MI). This differentiation facilitates identifying patterns within our large set of 115 countries. Income differences across countries result from differences in cumulative economic growth rates, which implies that general investment conditions have tended to be better in upper MI countries, followed by lower MI countries, and then LI countries. Our results reveal whether the same order holds for FR investment conditions. Differentiation by income group also facilitates examining FR's potential to achieve Sustainable Development Goal 1, No Poverty, which the UN Decade on Ecosystem Restoration emphasizes (UNEP and FAO 2020).

We conduct two secondary analyses in addition to our primary analysis of restorable forestland with favorable conditions for private FR investment. First, we investigate differences in potential FR benefits between areas with at least four favorable conditions and areas with less than four. Four is an arbitrary number, but a convenient one for partitioning our vast set of pixels (> 18 million) into two groups. It constitutes more than half the conditions in both scenarios and is consistent with our maintained, and we believe reasonable, assumption that private investment is more likely to occur where the number of favorable investment conditions is greater. The comparison of the two areas reveals whether private investment is more likely to supply some benefits than others, which could result in imbalanced progress toward restoration objectives. We examine six indicators of potential benefits, which refer to a mix of local and global, socioeconomic and environmental benefits. We describe these indicators in the Methods section.

Second, we compare the national FR commitments countries have made under the Bonn Challenge to our country-level estimates of the total area of restorable forestland and the total area with at least four favorable private FR investment conditions. This comparison reveals the physical feasibility of the commitments and the likelihood that private investment can play a substantial role in achieving them.

METHODS

This section provides a high-level view of our methods. Full details are provided in the Supplementary Information, which, along with our dataset and statistical code, is available for download on Zenodo (https://doi.org/10.5281/zenodo.15341984). Our analysis followed a straightforward series of five steps.

First, we constructed our pixel-level dataset by obtaining spatial variables from existing sources or generating new ones. We obtained most variables from the dataset for se.plan (FAO 2023, 2025), an online FR planning tool developed by the Food and Agriculture Organization of the United Nations (FAO) to support the UN Decade on Ecosystem Restoration. se.plan spans 139 LMICs in Africa, Asia and the Pacific, and Latin America and the Caribbean. It draws spatial data layers from many sources and uses Google Earth Engine to convert them to a common projection and 30-arcsecond resolution. Most variables in its database refer to ~2019. We extracted variables from the database on March 6, 2023. All additional variables that we generated matched the projection and resolution of the se.plan variables to the extent possible.

Second, we developed a working definition of restorable forestland available for private investment in LMICs (see below). We identified and retained for analysis all pixels that met the definition's criteria (Figure 1). We then applied algebraic functions in the statistical package Stata (StataCorp, 2023) to calculate total restorable area by country income group and 2019 land cover class (refer to Figure 2 in the Results section).

Third, for each scenario (base or NCS), we calculated the number of investment conditions with favorable values in each pixel. As described in the introduction, we defined "favorable" in a relative way: for each condition, we used Stata to split total restorable area across the LMICs into two halves: the half that was in pixels with relatively more favorable values of the condition, and the half that was in pixels with relatively less favorable values. We then used Stata to aggregate total restorable area across pixels with the same number of favorable conditions. We did the aggregation separately for each scenario—zero to seven conditions for the base scenario (refer to Figure 3 in the Results section), and zero to six conditions for the NCS scenario (Supplementary Figure 1)—with subaggregation of the areas by country income group.

Fourth, we used Stata to test the difference in the mean value of each of the six indicators of potential restoration benefits between pixels with at least four favorable conditions (i.e., more than half) and pixels with less than four. We ran these tests separately for the base and NCS scenarios (refer to Figure 4 in the Results section).

Finally, we compared national FR commitments under the Bonn Challenge to our estimates of total restorable area and total restorable area with at least four favorable conditions in the base scenario (refer to Figure 5 in the Results section). We drew information on Bonn Challenge commitments from the Global Restoration Commitment Database (Global Restoration Information Hub 2024).

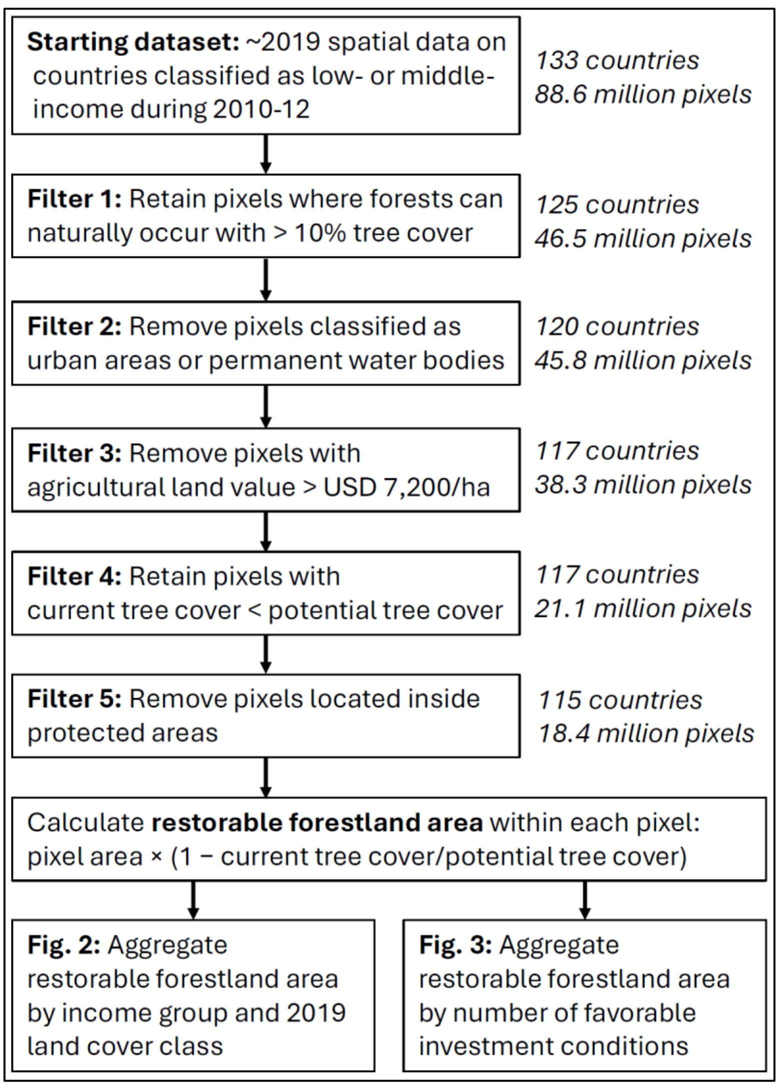

Figure 1. Data processing to identify areas of restorable forestland outside protected areas in LMICs and to generate the area estimates displayed in Figures 2 and 3 in the Results section.

Identifying pixels with restorable forestland

We selected countries that the World Bank classified as low- or middle-income (World Bank n.d. (a)) in at least two years during 2010–2012, which straddles the 2011 declaration of the Bonn Challenge. We applied five filters to identify pixels with restorable forestland (Figure 1). First, we used se.plan's ecological zones variable (FAO 2012) and potential tree cover variable (Bastin et al. 2019) to retain only pixels in zones where trees naturally occur and have potential cover greater than 10% (FAO 2018). Bastin et al. (2019) developed their potential tree cover estimates by using spatial data on 11 topographical, edaphic, and climatic variables and direct interpretation of nearly 80,000 very high resolution (≤ 1 m) satellite images. Second, we used se.plan's land cover variable (Buchhorn et al. 2020) to remove pixels classified as urban or permanent water bodies. Third, we ruled out restoration on higher-value agricultural land by removing pixels where se.plan's land opportunity cost variable (Busch et al. 2024) exceeded USD 7,200/ha, which is at the high end of commercial timberland values in LMICs (Cubbage et al. 2020). Fourth, we used se.plan's current tree cover variable (Buchhorn et al. 2020) to retain only pixels with current tree cover less than potential tree cover, which is our working definition of "forest degradation." Finally, we used se.plan's protected areas variable (UNEP-WCMC and IUCN n.d.) to remove pixels inside protected areas.

Calculating a pixel's restorable forestland area

We defined the restorable share of a pixel's area as the fraction without tree cover,

$$\textit{Restorable share} = 1 - (\textit{Current tree cover} \,/\, \textit{Potential tree cover}).$$

Due to the inclusion of potential tree cover in this expression, the definition implicitly accounts for natural variation in canopy cover across ecological zones. We calculated a pixel's restorable area by multiplying its restorable share by its area, from the se.plan database.

Determining conditions favoring private FR investment

We determined the seven (base scenario) and six (NCS scenario) conditions favoring private FR investment by reviewing prior studies on private FR investment and insights gained from focus groups in early 2023 with five representatives of international forestland investment companies, four private-sector representatives in Uganda, and one academic expert (Caradine et al. 2023). For the base scenario, this background research indicated that major conditions associated with higher revenues, lower costs, and lower risks include:

Higher revenues

(i) Higher *tree growth rates* (Brancalion et al. 2017, Ding et al. 2017, Binkley et al. 2020), which reflect the effects of better biophysical site conditions.

(ii) Higher growth rates of *domestic demand for wood products* (IUCN and WRI 2014, Binkley et al. 2020, Wellspring Development Capital Limited 2024), which help ensure sufficient markets and acceptable prices for wood from restored forests.

