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RESEARCH ARTICLE

Assessing risks and opportunities for tropical forests in the face of sustainable development

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Abstract

Understanding how countries' future development pathways could affect forests can help to avoid negative impacts and instead promote positive ones. Exploring this topic requires knowledge of which areas of the development agenda are likely to show the greatest progress, and how these expected changes relate to the drivers of deforestation and forest degradation that are currently affecting forests, or which may emerge as result of development-related changes. Based on this information, researchers, stakeholders and decisionmakers can engage in discussions to inform further research and interventions. We present an assessment framework that draws upon a range of data types to identify specific components of the development agenda that are likely to be of greatest relevance to forest conservation at the national level. We then assess the potential magnitude and likelihood of imminent changes in these areas over the short- to medium-term. We use this framework to assess 48 tropical countries, providing insights into the areas of sustainable development that are most likely to provide risks, opportunities or enabling conditions for forest conservation across much of the tropics. Our findings suggest that, across much of the tropics, ongoing risks to forests associated with agriculture, transport infrastructure and urban infrastructure could worsen, and that new risks from energy infrastructure could emerge. Opportunities relating to poverty reduction, tourism, and industry, among others, will require care to ensure that associated progress results in positive rather than negative forest impacts. Enabling conditions associated with, inter alia, improved education, inclusive decision-making, and effective governance, still have much room for improvement, and the anticipated likelihood of imminent progress in these areas varies between countries and regions. We discuss the implications of our findings for policymakers and development agencies, and consider potential future applications of our assessment protocol.

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Author summary

Forest conservation is a global priority that is affected by interactions with other areas of human progress. Some aspects of human development can hinder forest conservation, others can help to facilitate it, and yet others can have mixed (i.e. positive and/or negative) implications. For 48 tropical countries, we consider 24 Sustainable Development Goal (SDG) targets with previously documented implications for forest conservation. For each, we assess the amount of remaining progress to be made (a proxy for magnitude of potential impacts), and the likelihood that imminent progress will actually occur. We highlight agriculture and infrastructure as areas likely to exacerbate ongoing (or cause emerging) risks; poverty reduction, tourism and industry as areas that could provide mixed outcomes; and clean fuels, agricultural employment, migration management and settlement planning as areas that require greater efforts to ensure that forest conservation efforts are as effective as possible. However, as our findings vary between countries, we encourage national-level interpretation of our results to develop context-specific policies. This work is among the first efforts to assess potential SDG-forest interactions in an easy-to-interpret manner, and can aid policymakers to consider the forest-specific implications of anticipated national development trajectories, and to act accordingly.

Introduction

The 169 targets that comprise the UN Sustainable Development Goals, and which provide a framework for a universally prosperous and sustainable future, are acknowledged as having numerous synergies and trade-offs, which can respectively help or hinder the achievement of the targets in question [1–3]. Understanding synergies and trade-offs among the SDGs, and identifying where (and to what extent) they are (un)likely to emerge, can help identify key areas where increased intersectoral and interdisciplinary dialogue, research and action would help to mitigate against anticipated negative outcomes and facilitate positive ones [1,4].

In response to this, a growing number of studies are seeking to identify, map and forecast potential synergies and trade-offs between various components of the SDGs [5,6]. These studies have ranged from literature reviews and expert-driven approaches that produce qualitative or semi-quantitative outputs [e.g. 7–9], to more statistical and model-based approaches that can produce quantitative estimates of the likelihood that two or more goals or targets can or will be achieved simultaneously [e.g. 2,10–12]. Although studies seeking to anticipate potential future interactions are currently less numerous than those looking at past interactions, their outputs are likely to be of high utility to those seeking to develop appropriate polices and interventions, and so it is reasonable to assume that they will become more common over time. Presently, such studies are largely conducted by way of integrated bioeconomic models that simulate one or more scenarios [e.g. 13,14], yet research has shown that literature-based and expert-led methods have advantages over such approaches relating to interpretability, ease of application, supporting interdisciplinarity and collaboration, a reduced need for technical expertise, and a better ability to include socio-political and equality-related targets [5,15]. Moreover, recent work has shown that decisionmakers show a preference for simpler and more flexible methods over those with greater accuracy, precision, completeness or quantitative nature of the knowledge [16], suggesting an important role for literature- and expert-driven approaches in this field.

