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Global forest restoration and the importance of prioritizing local communities

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Forest restoration occupies centre stage in global conversations about carbon removal and biodiversity conservation, but recent research rarely acknowledges social dimensions or environmental justice implications related to its implementation. We find that 294.5 million people live on tropical forest restoration opportunity land in the Global South, including 12% of the total population in low-income countries. Forest landscape restoration that prioritizes local communities by affording them rights to manage and restore forests provides a promising option to align global agendas for climate mitigation, conservation, environmental justice and sustainable development.

Forest restoration is considered to be a crucial strategy for conserving global biodiversity and mitigating climate change[1–3]. New research identifies the global extent of forest restoration opportunities, demonstrates the promise of forest restoration for mitigating climate change and calls for more ambitious global forest restoration efforts[1–6]. There is some disagreement about the degree to which forest restoration can or should contribute to atmospheric carbon removal[7–9], as mitigating climate change depends on decarbonizing the economy while protecting intact forests and restoring degraded landscapes[10]. Yet prominent conservation initiatives such as 'global no net loss' of natural ecosystems, 'half for nature' and the Aichi Target 11 still combine conservation of intact natural habitat and restoration of degraded forests to reach their ambitious targets[11–13].

To progress those goals, recent research on forest restoration advances conservation and climate mitigation agendas with knowledge about where trees can be grown and the global potential for restoration. It often fails, however, to address the social implications of global forest restoration. Here, we argue that the success of global forest restoration critically depends on prioritizing local communities[14].

To realize its full potential, forest restoration cannot avoid rural populations. Confining restoration efforts to sparsely inhabited forest landscapes removes the concern of displacing or marginalizing local populations, but it limits global restoration in three ways. First, remote restoration regions (1 person per km^2 or less within a 500 km radius) represent only 11% of global forest restoration opportunity areas[15]. Second, because remote forest restoration is possible only in areas far from human settlements, fewer people will enjoy any local benefits. Third, pursuing only remote forest restoration would not contribute as meaningfully to biodiversity conservation. The tropics are home to a disproportionate amount of the world's biodiversity but contain only 0.68% of all remote restoration opportunities. Remote forest restoration holds promise for carbon sequestration, but global agendas that seek to deliver the greatest number of benefits from forest restoration will need to focus on populated landscapes[5].

Forest restoration initiatives must, therefore, identify how best to work with local communities. Approaches that exclude indigenous people and local communities, including some protected areas, have been associated with environmental conflicts, poor conservation performance and negative social outcomes[16–18]. Restoring forests without the consent of those who depend on the same land will probably lead to forced displacement (physical or economic) and/or costly monitoring and regulation to prohibit illegal (though often legitimate) activities.

Excluding indigenous people and local people from forest restoration also poses ethical problems. Such exclusion would force some of the most multidimensionally poor people—those who live in rural areas within low-income countries—to move or give up their current livelihood for a global carbon and biodiversity debt to which they contributed little[19]. Just and equitable climate mitigation and biodiversity conservation from forest restoration require the inclusion and participation of local communities[20,21].

As a mechanism of land and resource management, forest landscape restoration (FLR) has considerable potential to include local populations and improve local livelihoods. FLR was initially conceived as a management approach to promote ecological restoration and human well-being in degraded landscapes by engaging local stakeholders[22]. By including local stakeholders from the public, private and civil society sectors, proponents assert that FLR contributes to human well-being through the use and sale of forest products, increases in food as well as water security, and through diverse cultural values people hold for trees and forests[21–25]. However, competing definitions of FLR exist[26]. The Bonn Challenge to commence restoration of 350 million ha of forest landscapes by 2030 refers to FLR as large-scale forest restoration projects but does not emphasize the importance of engaging local stakeholders in planning and implementation processes[2,27,28]. Thus, many current debates about FLR reflect a lack of conceptual clarity and do not adequately address recent evidence as to how forest restoration can promote ecological as well as human well-being[24,29]. Here we define FLR as an approach to landscape planning and management that aims to restore ecological integrity and enhance human well-being on deforested and degraded lands through the inclusion and engagement of local stakeholders[22].