(iii) Better *market access* (IUCN and WRI 2014, Brancalion et al. 2017, Binkley et al. 2020, Wellspring Development Capital Limited 2024), which contributes to higher stumpage prices.

Lower costs

(iv) Lower opportunity costs (i.e., land costs) and lower FR implementation costs (e.g., costs of seedlings and labor to plant them) (Brancalion et al. 2017, Binkley et al. 2020, Busch et al. 2024). We refer to the sum of these two cost components as *FR costs*. Implementation costs in the base scenario refer solely to tree planting and do not include natural regeneration (Brancalion et al. 2017, Ding et al. 2017, Martin et al. 2021, Löfqvist et al. 2023a).

(v) A larger *scale* of land parcels, which can reduce transaction costs and provide scale economies (IUCN and WRI 2014, Brancalion et al. 2017, Ding et al. 2017, Löfqvist and Ghazoul 2019, Binkley et al. 2020, World Bank 2024, Wellspring Development Capital Limited 2024).

Lower risks

(vi) Stronger *property rights* (IUCN and WRI 2014, Brancalion et al. 2017, Ding et al. 2017, Löfqvist and Ghazoul 2019, Binkley et al. 2020, Löfqvist et al. 2023a, Wellspring Development Capital Limited 2024), which help assure investors that they will not face arbitrary loss of their land.

(vii) Lower *country risk* (IUCN and WRI 2014, Ding et al. 2017, Binkley et al. 2020, Löfqvist et al. 2023a, Wellspring Development Capital Limited 2024), which helps assure investors that they will reap an acceptable return on their investment.

These seven conditions do not include all conditions that our background research indicates influence private FR investments. In the Discussion and Practical Implications section, we mention additional conditions and discuss the implications of omitting them from our analysis.

The NCS scenario included the same conditions with two exceptions. First, we replaced the first two conditions, tree growth rates and domestic wood products demand, with the level of potential *carbon sequestration*, which is a better summary indicator of potential revenue from carbon markets. Second, we adjusted the fourth condition, FR costs, to accommodate natural regeneration in addition to tree planting, with FR implementation costs being lower in areas where natural regeneration is more likely to succeed (see below). Implementation costs for natural regeneration typically relate to fencing, other protective measures, and sometimes limited site preparation.

Measuring conditions favoring private FR investment

Data sources for these conditions in the base scenario were as follows:

(i) *Tree growth rate*: se.plan database (original source: Albanito et al. 2016); refers to potential annual production of woody biomass by fast-growing trees in rainfed conditions.

(ii) *Domestic wood products demand* (national variable not in se.plan database): We constructed this variable using national wood products data (FAO n.d. (a)), regional wood-processing conversion factors (FAO, ITTO, and United Nations 2020), and simple algebra to calculate the annual growth rate between 2000 and 2018.

(iii) *Market access*: se.plan database (original source: Weiss et al. 2018); refers to travel time in minutes to the nearest city in 2015.

(iv) *FR costs*: se.plan database. Busch et al. (2024) describe construction of this variable's opportunity cost component, which refers to the capitalized value of annual agricultural land rents (the portion of agricultural profit attributable to land instead of other production inputs). The implementation costs component encompasses both establishment costs in the first year of restoration and management costs in the subsequent 3–5 years. The se.plan team generated this component by extracting estimates of implementation costs from World Bank project documents, regressing the estimates on a set of variables hypothesized to influence them (Supplementary Table 5), and using the resulting model and the spatial variables in it to predict implementation costs by Level 1 administrative subdivisions (i.e., states/provinces) in the se.plan countries.

(v) *Scale*: This variable is restorable area per capita. We calculated it using pixel-level data on restorable area (described above), pixel area (se.plan database), and population density (se.plan database; original source: CIESEN 2018).

(vi) *Property rights*: se.plan database. The se.plan team generated this variable by downscaling the World Bank's national Rule of Law indicator (Kaufmann et al. 2010) to Level 1 subdivisions. It regressed the national indicator on population density (World Bank n.d. (c)), GDP per capita (World Bank n.d. (c)), and a dummy variable for British colonial history (Becker 2019) (Supplementary Table 3). It used the resulting model and gridded data on population density (CIESIN 2018) and GDP per capita (Kummu et al. 2018) to predict Level 1 subdivision values.

(vii) *Country risk* (national variable not in se.plan database): We drew this variable from Damodaran (2022a, 2022b), with regression used to impute missing values for a small number of countries (Supplementary Table 4). The country risk premium refers to the additional return an equity investor demands to compensate for the higher risk, if any, of investing in a country other than the United States.

As noted above, we made two changes to the conditions in the NCS scenario. First, we replaced conditions (i) and (ii) with the level of potential *carbon sequestration*. We obtained data on the latter variable from Walker et al. (2022). Second, we adjusted the implementation costs component of condition (iv) to allow natural regeneration in addition to tree planting:

$$\textit{Implementation costs}_{NCS} = (1 - 0.66 \times \textit{NR success}) \times \textit{Implementation costs}_{Base},$$

where *NR success* is a se.plan variable giving the likelihood of natural regeneration success on a 0 to 1 scale, based on Crouzeilles et al. (2019). The 0.66 mean cost reduction for fully successful natural regeneration is from the implementation costs model estimated by the se.plan team (Supplementary Table 5).

Measuring potential restoration benefits

We considered six indicators of potential restoration benefits, all expressed in physical terms, not monetary terms. They represent relative indicators of the potential magnitudes of benefits FR could supply if it were implemented successfully using tree species and forest management practices suitable for supplying those benefits.

Three of the indicators refer to local livelihood benefits: *population density* (presence of people is a precondition for local livelihood impacts) (Erbaugh et al. 2020, Löfqvist et al. 2023b); *woodfuel harvest* per hectare; and *forest-sector employment* per hectare. Two refer to global environmental benefits, *carbon sequestration* and number of *threatened species*. The latter is a commonly used measure of priority for biodiversity conservation, which is a third Sustainable Development Goal emphasized by the UN Decade on Ecosystem Restoration, SDG 15, Life On Land (UNEP and FAO 2020). The sixth indicator, *water sufficiency*, refers to avoidance of a potential disbenefit of large-scale tree-planting: increased evapotranspiration from increased tree cover is less likely to worsen water scarcity in regions where water is more sufficient (Jones et al. 2022).

We drew data for all six indicators from the se.plan database. Original sources for four of them were published sources: *population density* (CIESEN 2018); *carbon sequestration* (Walker et al. 2022), which is the same variable used as an investment condition in the NCS scenario; *threatened species* (Jenkins et al. 2013, Pimm et al. 2014); and *water sufficiency*, the inverse of water stress (Hofste et al. 2019).

The se.plan team generated the remaining two indicators by downscaling national data. For *forest-sector employment*, it used national data on employment in forest-related industries (International Labour Organization n.d.) and total forest area (FAO 2020) to calculate employment per hectare in 2000, 2010, 2015, and 2020, which it regressed on population density (World Bank n.d. (c)), GDP per capita (World Bank n.d. (c)), the share of planted forests in national forest area (FAO 2020), and fixed effects for FAO regions (Supplementary Table 6). It used the resulting model and gridded data on population density (CIESIN 2018) and GDP per capita (Kummu et al. 2018) to predict 2015 Level 1 subdivision values.

For *woodfuel harvests*, the se.plan team used national data on annual woodfuel harvests (FAO n.d. (a)) and total forest area (FAO 2020) to calculate woodfuel harvest per hectare in 2000, 2010, 2015, and 2020, which it regressed on population density (World Bank n.d. (c)), the square of population density, and country fixed effects (Supplementary Table 7). It used the resulting model and gridded data on population density (CIESEN 2018) to predict 2015 Level 1 subdivision values.

Testing mean differences in potential benefits

We used linear regression to test mean differences in potential benefits between pixels with at least four favorable investment conditions and those with less than four. For each scenario (base or NCS), we generated a dummy variable that equaled 1 for pixels with at least four favorable conditions and 0 for pixels with less than four favorable conditions. We regressed each of the six benefit indicators on the scenario's dummy variable, with pixels weighted by their restorable area and standard errors clustered by Level 1 subdivision to correct for heteroskedasticity and spatial correlation (Zeger and Liang 1986). The columns in Figure 4 are based on the estimated coefficients on the dummy variables from these 12 regressions (= six indicators × two scenarios). To make the estimates comparable across indicators, we expressed them as percentages of the indicators' mean values for pixels with less than four favorable conditions.

RESULTS

General characteristics of restorable forestland

Across the 115 LMICs in our sample, restorable forestland outside PAs totaled 881 Mha in 2019, which far exceeded the area inside protected areas (98 Mha). Figure 2 shows that approximately half (48%) of the 881 Mha was in upper MI countries, with a third (33%) in lower MI countries and a fifth (19%) in LI countries.