In many cases, forward looking assessments can be informed by data conveying the extent and likelihood of anticipated change in indicators thought to be relevant to the outcome(s) of

interest. Such data can be used at the earliest stages to identify key experts and stakeholders to include in the assessment process, and/or at later stages, for example to facilitate expert-led assessments or discussions to develop appropriate scenarios for use in quantitative model simulations. At the current time, and despite a wealth of available indicator data, there is no standardised way to consolidate this information in a way that can help facilitate the above outcomes. In this paper we demonstrate a straightforward assessment framework that can be used to derive readily interpretable data of this nature. While our intention is that our method should be used to precede or complement other existing methods in the ways described above, as we show here, the approach can also provide informative insights in its own right.

To demonstrate our framework, we focus on synergies and trade-offs affecting the conservation of forest ecosystems. Forest conservation receives notable attention in the SDGs, particularly under SDG 15 (life on land), where the topic features in three of its twelve targets [17]. Forests are also key to achieving several other SDG targets, including those relating to climate, water, health and economic growth, among others [18]. At many locations around the world, and especially in tropical regions (which form the focus of this study), forests are being depleted, often through processes associated with sustainable development (e.g. expansion of transport and energy infrastructure [19–21] or the production of food [22], among others). Given that a high proportion of tropical countries are considered 'underdeveloped' [23], the magnitude of potential impacts on forests as they pursue progress towards achieving the SDGs could be significant. Concurrently, however, these countries also have the potential to develop in areas that are associated with reduced damage to forests, including matters of governance [24] and education [25], among others.

By examining indicators from SDG targets with previously recorded implications for forests (e.g. from works such as [26] and [27]), and by linking these to known drivers of forest loss/degradation, we suggest that it is possible to identify aspects of the development agenda that may require attention in order to maximise forest conservation efforts. Our approach does not rest on any assumptions that a change in a given aspect of the development agenda will be guaranteed to result in a specific outcome, but instead highlights areas for which anticipated development progress could potentially result in risks, opportunities or enabling conditions for the conservation of forests, based on knowledge from past research. Based on this, researchers, stakeholders and other experts will be better able to consider the possible implications of anticipated changes for forests, and to subsequently advise policymakers and development agencies on the best ways to minimise trade-offs and maximise synergies.

In the context of forest impacts, SDG targets can be thought of as being either 'benign', or resulting in possible 'risks', 'enabling' conditions or 'opportunities' [26]. 'Benign' targets are those not expected to affect forests in any way. 'Risk' targets are potentially associated with negative forest impacts, which includes agriculture (e.g. target 2.3, double agricultural productivity (if it involves expansion into new areas)) and infrastructure (e.g. for energy (target 7.b), transport (target 9.1), or housing (target 11.1)). 'Enabling' targets are associated with conditions that enable forest conservation, which can include education (e.g. target 4.1), inclusive decision-making (e.g. targets 5.5 and 11.3), and sound governance (e.g. targets 16.5 and 16.6). 'Opportunity' targets are those for which forest outcomes can be either positive or negative, depending on context and/or the specifics of how the target is achieved. Examples include target 8.9 (increased tourism), which can both encourage forest conservation to attract visitors, but also deplete forests to make way for necessary infrastructure and to meet increased demands for forest resources [28]). Similarly, target 9.2 (increased industry and manufacturing), can cause damage through associated infrastructure, pollution and influxes of workers [29], but can also be beneficial if it promotes a shift away from expanding agriculture [30], or if

the added value from manufactured products means that less forest products are required to meet harvesters' financial needs [31].

Risk, enabling and opportunity targets manifest as forest impacts via drivers of deforestation and forest degradation (hereafter 'drivers'), which can be thought of as either direct (sometimes referred to as proximate) or underlying [32]. Direct drivers are activities or occurrences at the local level, such as illegal logging or agricultural expansion, which directly affect forests. Underlying drivers are fundamental social processes, such as political matters or demographic factors that underpin the direct causes. Direct drivers typically operate at the local level, while underlying drivers can operate from local to national levels, and may even involve multiple countries. Disentangling and exploring the ways in which future development trajectories may affect forests requires understanding of how a focal country (or some other geographic area) will pursue its development objectives. By linking this information to the direct or underlying drivers that are playing a role in ongoing forest change, it is possible to assess how existing drivers could be exacerbated or mitigated, or how new drivers could potentially emerge.