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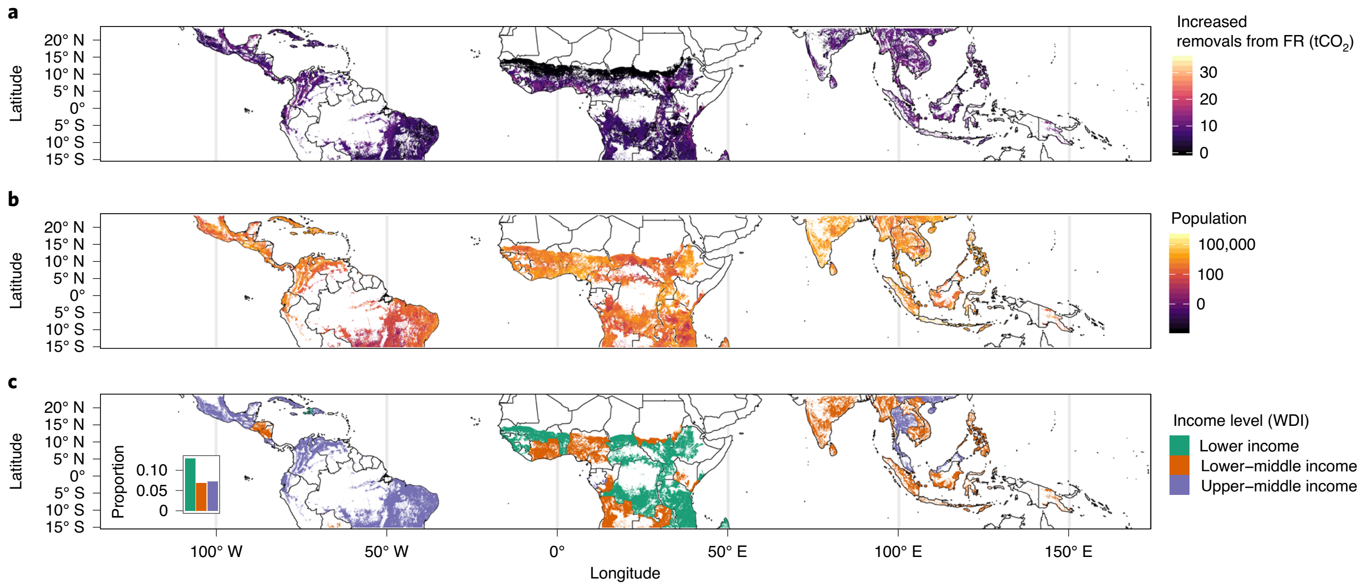

Fig. 1 | Forest restoration (FR) opportunity areas in the tropics. a, FR opportunity areas[15] by estimated carbon removal from 2020 to 2050 given a US\$20 tCO_2^{-1} scenario[4]. **b**, FR areas by population density (population per 5.55 km^2)[48]. **c**, FR areas by country-level income categories[50]. Inset: the proportion of people living in FR areas by income category. WDI, World Development Indicators.

To unite global agendas for climate mitigation, conservation and environmental justice, FLR must go beyond merely including local stakeholders and prioritize local communities. Given the uncertainty surrounding forest restoration and its impacts on human well-being[30–32], the tendency to implement restoration without consulting local stakeholders is untenable[33]. Consulting local stakeholders alone does not guarantee just and equitable forest restoration. However, there are numerous examples in the conservation sector where indigenous people and local communities have generated positive human and environmental outcomes when afforded rights to manage and use forests[16,34]. Technical training and equitable resource access reduce some risks associated with community resource management, including elite capture, overharvests and exclusion[35]. In many contexts, empowering communities to manage forests for restoration provides a reasonable and just approach to address contextual uncertainty, incorporate traditional ecological knowledge and assist forest proximate populations to receive the opportunities they desire from global restoration[28,36,37].