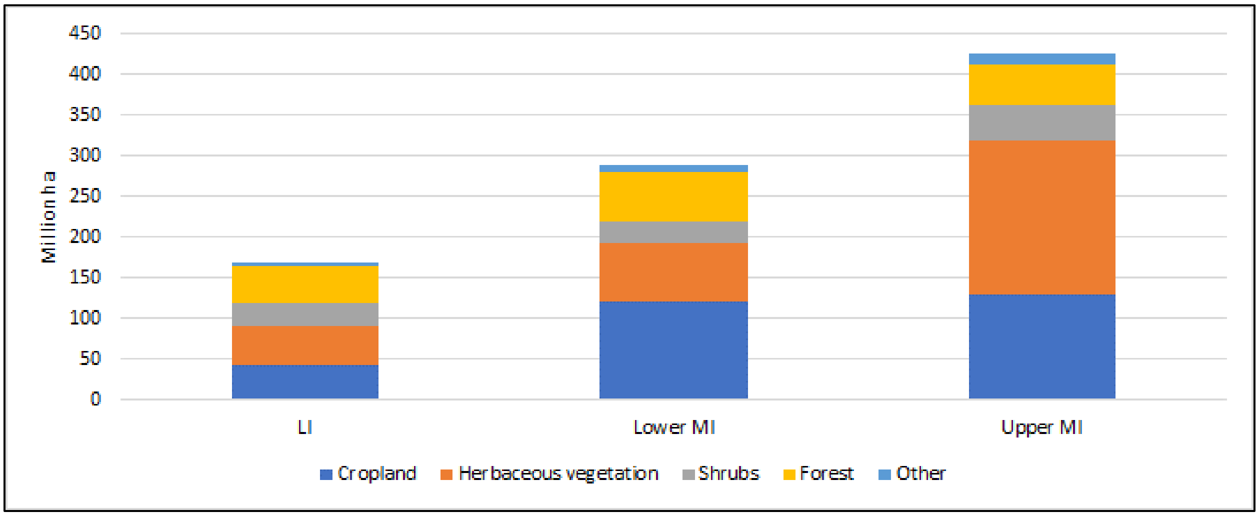

Figure 2. Restorable forestland outside protected areas in LMICs, by income group and 2019 land cover class. Note: LI = low income, MI = middle income. Areas are summed across 18.4 million pixels in 115 LMICs.

The land cover classes in Figure 2 are aggregate categories based on se.plan's land cover variable (Buchhorn et al. 2020). Most of the area was in agricultural use: 34% was cropland, and 35% was herbaceous vegetation. The latter was likely mostly pastureland, which is the typical use of forests converted to herbaceous vegetation in LMICs (Oliveira et al. 2020). Another 11% was shrubland, which could be pastureland, early successional forests, or both (Buchhorn et al. 2020, Oliveira et al. 2020). Prior research deems shrubland and land with herbaceous vegetation as being particularly attractive for large-scale tree planting (Cubbage et al. 2025). We reiterate that, irrespective of current land use, our estimates of restorable forestland refer exclusively to land where forests can naturally occur.

Only 18% of the area had forests as the dominant land cover. In principle, the apparent degradation of these forests (i.e., the gap between their potential and actual tree cover) could represent temporary canopy reductions caused by commercial timber harvesting under sustainable management plans, which would imply that FR investments are not necessary in that area. Two reasons lead us to doubt that such reductions account for much of the area. First, only 26% of the forest area in LMICs was under long-term management plans in 2020 (FAO 2020, Table 63). Second, most commercial timber harvesting in LMICs occurs in closed-canopy forests, and barely a third (38%) of the 18% had the potential to achieve this canopy coverage threshold (Bastin et al. 2019). Here, we have followed Buchhorn et al. (2020) in defining forests as “closed” if they have more than 70% canopy coverage.

In sum, as of 2019, most restorable forestland in LMICs was located outside PAs, and land use on most of it was some form of agriculture, not forestry. FR on this land is thus more appropriately termed afforestation than reforestation (FAO 2018).

Base scenario: restorable forestland area with favorable investment conditions

Which income group was more attractive for wood-driven investment is not apparent from descriptive statistics on the seven investment conditions (Table 1). Although mean values were more attractive in upper MI countries for four conditions (tree growth, scale, property rights, country risk premium), they were more attractive in LI countries for two (domestic wood products demand, FR costs) and lower MI countries for one (market access). Moreover, they varied greatly across pixels within each group, with standard deviations equaling or exceeding means in about half the cases.

To assess the combined effects of the seven conditions, we first split the 881 Mha into two halves for each condition: (i) the half with relatively more favorable values of the condition, i.e., higher or lower values depending on the condition per Table 1; and (ii) the half with relatively less favorable values. We then tallied the number of times each pixel was in the more favorable half across the seven conditions.

Table 1. Base scenario: variation in private FR investment conditions, between and within country income groups (LI = low income, MI = middle income).

Condition	Units	More attractive for private investment if …	LI		Lower MI		Upper MI	
			Mean	SD	Mean	SD	Mean	SD
Tree growth	Dry tons/ha/yr	Larger	4.31	4.81	4.09	4.68	**5.92**	5.12
Domestic wood products demand	%/yr	Larger	**5.18**	4.89	4.79	3.89	2.59	3.03
Market access	Minutes	Smaller	223	234	**168**	258	173	258
FR costs*	2020 USD/ha	Smaller	**3219**	1709	4105	2041	4802	2109
Scale	Hectares per capita	Larger	0.031	0.044	0.063	0.124	**0.183**	0.198
Property rights	Index, −2.5 to +2.5	Larger	−0.925	0.227	-0.498	0.231	**−0.455**	0.251
Country risk premium	%/yr	Smaller	15.1	4.1	9.6	5.2	**7.2**	6.2

Bold: *income group with most favorable mean value. Number of observations: LI, 3.5 million pixels; Lower MI, 6.1 million pixels; Upper MI, 8.8 million pixels. Means and SDs calculated with pixels weighted by their restorable forestland areas.*
**Sum of opportunity cost and implementation costs.*

This process revealed that barely half the area (466 Mha, 53%) had at least four (i.e., more than half) of the conditions being favorable in this relative sense (Figure 3). Defining the state of having "enough" favorable conditions more stringently, barely a fifth of the area (181 Mha, 21%) had at least five favorable conditions, with even smaller areas having at least six conditions (17 Mha, 1.9%) or all seven conditions (0.41 Mha, 0.047%) being favorable (Figure 3).

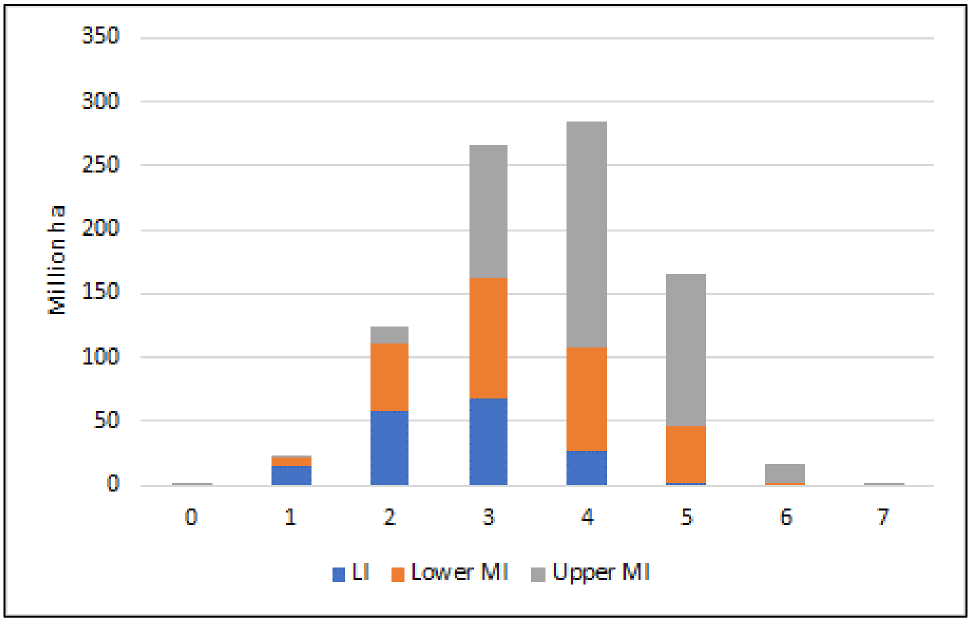

Figure 3. Base scenario: restorable forestland outside protected areas in LMICs, by number of favorable conditions for private FR investment. Note: LI = low income, MI = middle income. Areas are summed across 18.4 million pixels in 115 LMICs.

Making an analogy to the expected number of "heads" if a fair coin is tossed seven times, we would expect the percentages for at least four, at least five, at least six, and all seven conditions being favorable to be 50%, 23%, 6.3% and 0.78%, respectively, simply by random chance. The similarity of these percentages to the observed ones implies that spatial correlations among the favorable conditions generally do not have large positive values, which direct calculation of the correlations confirms (Supplementary Figure 2). Only three of the 21 correlations exceed 0.25, with the largest being 0.45 for the correlation of market access with property rights. These and a few smaller positive correlations are offset by negative correlations for other pairs of conditions, notably −0.47 for both market access with scale and domestic wood products demand with country risk.

Base scenario: differences between areas with larger and smaller numbers of favorable conditions

The heterogeneity of private investors suggests they do not necessarily all require the same number or set of conditions to be favorable. Moreover, they surely do not measure a given condition's favorability simply by dividing potentially restorable area into two halves. Nevertheless, it is reasonable to expect that private investment is more likely to occur in areas with a larger number of relatively more favorable conditions. Accordingly, we examined differences between areas with at least four favorable conditions (i.e., more than half the total number) and areas with less than four.