Our framework identifies specific components of the development agenda likely to be of relevance to forest conservation at the national level over the short- to medium-term, and subsequently assesses the possible magnitude and likelihood of imminent changes in these areas. The approach is based on the understanding that all changes to forests (whether positive or negative) manifest via drivers. It therefore follows that any external forces affecting forests (including those arising from progress towards development objectives) must be operating through the mitigation, exacerbation or creation of one or more drivers. It is important to keep in mind that not all drivers are affected/initiated by the same aspects of the development agenda, and also that multiple different components can bear influence on one or more drivers at any one time. There exists a large body of literature documenting how various aspects of development can affect forests, as well as on drivers and the factors thought to influence them, and it is based upon such information that we draw links between drivers and specific SDG targets in this work (see Materials and methods). A summary of the information on links between drivers and SDG targets is provided in S1–S3 Tables.

Where target-driver links exist, progress towards achieving the target in question can result in one of several outcomes (Fig 1). Where an enabling target is linked to an ongoing driver, then any progress towards achieving the target could help to mitigate the driver. However, if no ongoing drivers have links with a given enabling target, then progress towards achieving this target will (despite being highly desirable for other reasons) likely have minimal relevance for forest conservation. Where a risk target is linked to an ongoing driver, then any progress towards achieving the target could exacerbate the existing threats associated with the driver. If no ongoing drivers are linked to a given risk target, then progress towards achieving this target may result in emerging risks through one or more novel drivers. In the case of opportunity targets, which can present either risks or enabling conditions depending on contextual factors (including the specifics of how the target is addressed [26]), either of the four aforementioned outcomes could result. Where an opportunity target is linked with an ongoing driver, then progress towards its achievement could result in either mitigation or exacerbation of the driver. Where the same target is not associated with any ongoing drivers, any progress made may either result in an emerging risk from a novel driver, or in no forest-related outcome at all.

Having established the key driver-target links for a given focal area, two further questions are of interest: (1) 'what is the potential extent of impacts on associated drivers of achieving a given target?' and (2) 'what is the likelihood that progress in targets deemed to be of importance will occur in the imminent future?'. To investigate the first of these questions, it is

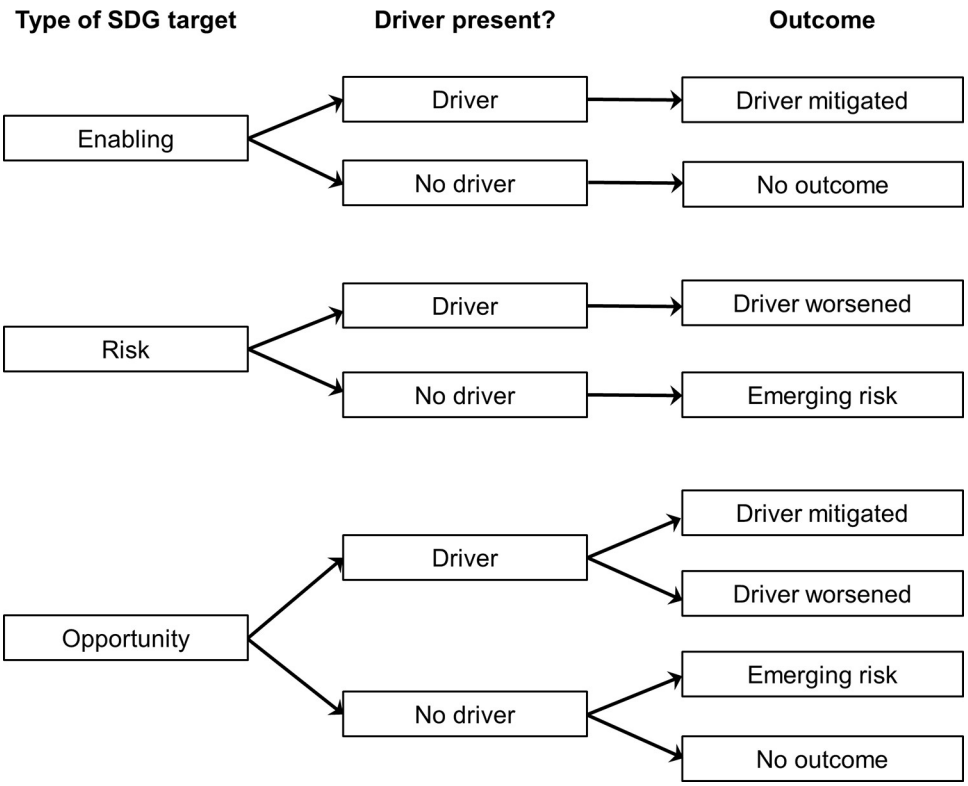

Fig 1. Illustration of how enabling, risk and opportunity SDG targets can either mitigate, worsen or create drivers of deforestation and forest degradation.