The potential synergies from prioritizing local communities through FLR emphasize the importance of determining where forest restoration, human populations and development intersect. Our analysis examines the overlap between opportunities for tropical forest restoration, human populations, development and national policies for community forest ownership to identify where focusing forest restoration efforts might best benefit both people and the planet. We focus on the tropics because of the synergies between carbon sequestration, biodiversity conservation and human well-being benefits that FLR affords there[5]. We aggregate our data to present country-level estimates because nation states remain primary actors in setting carbon removal and landscape restoration targets[2].

We find that 294.5 million people live in recently tree-covered areas representing tropical forest restoration opportunities in the Global South. Many more people live near these forest restoration opportunities. One-third of the tropical population in our analysis (~1.01 billion people) live within 8 km of land predicted to enable forest restoration from 2020 to 2050, given a moderate carbon tax incentive (US\$20 tCO_2^{-1}). Supplementary Table 1 provides additional information on population estimates across different forest restoration opportunities and methods.

Forest restoration opportunities, population and development vary widely by country (Fig. 1). Brazil (BRA), the Democratic Republic of the Congo (COD), India (IND) and Indonesia (IDN) have the greatest number of people living in or near (<8 km) forest restoration opportunity areas with the greatest potential to remove carbon (Fig. 2a). Crafting global FLR strategies that seek to deliver sustainable development benefits to the most local people within the fewest countries would do well to focus on these nations. However, FLR may generate greater population-level benefits in nations where forest restoration opportunities, and the people who depend on them, represent a substantial proportion of their respective total. Political, market and civil society actors in these same countries are likely to enhance international activity and investment in FLR with national efforts, should restoration provide well-being benefits. Countries with a greater proportion of forest restoration opportunity area include COD, Tanzania (TZA), the Central African Republic (CAF), and Mozambique (MOZ) (Fig. 2b).

FLR investments hold the promise to improve the livelihood and well-being of millions who are often underserved by standard investments in infrastructure and development. Within low-income countries, 12% of the population lives in forest restoration opportunity areas (Fig. 1c). Forest restoration opportunities exist outside the areas of greatest human pressure, and populations in these areas often face greater infrastructural and developmental deprivation. Nighttime light radiance indicates the extent and magnitude of electrical infrastructure and usage, and it is strongly correlated with a host of development indicators[38–40]. Areas in low-income nations with the least nighttime light radiance and the greatest carbon removal potential indicate where FLR might best complement sustainable development agendas. There are many opportunities in Central, Eastern and Southern Africa to restore forests and provide socioeconomic and infrastructure benefits to local people facing many multidimensional deprivations (Fig. 2 and Supplementary Fig. 1). However, concurrently improving infrastructure and restoring forests does create additional risks, since forest cover loss and degradation often follow infrastructure development[41]. Providing indigenous people and local communities with the ability to participate in managing forest landscapes via resource rights can moderate