Upper MI countries accounted for the largest share of the 466 Mha with at least four favorable conditions (66%, 308 Mha), while LI countries accounted for the smallest share (6%, 27 Mha) (Figure 3). Upper MI countries were thus overrepresented, and LI countries underrepresented, relative to their shares of total restorable forestland (Figure 2). Of the ten countries having the largest areas with at least four favorable conditions, seven were upper MI countries: from largest to smallest, Brazil, Argentina, China, Colombia, Mexico, South Africa, and Turkey (Supplementary Table 1). The remaining three were lower MI countries: India, Iran, and Indonesia. These ten countries accounted for more than two-thirds (69%, 321 Mha) of the total restorable area with at least four favorable conditions, which is disproportionately large relative to their share of total restorable forestland (48%, 424 Mha). Across the 115 LMICs we analyzed, restorable area with more investment conditions being favorable than not is thus relatively highly concentrated in a small number of countries, none of them in the LI group.

The six indicators of potential restoration benefits suggest that restoration driven by wood markets would be more likely to generate local livelihood benefits than global environmental benefits (Figure 4, blue columns). Mean values of human population density and forest-sector employment were both much higher—81% and 220%, respectively—in areas with at least four favorable conditions than in areas with less than four. These estimates indicate that human populations in areas with at least four favorable conditions were nearly twice as dense as in areas with less than four conditions, while forest-sector employment was more than three times as large. Mean values differed much less between the two areas for the other potential benefit indicators, including all three environmental indicators. The lack of difference in mean water sufficiency between areas with at least four favorable conditions and areas with less than four favorable conditions implies that private FR investment is no more likely to occur in water-stressed regions than water-sufficient regions.

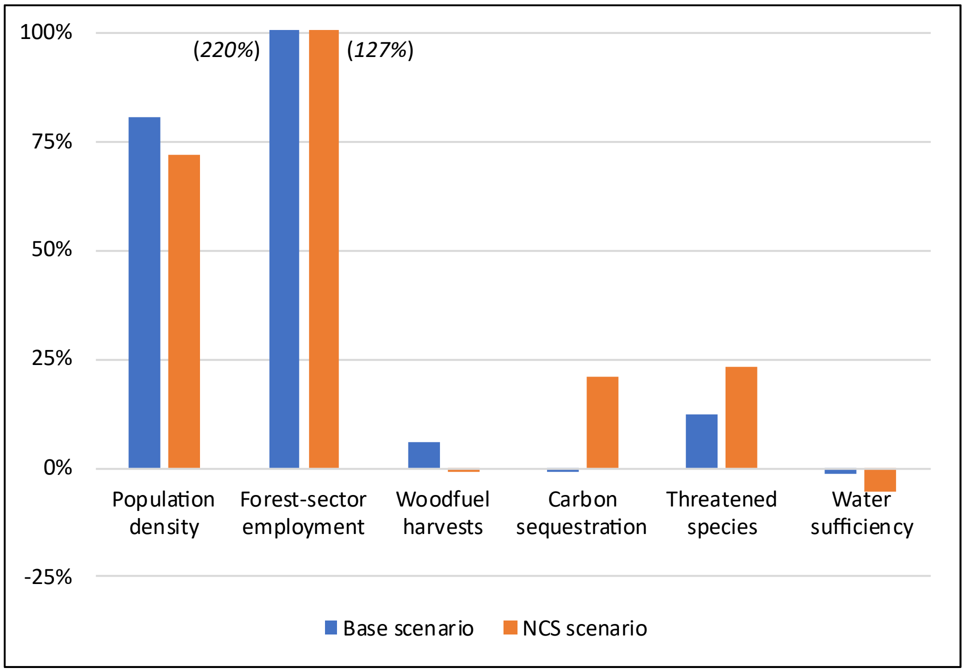

Figure 4. Indicators of potential benefits of private FR, by scenario. Each column shows the % difference between an indicator's mean value for restorable areas with at least four favorable private investment conditions and its mean value for restorable areas with less than four favorable conditions. Two-tailed t-tests indicate that differences are significant at $p < 0.01$ for population density and forest-sector employment in both scenarios, $p < 0.01$ for carbon sequestration and threatened species in the NCS scenario, $p < 0.05$ for threatened species in the base scenario, and $p > 0.15$ for all other indicators. Number of observations: 18.4 million pixels in 115 LMICs, with small differences between indicators and scenarios due to missing data.

NCS scenario

Results were broadly similar for the NCS scenario: aggregate areas with most of the conditions being favorable continued to be small (Supplementary Figure 1); and the distribution of those areas continued to slant toward upper MI countries, which accounted for 69% of the area with at least four favorable conditions (Supplementary Figure 1, Supplementary Table 2). Across all income groups, two-thirds (591 Mha, 67%) of the restorable area had at least half (i.e., three or more) of the conditions favorable. Only a third (287 Mha, 33%) had more than half of the conditions favorable (i.e., at least four), with less than a tenth (70 Mha, 8%) having at least five favorable conditions and less than 1% (4.3 Mha, 0.49%) having all six conditions being favorable.

The corresponding percentages from a fair coin toss are 66%, 34%, 11%, and 1.6% for at least three, at least four, at least five, and all six conditions, respectively. The similarity of the observed percentages to these based on random chance again implies a general lack of large positive spatial correlations among the favorable conditions, which is again confirmed by direct calculation of the correlations (Supplementary Figure 3). Only two of the 15 correlations exceed 0.25, with the largest being 0.45 for the correlation of market access with property rights. These and smaller positive correlations are again offset by negative correlations for other pairs of conditions. The second largest negative correlation is a −0.36 correlation of potential carbon sequestration with scale, which is consistent with evidence from previous research that much restorable forestland is found on agricultural smallholdings (Shyamsundar et al. 2022) and suggests a challenge for identifying large individual tracts of land for carbon project development.

Two expected but notable differences occurred between the base and NCS scenarios. First, the allowance for natural regeneration in the NCS scenario caused mean FR costs in areas with at least four favorable conditions to be lower in that scenario (USD 3,695/ha) than in the base scenario (USD 4,377/ha). Second, potential carbon benefits, which are measured by the same variable that is an investment condition in the NCS scenario, were now substantially larger (21%) in areas with at least four favorable conditions than in areas with less than four (Figure 4, orange columns). Although this value was much smaller than those for population density (72%) and forest employment (127%), it was a reversal of the small negative value for potential carbon benefits in the base scenario (−1%). The value for potential biodiversity benefits (23%) also increased, nearly doubling compared to the base scenario (12%). The value for the water sufficiency indicator was negative but small (−5%) and not statistically significant (p = 0.17).

Bonn Challenge

Bonn Challenge commitments refer to total areas to be restored to forest by 2030. Fifty-nine LMICs have declared national commitments (Global Restoration Information Hub 2024), ranging from 9,000 ha in Georgia to 26 Mha in India (Supplementary Table 8). The median national commitment is 1.5 Mha. The 59 countries are nearly evenly distributed across the LI group (18 countries), the lower MI group (21 countries), and the upper MI group (20 countries). Approximately half are in Sub-Saharan Africa (30 countries), and over a quarter are in Latin

America and the Caribbean (16 countries). Fourteen countries in Latin America and the Caribbean account for most of the 20 countries in the upper MI group.

A large majority of the national commitments—50 out of 59—are smaller than our estimates of total restorable area. Most Bonn Challenge countries have therefore made commitments that are, in principle, feasible from a physical land-area standpoint and perhaps also from an economic standpoint, as total restorable area by our definition excludes high opportunity cost lands. All nine countries that have made seemingly infeasible commitments are in the LI or lower MI group, with eight being in Sub-Saharan Africa. (See yellow-highlighted values in the penultimate column of Supplementary Table 8.) Some of these commitments might be feasible if our estimates of restorable area included land within PAs.

The Global Restoration Commitment Database (Global Restoration Information Hub 2024) does not report national commitments by expected funding sources, but our results indicate that private investment is not a promising source for many LMICs. Over half (31) of the 59 Bonn Challenge LMICs have national commitments that exceed our base-scenario estimates of restorable areas with at least four favorable investment conditions (Figure 5, Supplementary Table 8). All but two of these countries are in the LI or lower MI group, and most are in Sub-Saharan Africa (24 countries). (See yellow-highlighted values in the last column of Supplementary Table 8.) The aggregate commitment across the 31 countries, 121 Mha, is four times greater than the aggregate area with at least four favorable investment conditions in the countries, 29 Mha. Many LMICs have made Bonn Challenge commitments that will likely require funding primarily from sources other than the private sector.