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appropriate to use data pertaining directly to the SDG targets themselves (e.g. official SDG indicator data, or similar) to quantify the remaining progress required until the target is considered 'achieved'. A greater level of required progress is indicative of greater potential for significant forest impacts. Investigating the second question is challenging, not least because many components of the development agenda are subject to myriad factors that mean that progress is rarely guaranteed. Our framework rests on the expectation that countries that have either exhibited recent progress in, or are clearly prioritising actions to address a target are more likely to achieve imminent progress than countries for which neither applies, and that countries where both aspects are true are more likely still. We apply this logic to selected countries and SDG targets in order to classify their current status as either 'poor', 'medium' or 'good', and the likelihood of imminent change as either 'unlikely', 'possible' or 'likely' (see Materials and methods).

By combining outcomes from the two questions above, we can characterise the key areas of development likely to affect forests in terms of both the potential magnitude of their impacts and the likelihood that any progress will actually occur. The process through which our framework combines these various information types to derive a final assessment is illustrated in Fig 2. Our approach yields one of nine possible combinations, which, depending on the nature of the target itself (i.e. risk, opportunity or enabling) can inform target-specific policy recommendations that governments or other agencies could enact in order to minimize risks or facilitate benefits to forests (Fig 3).

Using this framework, we assessed the potential impacts of 24 selected SDG targets (five 'risk', nine 'opportunity' and ten 'enabling' targets) on existing and possibly emerging drivers