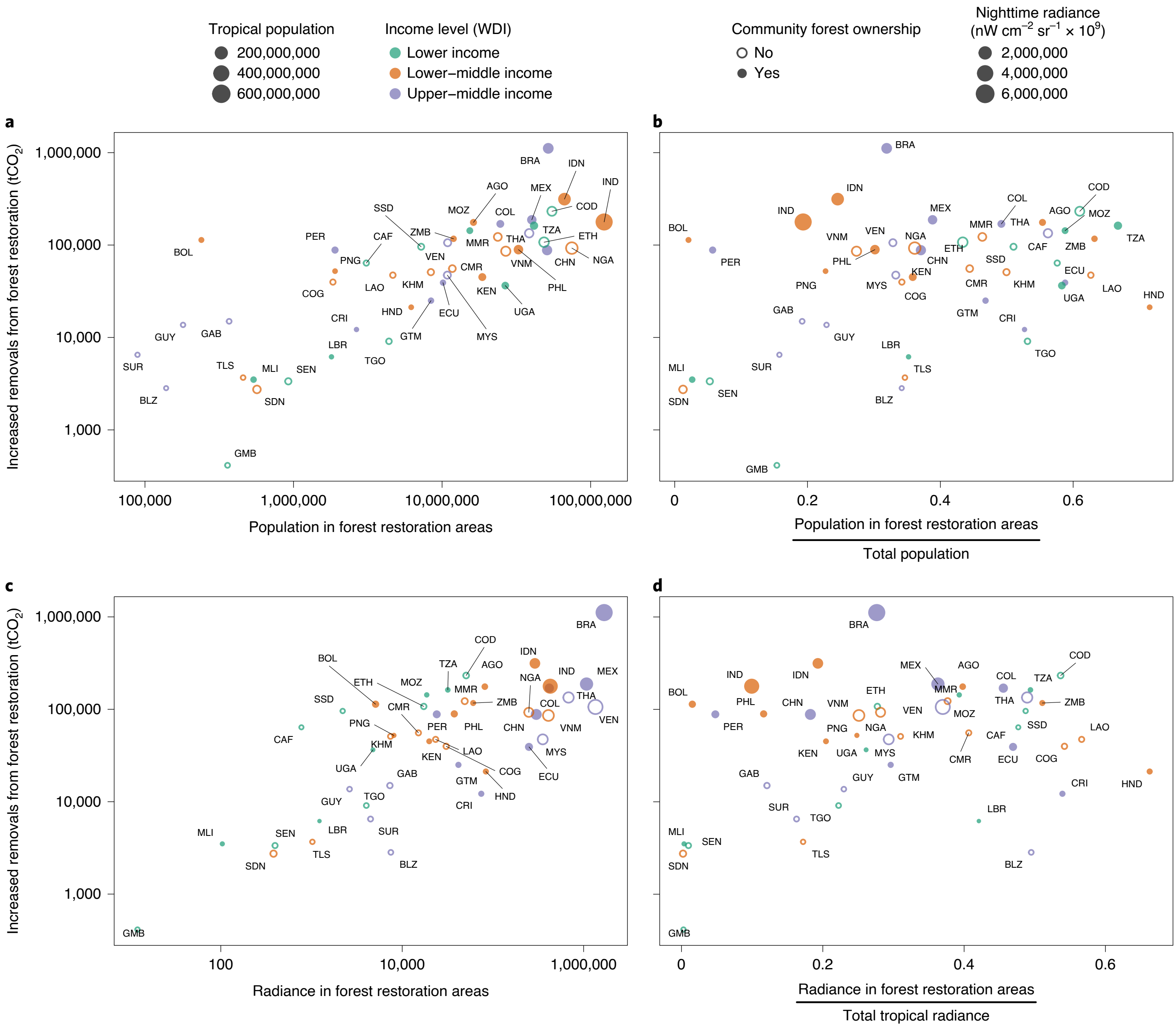

Fig. 2 | Country-level population and nighttime light radiance by increased removals from reforestation. a, Countries plotted in reference to population[48] in FR opportunity areas by increased removals from forest restoration in tCO_2. **b**, The proportion of country population in FR areas by increased removals. **c**, Total nighttime light radiance[49] by increased removals. **d**, The proportion of nighttime light radiance in FR areas by total tropical nighttime light radiance. Increased removals are predicted under a US\$20 tCO_2^{-1} scenario from 2020 to 2050. Nighttime light radiance is measured in nW cm^{-2} sr^{-1} × 10^9. All panels visualize 45 countries that represent 90% of the total FLR opportunity area in the tropics. Supplementary Information contains plots with all countries ($n = 69$). See Supplementary Table 3 for country codes.

the relationship between improved infrastructure, forest cover loss and human well-being[42].