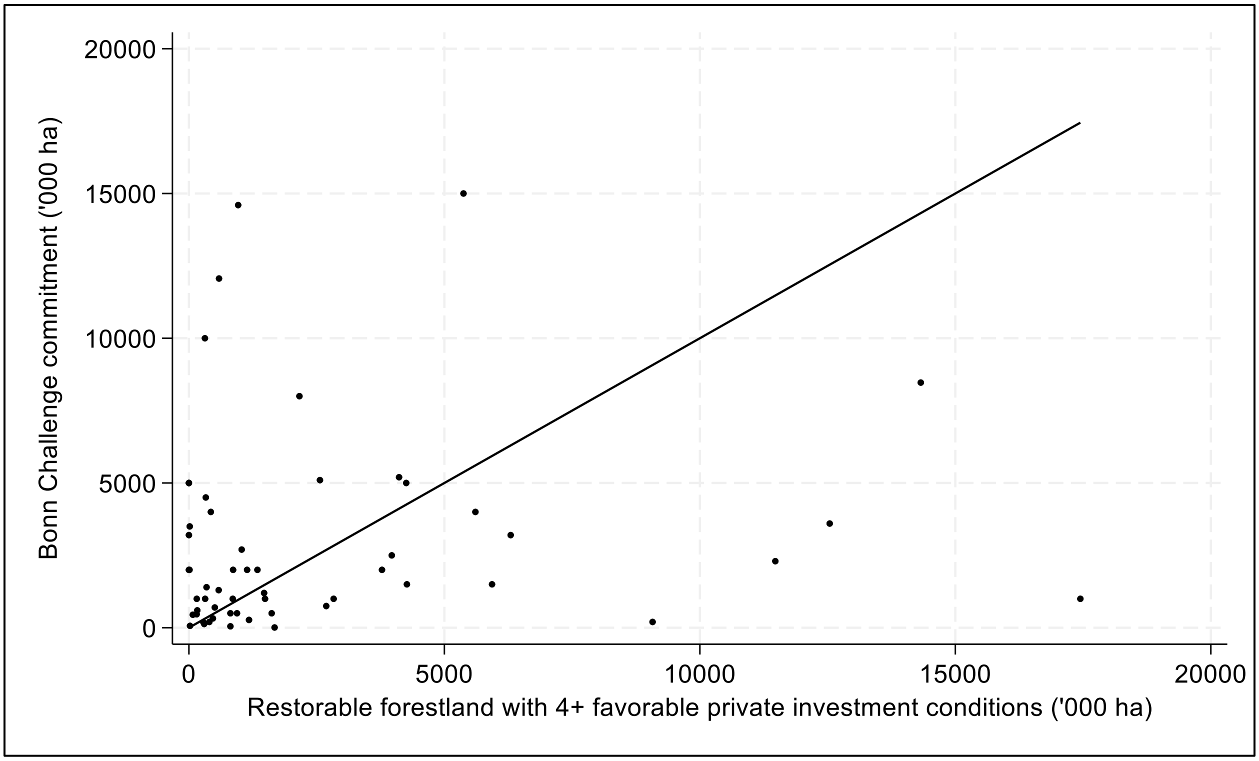

Figure 5. Base scenario: comparison of national FR commitments under the Bonn Challenge to estimates of national restorable forestland with at least four favorable private investment conditions. Each dot refers to an individual country. Countries above the 45° line have commitments that exceed their total area of restorable forestland with at least four favorable private investment conditions. The figure displays information on 56 countries, excluding three countries with restorable forestland exceeding 20 Mha (Brazil, India, Argentina; all are below the 45° line). See Supplementary Table 8 for country details. Source of data on Bonn Challenge commitments: Global Restoration Information Hub (2024).

DISCUSSION AND PRACTICAL IMPLICATIONS

Our analyses of the base and NCS scenarios yielded the same two main findings: (i) almost no restorable forestland (< 1%) has all conditions favorable for private FR investment, and much of it has less than four favorable conditions (47% in the base scenario, 67% in the NCS scenario); and (ii) restorable forestland with more favorable conditions is predominantly in upper MI countries, not lower MI or LI countries, and it tends to have greater potential to supply local livelihood benefits than global environmental benefits. These findings imply that, under current conditions, private investment will finance only a relatively small portion of FR in LMICs compared to the total area that potentially could be restored, and it will primarily serve a subset of FR objectives. They validate concerns about private investment flowing to a relatively small group of LMICs and generally not to FR projects that supply global public goods, in particular biodiversity (Brancalion et al. 2017, Löfqvist and Ghazoul 2019, Löfqvist et al. 2023a). Our findings also imply that private investment is not likely to be a feasible funding source for many LMICs' national FR commitments under the Bonn Challenge.

These findings are reinforced when one considers that a lack of data prevented us from including additional conditions that matter to many private investors, such as site-specific information on suitable tree species and regeneration methods, proximity to nurseries that can supply those species, skilled expertise for implementing FR projects, forestry regulations that encourage tree-growing, trade policies that allow free access to international markets, and detailed information on local market outlooks and local wood value chains (IUCN and WRI 2014, Binkley et al. 2020, Shyamsundar et al. 2022, Ashton et al. 2024, Wellspring Development Capital Limited 2024). Access to credit is a particular obstacle for many smallholders in LMICs (Shyamsundar et al. 2022). We also ignored generic impediments to private FR investment that do not vary between or within countries, such as the illiquidity of forestland investments (IUCN and WRI 2014, Ding et al. 2017, Binkley et al. 2020, Löfqvist et al. 2023a, World Bank 2024) and inadequate investment conditions for wood-processing facilities, which are a key link in sustainable value chains that generate domestic demand for locally grown wood (Binkley et al. 2020, Caradine et al. 2023, Wellspring Development Capital Limited 2024). The high-level nature of our analysis also precluded an assessment of compliance with principles the UN Decade on Ecosystem Restoration has formulated to ensure that restoration programs generate benefits for both people and nature (FAO, IUCN, CEM, and SER 2021).

Our findings are tempered by the fact that some private investors care about more than just the financial return on investment (e.g., corporations with net-zero targets, impact investors), while others are willing to incur high risks if returns are sufficiently high (Löfqvist and Ghazoul 2019, World Bank 2022, 2024). A risk-loving, wood-driven investor might have a "glass half full" perspective and view the > 400 Mha with at least four favorable investment conditions as offering abundant investment opportunities, despite not all conditions being favorable. Yet, many investors have a low risk tolerance and a fiduciary responsibility to maximize their return for a given risk level. These investors include pension funds and other financial institutions that have dominated global forestland investment in recent decades (Binkley et al. 2020, World Bank 2024).

The general thrust of our findings is remarkably similar to findings reported in a recent study by Cubbage et al. (2025), who applied methods very different from ours to LMICs in Latin America and Asia. The authors aimed to determine the feasibility of a single country planting an additional 10 Mha of forest plantations by 2030. They used country-level information, drawing historical and projected levels of tree planting from four previous studies and supplementing that information with additional country-level data. Although their spatial units were orders of magnitude more aggregate than our 30-arcsecond pixels, and although they did not assess specific investment conditions as explicitly as we did, the four countries they identified as being most able to plant large areas—Brazil, China, India, and Argentina—are also in the top four on our list of countries with the largest restorable area having with at least four favorable investment conditions (Supplementary Table 1). Our fifth country, Colombia, is sixth on their list, while their fifth country, Indonesia, is tenth on ours. Their overall conclusion, that “the likelihood of any country planting an additional 10 million ha of forests in the next decade is extremely small” (p. 25), is consistent with our finding of a general lack of locations with large numbers of favorable conditions for private FR investment. The methodological differences between their study and ours make the two studies highly complementary in our view and suggest to us that these common findings are robust.

The investment conditions included in our analysis are not immutable. In principle, LMIC governments can change them and encourage higher levels of private FR investment by providing various forms of public-sector support: financial, informational, infrastructural, institutional. Case studies are becoming available on successful instances of governments providing this support (World Bank 2024). We offer the following general examples for the investment conditions we analyzed.

Improving investment conditions: revenues

Government extension services can contribute to raising *tree growth rates* for planted species by providing landholders and other potential investors with better information on suitable species and appropriate regeneration methods and management practices (IUCN and WRI 2014, Binkley et al. 2020). This silvicultural information is lacking in many tropical locations (Ashton et al. 2024). Its public-good nature makes a strong case for government investment in the research needed to generate it. Research can also develop techniques that accelerate natural regeneration (Gan et al. 2023).

Governments can boost *domestic demand for wood products* by favoring wood products in public-sector procurement programs. The public sector is a nontrivial economic sector: government expenditure on goods and services accounted for a median of 15% of 2020 gross domestic product (GDP) in the LMICs in our analysis and exceeded 25% in 30% of them (World Bank n.d. (c)). Governments can also promote use of wood as a low-carbon construction material by revising building regulations (Binkley et al. 2020, Mishra et al. 2022, Wellspring Development Capital Limited 2024) and as a reduced-carbon commercial energy source by removing obstacles to substituting woody biomass for fossil fuels in power plants (Campbell et al. 2008, Favero et al. 2020). Boosting demand is important because decades of global expansion of timber plantations and other planted forests (Payn et al. 2015) have stabilized growing stocks of wood in the world's forests (FAO 2020), resulting in stagnant timber prices that diminish financial incentives for wood-driven investments (Vincent et al. 2021). Controlling illegal logging in public forests could also help by preventing unsustainable timber supplies from undermining prices for plantation-grown wood.

Carbon-driven FR also faces a financial-incentive challenge in LMICs (Löfqvist and Ghazoul 2019, Vincent et al. 2021, Ashton et al. 2024): average carbon prices in forest carbon offset projects (Forest Trends' Ecosystem Marketplace 2024) are a small fraction of the estimated social cost of carbon (Rennert et al. 2022). In addition, forest carbon project standards and associated government requirements are often complex or unclear, highly variable, and thus costly to navigate (World Bank 2024). Furthermore, recent impact evaluations have revealed that a large share of existing forest carbon offsets in LMICs, in particular those associated with the REDD+ program, have not supplied additional carbon sequestration (West et al. 2023). Resolving these problems requires actions that are not entirely within the scope of individual LMIC governments, but it is a necessary condition for scaling up private investment in carbon-driven FR.

Governments can improve *market access* through investments in roads and other infrastructure (Binkley et al. 2020). Given our finding that most restorable forestland outside protected areas is currently in agricultural use, infrastructure for transporting seedlings and other inputs to restoration sites and transporting harvested wood from those sites to markets is more likely to be already in place compared to FR sites inside protected areas, though not necessarily in good repair. In some locations, government investment is needed to upgrade or construct infrastructure specific to wood supply chains, such as heavy-duty roads, railroads, bridges, and port facilities (Binkley et al. 2020).