Most forest restoration opportunity areas and their associated populations exist in countries with legal foundations for community forest ownership. Community forest ownership includes the following rights afforded in perpetuity: forest access, resource withdrawal, exclusion as well as due process and compensation[43]. As such, ownership represents a stronger set of resource rights than community forest management or access alone. In this analysis, countries with pre-existing legal frameworks and evidence of community forest ownership ($n = 22$) contain two-thirds of forest restoration opportunity areas (Fig. 2 and Supplementary Table 2). Further, countries that provide forest ownership rights to communities contain 70% of people living in or near forest restoration opportunity areas (Supplementary Table 2), representing a large proportion of their total tropical population (Fig. 2a,b). A legal framework for community forest rights and evidence of their recognition do not guarantee faithful implementation of community forest ownership, but their absence indicates that forest proximate communities are excluded from making authorized decisions about the future of the forests on which they depend. This implies a greater likelihood of exclusion from forest areas, forest products and related benefits. Continued efforts to expand community forest ownership are essential, and they are of pressing national importance in countries with a substantial proportion of people living in forest restoration opportunity areas, such as CAF, COD, Thailand (THA) and the Lao People's Democratic Republic (LAO) (Fig. 2b). To advance global restoration while prioritizing forest proximate peoples through community forest rights, FLR must emphasize the importance of locally managed restoration.

FLR that prioritizes local communities represents a just mechanism for global forest restoration. Recent research highlights the importance of forest restoration to climate mitigation agendas, and it advances the ability to locate forest restoration opportunities. It remains essential to assess this information in relation to institutional, social and political circumstances to determine how FLR can best contribute to equitable and sustainable climate solutions. Excluding local communities from global forest restoration limits our ability to mitigate climate change, and it risks resistance, conflict and perpetuating environmental injustices. Empowering local communities to restore forests can provide human well-being benefits to millions of the most deprived and marginalized people as well as environmental benefits for all.

Methods

Forest restoration opportunity areas. We combine two datasets to identify areas that represent opportunities for forest restoration. Combining data that classifies forest restoration opportunities using demographic, geographic and land-cover data with estimates from a land-change model that predicts carbon removal from forest restoration provides more conservative estimates of where, and to what extent, forest restoration is likely to mitigate climate change.

We first define forest restoration opportunity areas as wide-scale and mosaic restoration areas in the tropics identified in the 'Global map of forest landscape restoration opportunities'[15]. Wide-scale restoration areas have the potential to support closed forest canopy and contain population densities of less than 10 people per km^2. Mosaic restoration areas are similarly able to support closed forest canopy but contain population densities of between 10 and 100 people per km^2. Forest restoration areas from the 'Global map' are identified by layering data. Through this method, deductively determined cut-off points and population densities applied to spatial biophysical and human pressure datasets identify locations most amenable to forest restoration. Other studies of global forest restoration opportunities and land-cover patterns employ this method of spatial identification[5,44]. Among the global set of forest restoration opportunities, we focus on opportunities in tropical countries, because of the potential these areas have for removing atmospheric carbon, promoting biodiversity conservation and contributing to the well-being of forest proximate people[3,5].

We further define forest restoration opportunities using estimates of where, and to what extent, atmospheric carbon removal from forest restoration would occur given a moderate economic incentive. Estimates of carbon removal come from a land-change model that calculates where a US\$20 tCO_2^{-1} carbon tax is likely to incentivize forest restoration from 2020 to 2050, based on tree cover in 2000 and 2010, topographical variation as well as agricultural opportunity costs[4]. Though the model estimates forest restoration and carbon removal using a US\$20 tCO_2^{-1} scenario, these data broadly represent where a moderate financial incentive equal to or greater than the value generated by a carbon tax is likely to promote forest restoration. Importantly, this approach improves upon many studies that identify forest restoration opportunities through layering, because it explicitly models carbon removal from forest restoration as a function of opportunity costs based on prices of regional agricultural products.