Improving investment conditions: costs

Governments can reduce *opportunity costs* of restorable forestland by reducing subsidies that artificially increase financial returns to agriculture relative to forestry returns (World Bank 2022, 2024, Ding et al. 2021, FAO 2022, FAO, UNDP, and UNEP 2021), with appropriate consideration of the potential impacts of agricultural subsidy reduction on food security and the welfare of rural communities. More directly, governments can offer favorable tax treatment of private forestland (Binkley et al. 2020), which governments of some LMICs already do (Enters et al. 2003).

Governments can also make degraded public forestland with a low opportunity cost available to private investors through "restoration concessions" (Harrison et al. 2020). Under these schemes, governments offer long-term licenses (60–100 years) and rights to earn future revenue from timber and other sources (e.g., carbon) to private parties who agree to invest in silvicultural activities necessary for restoring the productivity of the forestland. Experience with these concessions appears to be greatest in Indonesia (nearly 1 Mha since 2004). Unfortunately, it indicates that most concessions have been hindered by insufficient revenue streams and onerous regulations, which underscores the importance of points made in the preceding subsection.

Governments can reduce *implementation costs* by investing directly in nurseries or offering incentives for private nurseries that boost the supply of desired planting stocks (Löfqvist and Ghazoul 2019, Binkley et al. 2020). They can also offer planting subsidies when rural development benefits or environmental benefits justify subsidizing private planting (Binkley et al. 2020). They can reduce costs indirectly by providing landholders with information on the cost-effectiveness of different regeneration methods (Busch et al. 2024) and new technologies that improve the efficiency of restoration interventions (Castro et al. 2021). Advances in remote sensing and information technologies are making generation and dissemination of cost-reducing FR information increasingly feasible (Swift Geospatial n.d.).

Outgrower schemes (Wellspring Development Capital Limited 2024, Vincent et al. 2021) and cooperatives (Löfqvist and Ghazoul 2019) are promising means of agglomerating individual forest landholdings to gain *scale*. Companies that purchase wood organize and finance outgrower schemes, while governments and nongovernmental organizations (NGOs) typically fund cooperatives. Governments and NGOs also play an essential role in ensuring that companies treat landholders who participate in outgrower schemes equitably (Löfqvist and Ghazoul 2019). The need for FR programs to engage local communities equitably is attracting increased attention (Erbaugh et al. 2020, FAO 2022, Löfqvist et al. 2023b, World Bank 2024).

Improving investment conditions: risks

Substantial strengthening of property rights and lowering of country risks is unlikely to occur within the near-term time horizon of initiatives such as the Bonn Challenge and the UN Decade on Ecosystem Restoration, but improvements in these conditions are possible over longer time frames. Despite decades of land titling programs by governments and aid agencies, *property rights* remain poorly defined, poorly enforced, or both in many LMICs (Feyertag et al. 2020). China and Vietnam offer evidence that tenure reform programs can boost landholder investment in tree-growing after one to two decades (FAO 2022).

Country risks are generated by complex combinations of social, political, and economic factors that governments cannot easily change in a risk-lowering direction. Actions to mitigate the impacts of these risks are nevertheless possible. Governments could underwrite some risk-coverage mechanisms, such as first-loss guarantees (Ding et al. 2017, Löfqvist and Ghazoul 2019). The World Bank or another international financial institution could offer insurance products for some types of political risks and create facilities to buffer swings in forestland asset values caused by foreign exchange volatility (Binkley et al. 2020).

Blended finance and coordinated policy interventions

The foregoing discussion exposes a conundrum in FR finance: private investment is essential because public-sector funds are insufficient, but private investment will be but a trickle if public-sector investments do not improve conditions for it. Given deteriorating fiscal balances in LMICs (United Nations 2023), much of the funding for needed public-sector investments must come from sources other than LMIC governments: from aid agencies, development banks, foundations, and NGOs. Scaling up private FR investment thus requires blended finance, with funds from these external sources and, where possible, country governments supporting public-sector investments that make LMICs more attractive to private FR investors (Löfqvist and Ghazoul 2019, Binkley et al. 2020, World Bank 2022, 2024, Löfqvist et al. 2023a). Given that investment attractiveness has multiple dimensions, blended finance is more likely to succeed when it is combined with packages of coordinated policy interventions that address those multiple dimensions instead of piecemeal interventions that target individual investment impediments (Ding et al. 2017, Binkley et al. 2020, World Bank 2022, 2024).

Our analysis indicates that locations favorable for carbon-driven private FR investment have potential to supply biodiversity benefits too. Biodiversity credit programs are much less developed than carbon programs, however, which reduces the incentive for forest carbon investors to favor biodiversity-enhancing FR projects over carbon plantations. At present, payment for ecosystem services programs funded by governments and NGOs might be the most promising means of incentivizing private FR investors to supply not only carbon benefits but also biodiversity benefits and other important environmental benefits of restored forests (Löfqvist and Ghazoul 2019, Binkley et al. 2020, World Bank 2022, 2024, Ashton et al. 2024).

CONCLUSIONS

We recapped our main findings at the start of the Discussion and Practical Implications section and highlighted policy implications throughout that section. Rather than repeating the same information here, we will conclude by suggesting three topics for future research that can advance knowledge on scaling up private FR investment in LMICs

Researchers are continually generating new data sources useful for developing spatial data layers on FR benefits, costs, and risks. This research progress might make it possible to expand the set of private FR investment conditions included in the type of large-scale, spatially disaggregated analysis we have conducted. It already offers data that could be used to develop improved versions of some of the se.plan layers. Our first two suggestions pertain to this opportunity.

The first suggestion is to update se.plan’s cost layers. Key inputs to the se.plan opportunity cost layer were gridded data on crop production and livestock numbers in 2010 and multi-country, farm-level survey data on revenues and costs of growing crops and rearing livestock during 2004–2017 (see Supplementary Information). Updated versions of all these data sources have become available in the past year: gridded crop production (International Food Policy Research Institute 2024) and gridded livestock numbers (FAO 2024), both for 2020; and several years of additional farm-level survey data (FAO n.d. (b)). Additional data on implementation costs, including estimates for FR projects by implementers other than the World Bank, have also become available (Busch et al. 2024, Verhoeven et al. 2024). Interestingly, one of those studies (Busch et al. 2024) reported no significant difference in mean implementation costs between World Bank projects and other projects, which offers reassurance that our use of implementation cost data from World Bank projects did not distort our findings.

The second suggestion is to update se.plan's layer on tree growth rates, which is from a nearly ten-year-old source that has coarse resolution (30 arcminutes) and refers to a single type of planted forest (Albanito et al. 2016). Busch et al. (2024) have prepared data layers that have much higher resolution (30 arcseconds), are based on site-level datasets that span a wider range of geographical sites and longer time periods, and differentiate growth rates of planted forests by major genera. Their layers also differentiate growth rates in naturally regenerated forests from those in planted forests, which would increase confidence in analyses that focus on natural regeneration or compare it to tree planting.

The final suggestion is to use data from an investor survey to develop a more refined approach for assessing the relative attractiveness of different areas for private FR investment. Our study used a simple two-step approach: first, we assessed the relative attractiveness of a given pixel for an individual investment condition in a binary fashion, by assigning it to the more favorable or less favorable half of the distribution of values for that condition; and second, we assessed the pixel's relative attractiveness across the entire set of conditions by tallying the number of favorable cases. A more refined method would first convert the conditions to a common continuous scale, such as on the interval 0–1. Then, it would weight the conditions to form an investment attractiveness index. Information on the weights could be drawn from a representative survey of FR investors, which would ask investors to rate the relative importance of investment conditions on a Likert scale (e.g., 1–5).

Gaining access to a globally representative investor group, including in LMICs, and achieving a high response rate would likely require partnering with an organization that has successfully surveyed that group. Possible organizations include the World Economic Forum, which has surveyed private investors on environmental topics since the late 1990s (Panayotou and Vincent 1997), and the World Bank, which has surveyed business owners and managers since 2005 (World Bank n.d. (b)). In addition to an overall index based on mean or median values of the importance ratings across all survey respondents, indices could be generated for particular investor types, such as financial institutions, corporations, and impact investors, which our analysis was not able to distinguish from each other. Indices could also be generated for specific geographical regions and country groups, which our findings indicate differ substantially in terms of attractiveness for private FR investment.

CONFLICTS OF INTEREST

The authors confirm they have no conflicts of interest.

ACKNOWLEDGMENT

The authors acknowledge funding for se.plan development and the research reported here from the UN Decade on Ecosystem Restoration Multipartner Trust Fund; the Ministry of Agriculture, Forestry and Fisheries of Japan; the FAO Regional Office for Asia and the Pacific; the US SilvaCarbon program; the joint US Agency for International Development and National Aeronautics and Space Administration initiative SERVIR (NASA Applied Sciences Capacity Building Program); and Duke University. They thank the Google Earth Engine team for technical support; Clark Binkley and Petri Lehtonen for comments on manuscript drafts; ten experts on international forestland investment who participated in focus groups held in early 2023 for an associated master's student project at Duke University; and Aria Cai, Grace Chan, Elise Harrigan, Robert Mansour Harrison, Katie Krejsa, Ashley Novak, and Cal Oakley for research assistance. JRV acknowledges sabbatical support from Duke University, the World Bank, and the University of California at Berkeley, which launched work on the implementation cost dataset.