The 'Global map' and carbon removal spatial datasets differed in extent and resolution. We analyse forest restoration opportunities in the tropics from 23.4° N to 15° S, because both datasets contain information across this spatial extent. Within this extent, the 'Global map' data contain pixels measuring 30 arcsec (~1 km), while the carbon removal dataset contains pixels measuring 3 arcmin (~5.55 km). To identify forest restoration opportunities as the union of these datasets, we calculated the percent of 'Global map' opportunity areas within each pixel of carbon removal from forest restoration estimated by the land-change model. Country-level aggregates for carbon removal by population, as well as carbon removal by nighttime light radiance, vary in accordance with the 'Global map' opportunity threshold (Supplementary Figs. 2–5). We present the 30% threshold findings in the main text to mirror the standard of using 30% canopy cover to categorize 30 m pixels as tree covered[45]. However, the findings we report in the main text are largely robust to varying the threshold for 'Global map' opportunity areas between 30% and 50% (Supplementary Figs. 2–5).

Using mutually informative datasets improves the identification of forest restoration areas and their potential for carbon removal. By combining the 'Global map' and carbon removal datasets, our findings draw from strengths of both datasets, and avoid (what some have considered) overestimation of forest restoration opportunities in high-population-density croplands (>100 people per km^2) and native grasslands[46,47]. We dropped all 'Global map' opportunity areas with over 100 people per km^2, and our analysis does not include areas without at least 30% tree cover in 2000 or 2010[4]. Thus, the forest restoration opportunity areas in this research represent estimates of where forest restoration is most likely to occur in regions that were tree covered in the twenty-first century. Future research might apply the methods of this analysis to compare estimates across additional datasets that identify additional forest restoration opportunities and global tree-carrying capacities[1,5].

Estimating population, nighttime light radiance and income categories in FLR areas. We combine forest restoration opportunities with spatial data on population and nighttime light radiance, as well as country-level data on income categories, to provide demographic, infrastructural and economic insights concerning forest restoration opportunities. The population[48] and nighttime light radiance data[49] have the same spatial resolution as the data from the 'Global map'. Thus, we aggregated these data to match our forest restoration opportunity area data. The number of people within restoration opportunity areas measuring 30 arcsec differed from the number of people within areas measuring 3 arcmin that provide any carbon removal additionality under a US\$20 tCO_2^{-1} carbon tax. We estimate that approximately 294.5 million people live directly within forest restoration opportunity areas (30 arcsec), over two-thirds of the total tropical population (2.37 billion people) in this analysis live within 8 km of any predicted carbon removal from forest restoration between 2020 and 2050 given in a US\$20 tCO_2^{-1} incentive, and 1.01 billion people live in forest restoration opportunities identified in this study as a 3 arcmin area with any predicted carbon removed from forest restoration and covered by at least 30% of mosaic or wide-scale restoration opportunities identified by the 'Global map' (Fig. 2). Supplementary Fig. 6 visualizes country-level information for forest restoration opportunities defined as the union of the 'Global map' and predicted carbon removal data, without imposing a minimum coverage threshold.

The income categories in this research follow the World Bank classification scheme, which categorizes countries into low income, lower-middle income and upper-middle income on the basis of gross national income (GNI) per capita. Low-income countries have a GNI per capita of less than US\$1,025; lower-middle income countries, between US\$1,026 and US\$3,995; and upper-middle income countries, US\$3,996 and \$12,375[50]. For pixel-level visualization, we overlaid country boundaries with forest restoration opportunity areas to determine the related income category per pixel. To calculate the proportion of people per income category within forest restoration opportunity areas (Fig. 1c), we used the total number of people per country, including people who live in areas outside the extent of Fig. 1.