REFERENCES CITED

Albanito F, Beringer T, Corstanje R, Poulter B, Stephenson A, Zawadzka J, Smith P. 2016. Carbon implications of converting cropland to bioenergy crops or forest for climate mitigation: A global assessment. GCB Bioenergy 8(1):81-95. https://doi.org/10.1111/gcbb.12242

Ashton MS, Martin MP, Vincent JR. 2024. People today who plant trees successfully do it for livelihoods and income not for biodiversity or climate mitigation. Front. For. Global Change 7:1372409. https://doi.org/10.3389/ffgc.2024.1372409

Bastin JF, Finegold Y, Garcia C, Mollicone D, Rezende M, Routh D, Zohner CM, Crowther TW. 2019. The global tree restoration potential. Science 365(6448):76-79. https://doi.org/10.1126/science.aax0848

Becker B. 2019. Introducing COLDAT: The Colonial Dates Dataset. SOCIUM SFB 1342 WorkingPapers 2. Bremen: SOCIUM Research Center on Inequality and Social Policy, University of Bremen. Available from: https://www.socium.uni-bremen.de/f/51ebd445c4.pdf

Binkley CS, Stewart F, Power S. 2020. Pension-fund investment in forestry. Equitable growth, finance & institutions insight. Washington, DC: The World Bank. https://doi.org/10.1596/35167

Brancalion PHS, Lamb D, Ceccon E, Boucher D, Herbohn J, Strassburg BBN, Edwards DP. 2017. Using markets to leverage investment in forest and landscape restoration in the tropics. For. Policy Econ. 85:103-113. https://doi.org/10.1016/j.forpol.2017.08.009

Brancalion PHS, Niamir A, Broadbent E, Crouzeilles R, Barros FSM, Almeyda Zambrano AM, Baccini A, Aronson J, Goetz S, Reid JL, Strassburg BBN, Wilson S, Chazdon RL. 2019. Global restoration opportunities in tropical rainforest landscapes. Sci. Adv. 5(7):eaav3223. https://doi.org/10.1126/sciadv.aav3223

Buchhorn M, Lesiv M, Tsendbazar NE, Herold M, Bertels L, Smets B. 2020. Copernicus global land cover layers-collection 2. Remote Sens. 12(6):1044. https://doi.org/10.3390/rs12061044

Busch J, Bukoski JJ, Cook-Patton SC, Griscom B, Kaczan D, Potts MD, Yi Y, Vincent JR. 2024. Cost-effectiveness of natural forest regeneration and plantations for climate mitigation. Nat. Clim. Change 14(9):996-1002. https://doi.org/10.1038/s41558-024-02068-1

Campbell JE, Lobell DB, Genova RC, Field CB. 2008. The global potential of bioenergy on abandoned agriculture lands. Environ. Sci. Technol. 42(15):5791-5794. https://doi.org/10.1021/es800052w

Caradine R, Ezekiel M, Piacsek G, Wang M. 2023. Linking forest restoration to sustainable value chains with se.plan. Master's project, Duke University. Available at: https://hdl.handle.net/10161/27192

Castro J, Morales-Rueda F, Navarro FB, Löf M, Vacchiano G, Alcaraz-Segura D. 2021. Precision restoration: A necessary approach to foster forest recovery in the 21st century. Restor. Ecol. 29(7):e13421. https://doi.org/10.1111/rec.13421

Center for International Earth Science Information Network (CIESIN). 2018. Gridded population of the world, version 4 (GPWv4): land and water area, revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). Available at: https://doi.org/10.7927/H4Z60M4Z. Accessed January 4, 2021.

Crouzeilles R, Barros FSM, Molin PG, Ferreira MS, Junqueira AB, Chazdon RL, Lindenmayer DB, Tymus JRC, Strassburg BBN, Brancalion PHS. 2019. A new approach to map landscape variation in forest restoration success in tropical and temperate forest biomes. J. Appl. Ecol. 56:2675-2686. https://doi.org/10.1111/1365-2664.13501

Cubbage F, Kanieski B, Rubilar R, Bussoni A, Morales Olmos V, Balmelli G, Mac Donagh P, Lord R, Hernández C, Zhang P, Huang J, Korhonen J, Yao R, Hall P, Del La Torre R, Diaz-Balteiro L, Carrero O, Monges E, Tran Thi Thu H, Frey G, Howard M, Chavet M, Mochan S, Hoeflich VA, Chudy R, Maass D, Chizmar S, Abt R. 2020. Global timber investments, 2005 to 2017. For. Policy Econ. 112:102082. https://doi.org/10.1016/j.forpol.2019.102082

Cubbage F, Davis R, Korhonen J, Nepal P, Kanieski B. 2025. Comparative assessment of global wood fiber and forest carbon sequestration prospects. J.For.Bus.Res. 4(1): 1-36. https://doi.org/10.62320/jfbr.v4i1.66

Damodaran A. 2022a. Country risk: determinants, measures, and implications: the 2022 edition. New York, NY: Stern School of Business, New York University. https://doi.org/10.2139/ssrn.4161010

Damodaran A. 2022b. Equity risk premiums (ERP): determinants, estimation, and implications: the 2022 edition. New York, NY: Stern School of Business, New York University. Available at: https://pages.stern.nyu.edu/~adamodar/

Ding H. et al. 2017. Roots of prosperity: The economics and finance of restoring land (World Resources Institute, Washington DC).

Ding H, Markandya A, Feltran-Barbieri R, Calmon M, Cervera M, Duraisami M, Singh R, Warman J, Anderson W. 2021. Repurposing agricultural subsidies to restore degraded farmland and grow rural prosperity. World Resources Institute, Washington, DC. https://doi.org/10.46830/wrirpt.20.00013

Enters T, Durst PB, Brown C. 2003. What does it take to promote forest plantation development? Incentives for tree-growing in countries of the Pacific Rim. Unasylva 54(212):11-18.

Erbaugh JT, Pradhan N, Adams J, Oldekop JA, Agrawal A, Brockington D, Pritchard R, Chhatre A. 2020. Global forest restoration and the importance of prioritizing local communities. Nat. Ecol. Evol. 4:1472-1476. https://doi.org/10.1038/s41559-020-01282-2

FAO. n.d. (a). FAOSTAT: Forestry Production and Trade. Available at http://www.fao.org/faostat/en/#data/FO. Accessed July 22, 2023.

FAO. n.d. (b). RuLIS: Rural Livelihoods Information System. Available at https://www.fao.org/in-action/rural-livelihoods-dataset-rulis/en/. Accessed June 22, 2020.

FAO. 2012. Global ecological zones for FAO forest reporting: 2010 Update (FAO, Rome).

FAO. 2018. Global Forest Resources Assessment 2020: Terms and Definitions (FAO, Rome).

FAO. 2020. Global Forest Resources Assessment, 2020: Main Report (FAO, Rome).

FAO. 2022. The State of the World's Forests 2022 (FAO, Rome).

FAO. 2023. se.plan. Available from: https://docs.sepal.io/en/latest/modules/dwn/seplan.html.

FAO. 2024. GLW 4: Gridded Livestock Density (Global - 2020 - 10 km). Available at https://data.amerigeoss.org/dataset/9d1e149b-d63f-4213-978b-317a8eb42d02.

FAO. 2025. se.plan: A forest restoration suitability decision support tool. Available from: https://www.fao.org/in-action/sepal/activities/seplan/en.

FAO and Global Mechanism of the UNCCD. 2015. Sustainable financing for forest and landscape restoration: Opportunities, challenges and the way forward (FAO, Rome).

FAO, ITTO, and United Nations. 2020. Forest Product Conversion Factors (FAO, Rome).

FAO, IUCN, CEM, and SER. 2021. Principles for Ecosystem Restoration to Guide the United Nations Decade 2021-2030 (FAO, Rome).

FAO, SCBD, and SER. 2024. Delivering restoration outcomes for biodiversity and human well-being: Resource guide to target 2 of the Kunming-Montreal Global Biodiversity Framework (FAO, Rome; SCBD, Montreal; and SER, Washington, DC).

FAO, UNDP, and UNEP. 2021. A multi-billion-dollar opportunity: Repurposing agricultural support to transform food systems. Food and Agriculture Organization of the United Nations, Rome.

Favero A, Daigneault A, Sohngen B. 2020. Forests: carbon sequestration, biomass energy, or both? Sci. Adv. 6(50):eaay6792. https://doi.org/10.1126/sciadv.aay6792

Feyertag J, Childress M, Flynn R, Langdown I, Locke A, Nizalov D. 2020. Prindex Comparative Report 2020: A global assessment of perceived tenure security from 140 countries. Overseas Development Institute, London. Available from: https://www.prindex.net/reports/prindex-comparative-report-july-2020/

Forest Trends' Ecosystem Marketplace. 2024. State of the Voluntary Carbon Market 2024 (Forest Trends Association, Washington DC). Available from: https://www.forest-trends.org/publications/state-of-the-voluntary-carbon-market-2024/

Gan JL, Grainger MJ, Shirley MDF, Pfeifer M. 2023. How effective are perches in promoting bird-mediated seed dispersal for natural forest regeneration? A systematic review protocol. Environ. Evidence 12:15. https://doi.org/10.1186/s13750-023-00308-z

Global Restoration Information Hub. 2024. Global Restoration Commitment Database. Available from: https://grih.info/reports/. Accessed March 6, 2025.