Community resource rights and tenure. This research considers community tenure to be a bundle of resource rights that enable communities to manage land areas for their own benefit[51,52]. Following the Rights and Resources Initiative, this research divides community forest tenure into two categories[43]. The first category is community ownership of forest areas. Community ownership of forest areas provides the rights to access forests, withdraw forest resources, manage forest resources and exclude others from using resources. Community forest ownership is not limited by the need for renewal or oversight, and communities that own forests have the right to due process and compensation. The second category of community forest tenure refers to a bundle of rights that enable communities to manage forests in perpetuity. Community forest management rights include all the rights of community ownership, except for the right to due process and unlimited duration of rights. Community forest management rights often coincide with co-management governance strategies, where a governmental authority and a group of local people work together to manage forest areas. We further distinguish between countries that have a legal basis for community forest tenure (ownership or designation) and countries for which there is evidence of communities that legally hold tenure rights. We gather evidence from research conducted by the Rights and Resources Initiative[43,53].

Of the 106 low- and middle-income countries in the tropics within this dataset, 73 contained forest restoration opportunities as defined in this research. There are 42 countries that have a legal basis for community forest tenure[43,53]. Of these 42 countries, 22 have a legal basis for community forest ownership and provide some evidence of providing those rights. Supplementary Table 2 highlights these 42 countries, ordered by evidence and legal basis for community forest ownership, evidence and legal basis for community forest designation, and the total amount of FLR opportunity area. All World Bank country codes for countries in this analysis are listed in Supplementary Table 3.

Reporting Summary. Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

Data for and from this analysis are available at the Harvard Dataverse (https://doi.org/10.7910/DVN/YUUXKU). The folder contains instructions for obtaining all input and output data that it does not contain due to size or sharing limitations.

Code availability

Code for analysis is available at the Harvard Dataverse (https://doi.org/10.7910/DVN/YUUXKU). The folder contains information on setting up the Docker container to reproduce analysis as well as static versions of software dependencies that are not part of the default Docker image.

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Author contributions

J.T.E., J.A., J.A.O. and A.C. designed the analyses. J.T.E., J.A. and N.P. compiled the data and conducted the analyses. J.T.E., J.A.O., R.P., D.B., A.A. and A.C. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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☒	☐	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
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☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☒	☐	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☒	☐	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	All data is publicly available and cited within the research.
Data analysis	All data was analyzed and visualized using R version 3.6.2 software. All script and primary data are publicly available.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors/reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Research guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A list of figures that have associated raw data
- A description of any restrictions on data availability

All code for analysis, all figures, and most output data are available at the Harvard Dataverse (https://doi.org/10.7910/DVN/YUUXKU). This folder includes instructions for obtaining input data and output data not present, and setting up Docker container to reproduce analysis. The folder also contains static versions of software dependencies that are not part of the default Docker image.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This study visualizes and describes how the potential for forest landscape restoration (FLR) intersects with socio-political variables. It uses publicly available, quantitative spatial data on FLR opportunity areas, the amount of carbon dioxide predicted to be removed through forest cover gain in the the tropics, gridded population data, and nighttime light data. These spatial data were resampled at 3 arcminute pixels across the tropics. This research also incorporates national-level data for income category and the legal basis for community forest rights.
Research sample	This research examines all countries in the tropics, as defined and stated in the "Methods" section.
Sampling strategy	This research includes all countries in the tropics, as defined and stated in the "Methods" section. All tropical countries with a 3 arcminute pixel of land with 30% or more of its area identified as an FLR opportunity area are included in visualizations within the Main Text. Additional visualizations that use alternate cut-points are included in the "Supplemental Information" to investigate the robustness of major findings.
Data collection	Data in this research are publicly available.
Timing	Data in this research were published or made available between 2011 and 2018.
Data exclusions	No data was excluded from this study.
Non-participation	This research did not use human subjects.
Randomization	Observations were not divided into experimental groups or randomized.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study	
☒	☐	Antibodies
☒	☐	Eukaryotic cell lines
☒	☐	Palaeontology
☒	☐	Animals and other organisms
☒	☐	Human research participants
☒	☐	Clinical data

Methods

n/a	Involved in the study	
☒	☐	ChIP-seq
☒	☐	Flow cytometry
☒	☐	MRI-based neuroimaging