Griscom BW, Adams J, Ellis PW, Houghton RA, Lomax G, Miteva DA, Schlesinger WH, Shoch D, Siikamäki JV, Smith P, et al. 2017. Natural climate solutions. PNAS 114(44):11645-11650. https://doi.org/10.1073/pnas.1710465114

Harrison RD, Swinfield T, Ayat A, Dewi S, Silalahi M, Heriansyah I. 2020. Restoration concessions: A second lease on life for beleaguered tropical forests? Front. Ecol. Environ. 18(10):567-575. https://doi.org/10.1002/fee.2265

Hofste R, Kuzma S, Walker S, Sutanudjaja EH, Bierkens MFP, Kuijper MJM, Faneca Sánchez M, van Beek R, Wada Y, Galvis Rodríguez S, Reig P. 2019. Aqueduct 3.0: updated decision-relevant global water risk indicators. Technical Note. Washington, DC: World Resources Institute. https://doi.org/10.46830/writn.18.00146

International Food Policy Research Institute. 2024. Global Spatially-Disaggregated Crop Production Statistics Data for 2020 Version 1.0. Available at https://doi.org/10.7910/DVN/SWPENT.

International Labour Organization. n.d. ILOSTAT. Available at https://ilostat.ilo.org/data. Accessed December 8, 2020.

IUCN and WRI. 2014. A guide to the restoration opportunities assessment methodology (ROAM) (IUCN, Gland, Switzerland).

Jenkins CN, Pimm SL, Joppa LN. 2013. Global patterns of terrestrial vertebrate diversity and conservation. PNAS 110(28):E2602-E2610. https://doi.org/10.1073/pnas.1302251110

Jones J, Ellison D, Ferraz S, Lara A, Wei X, Zhang Z. 2022. Forest restoration and hydrology. For. Ecol. Manage. 520:120342. https://doi.org/10.1016/j.foreco.2022.120342

Kaufmann D, Kraay A, Mastruzzi M. 2010. The worldwide governance indicators: methodology and analytical issues. Policy research working paper no. 5430. Washington, DC: World Bank. https://doi.org/10.1596/1813-9450-5430

Kummu M, Taka M, Guillaume JHA. 2018. Gridded global datasets for gross domestic product and human development index over 1990-2015. Sci. Data 5:180004. https://doi.org/10.1038/sdata.2018.4

Löfqvist S, Ghazoul J. 2019. Private funding is essential to leverage forest and landscape restoration at global scales. Nat. Ecol. Evol. 3, 1612-1615. https://doi.org/10.1038/s41559-019-1031-y

Löfqvist S, Garrett RD, Ghazoul J. 2023a. Incentives and barriers to private finance for forest and landscape restoration. Nat. Ecol. Evol. 7:707-715. https://doi.org/10.1038/s41559-023-02037-5

Löfqvist S, Kleinschroth F, Bey A, de Bremond A, DeFries R, Dong J, Fleischman F, Lele S, Martin DA, Messerli P, et al. 2023b. How social considerations improve the equity and effectiveness of ecosystem restoration. BioScience 73(2):134-148. https://doi.org/10.1093/biosci/biac099

Martin MP, Woodbury DJ, Doroski DA, Nagele E, Storace M, Cook-Patton SC, Pasternack R, Ashton MS. 2021. People plant trees for utility more often than for biodiversity or carbon. Biol. Conserv. 261:109224. https://doi.org/10.1016/j.biocon.2021.109224

Meli P. et al. 2023. Mapping the information landscape of the United Nations Decade on Ecosystem Restoration strategy. Restor. Ecol. 31, e13810. https://doi.org/10.1111/rec.13810

Mishra A, Humpenöder F, Churkina G, Reyer CPO, Beier F, Bodirsky BL, Schellnhuber HJ, Lotze-Campen H, Popp A. 2022. Land use change and carbon emissions of a transformation to timber cities. Nat. Commun. 13:4889. https://doi.org/10.1038/s41467-022-32244-w

OECD. 2022. Aid in support of environment (OECD, Paris).

Oliveira J, Campbell EE, Lamparelli RAC, Figueiredo GKDA, Soares JR, Jaiswal D, Monteiro LA, Vianna MS, Lynd LR, Sheehan JJ. 2020. Choosing pasture maps: an assessment of pasture land classification definitions and a case study of Brazil. International Int. J. Appl. Earth Obs. Geoinf. International 93:102205. https://doi.org/10.1016/j.jag.2020.102205

Panayotou T, Vincent JR. 1997. Environmental regulation and competitiveness. In: The Global Competitiveness Report 1997. World Economic Forum, Geneva.

Payn T, Carnus J-M, Freer-Smith P, Kimberley M, Kollert W, Liu S, Orazio C, Rodriguez L, Silva L, Wingfield M. 2015. Changes in planted forests and future global implications. For. Ecol. Manage. 352:57-67. https://doi.org/10.1016/j.foreco.2015.06.021

Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO. 2014. The biodiversity of species and their rates of extinction, distribution, and protection. Science 344(6187):1246752. https://doi.org/10.1126/science.1246752

Rennert K, Errickson F, Prest BC, Rennels L, Newell RG et al. 2022. Comprehensive evidence implies a higher social cost of CO_2. Nature 610:687-692. https://doi.org/10.1038/s41586-022-05224-9

Shyamsundar P, Cohen F, Boucher TM, Kroeger T, Erbaugh JT, Waterfield G, Clarke C, Cook-Patton SC, Garcia E, Juma K, Kaur S, Leisher C, Miller DC, Oester K, Saigal S, Siikamaki J, Sills EO, Thaung T, Trihadmojo B, Veiga F, Vincent JR, Yi Y, Zhang XX. 2022. Scaling smallholder tree cover restoration across the tropics. Global Environ. Change 76:102591. https://doi.org/10.1016/j.gloenvcha.2022.102591

StataCorp. 2023. Stata Statistical Software: Release 18 (College Station, Texas).

Strassburg BBN, Iribarrem A, Beyer HL, et al. Global priority areas for ecosystem restoration. Nature 586, 724-729 (2020). https://doi.org/10.1038/s41586-020-2784-9

Swift Geospatial. n.d. Geospatial Forestry Platform. Available at https://forestryplatform.com/.

UNEP and FAO. 2020. The United Nations Decade on Ecosystem Restoration: Strategy (UNEP, Nairobi and FAO, Rome).

UNEP and FAO. n.d. What is ecosystem restoration? Available from: https://www.decadeonrestoration.org/what-ecosystem-restoration.

UNEP-WCMC and IUCN. n.d. Protected Planet: The World Database on Protected Areas. Available at www.protectedplanet.net.

United Nations. 2023. World economic situation and prospects 2023 (United Nations, New York).

United Nations General Assembly. 2019. Resolution 73/284 Adopted by the General Assembly on 1 March 2019: United Nations Decade on Ecosystem Restoration 2021-2030 (United Nations, New York).

Verhoeven D, Berkhout E, Sewell A, van der Esch S. 2024. The global cost of international commitments on land restoration. Land Degrad. Dev. 35(16):4864-4874. https://doi.org/10.1002/ldr.5263

Vincent JR, Curran SR, Ashton MS. 2021. Forest restoration in low- and middle-income countries. Annu. Rev. Environ. Resour. 46:289-317. https://doi.org/10.1146/annurev-environ-012220-020159

Walker WS, Gorelik SR, Cook-Patton SC, Baccini A, Farina MK, Solvik KK, Ellis PW, Sanderman J, Houghton RA, Leavitt SM, Schwalm CR, Griscom BW. 2022. The global potential for increased storage of carbon on land. PNAS 119:e2111312119. https://doi.org/10.1073/pnas.2111312119

Weiss DJ, Nelson A, Gibson HS, Temperley W, Peedell S, Lieber A, Hancher M, Poyart E, Belchior S, Fullman N, Mappin B, Dalrymple U, Rozier J, Lucas TCD, Howes RE, Tusting LS, Kang SY, Cameron E, Bisanzio D, Battle KE, Bhatt S, Gething PW. 2018. A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature 553:333-336. https://doi.org/10.1038/nature25181

Wellspring Development Capital Limited. 2024. Lessons from 30 Years of African Commercial Forestry Investments and Implications for the Future (Buckinghamshire, UK). Available from: https://www.gatsbyafrica.org.uk/app/uploads/2024/02/lessons-from-30-years-of-african-commercial-forestry-investments-and-implications-for-the-future-final-abridged.pdf

West TAP, Wunder S, Sills EO, Börner J, Rifai SW, Neidermeier AN, Frey GP, Kontoleon A. 2023. Action needed to make carbon offsets from forest conservation work for climate change mitigation. Science 381(6660):873-877. https://doi.org/10.1126/science.ade3535

World Bank. n.d. (a). World Bank Country and Lending Groups. Available at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups. Accessed July 13, 2020.

World Bank. n.d. (b). World Bank Enterprise Surveys. Available at https://www.enterprisesurveys.org/en/enterprisesurveys.

World Bank. n.d. (c). World Development Indicators. Available at https://databank.worldbank.org/source/world-development-indicators. Accessed December 8, 2020 and April 9, 2024.

World Bank. 2022. Scaling up ecosystem restoration finance: A stocktake report (World Bank, Washington DC).

World Bank. 2024. Blueprints for private investment in ecosystem restoration: lessons from case studies (World Bank, Washington DC).

WRI. 2011. Global assessment of opportunities for restoration of forests and landscapes: final report to UNEP WCMC (World Resources Institute, Washington DC).

Zeger SL, Liang KY. 1986. Longitudinal data analysis for discrete and continuous outcomes. Biometrics 42(1):121-130. https://doi.org/10.2307/2531248