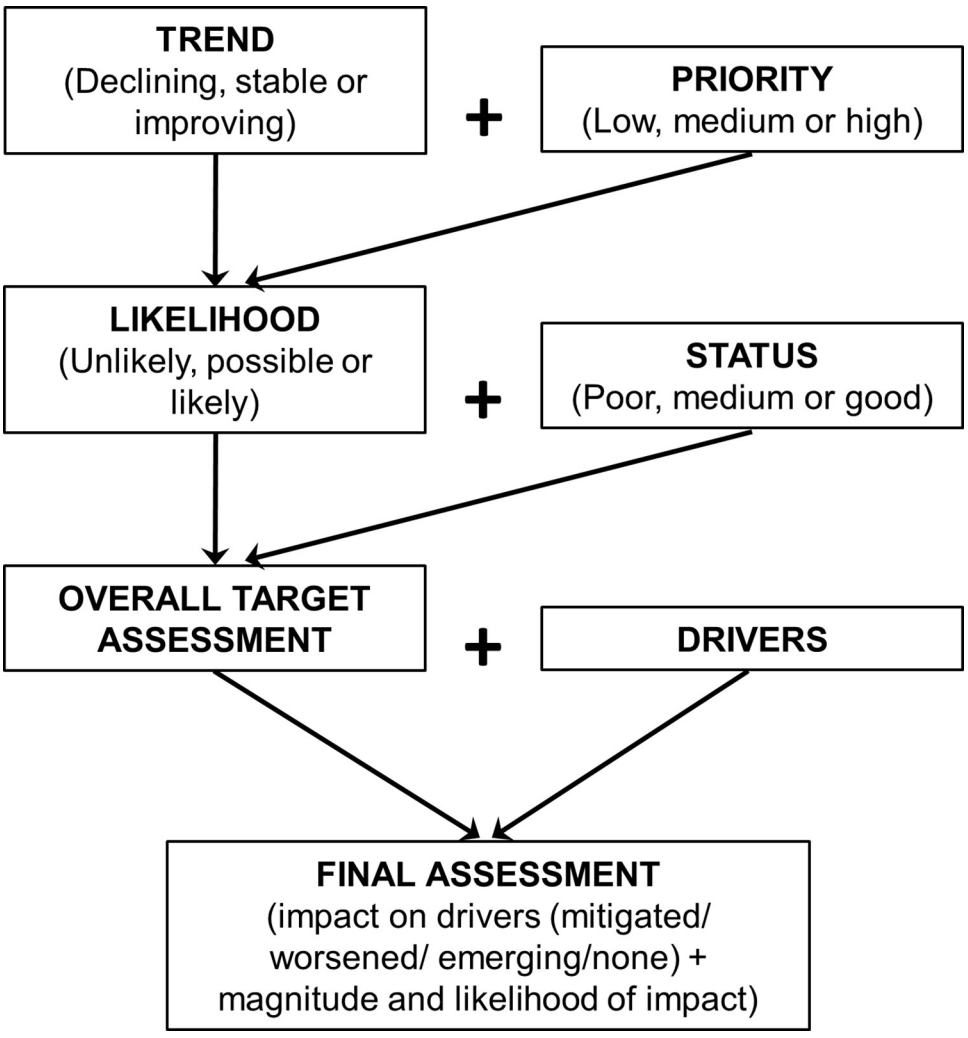

Fig 2. Illustration of our assessment framework. For each SDG target, data on recent trend and assigned priority are combined to assess the likelihood of progress. This is combined with an assessment of the current status (indicative of the scale of potential progress) to derive an overall target assessment, which is further cross-referenced with information on national-level drivers to determine whether the anticipated target changes identified are expected to interact with existing (or create novel) drivers of forest change, as shown in Fig 1.

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for 48 tropical countries spanning three major world regions (Africa, Asia/Pacific and Latin American/Caribbean (LAC)). Data for 25 SDG indicators (or appropriate proxy data) were used to assess the current status and recent trends of each country with respect to 24 forest-relevant SDG targets (one opportunity target (target 7.1 on energy access) was split into two). National development plans were reviewed in order to gauge the level of government priority assigned to each target, and these two elements combined to provide an overall assessment of each target for each country. Target assessments were linked with information on the ongoing drivers in each country, gathered through literature reviews, in order to assess if/how anticipated development progress in each country might be expected to interact with ongoing (or potentially emerging) issues surrounding forest conservation.

This paper targets those engaged in sustainable development and/or forest conservation in the tropics, and hopes to provide an early indication of the aspects of national-level development that may require attention in order to help minimise damage to forests, and instead

Fig 3. Policy responses that can promote synergies and avoid trade-offs for forest conservation vary for risk (red), opportunity (blue) and enabling (green) targets, and according to current status and likelihood of imminent change. Following individual target-level assessments, this guide can be used to help identify an appropriate response.

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facilitate their conservation. The work is not intended as a definitive forecast of how the SDGs will affect tropical forests, but rather as a means for researchers, stakeholders, policymakers and development agencies to easily identify how anticipated changes may (or may not) potentially affect forests, for better or for worse. Based on this information they should engage in follow-up discussions, with the aim of informing more robust forecasts, and ultimately making development trajectories more environmentally sustainable.

Results

For 48 tropical countries, we characterised 24 SDG targets in terms of their (i) relevance to ongoing or potentially emerging drivers of deforestation and forest degradation (see S4 Table and S1 Fig for a country-level summary of recorded drivers); (ii) magnitude of progress that can feasibly be made (indicative of the potential scale of any associated impacts); and (iii) the likelihood that progress will actually be made. In doing so, we generated 1,167 separate assessments (data were unavailable for 81 cases, or 6.5% of a possible 1,248).

Had universal target-driver relationships been assumed (i.e. if drivers were not used to select targets of relevance), then a total of 99 additional cases (8.5% of those with data), which were assessed as 'no concern' using the current approach, would have been flagged as relevant. Notable targets in this regard include 7.2 (renewable energies), 10.7 (migration management), and 16.1 (no conflict). Cases where target 7.2 would otherwise have been deemed relevant are most frequent among African countries, while for 10.7 they only include countries from Asia-Pacific and LAC, and for 16.1 they span all three regions. In a similar way, had universal target-driver relationships been assumed, then a total of 41 cases currently assessed as 'emerging risks', would have been deemed potentially ongoing risks. These cases mostly relate to energy targets (SDG 7) and are more common among African countries than elsewhere. These relatively low proportions are indicative of the fact that many countries considered in this work are currently subject to wide range of drivers of deforestation and forest degradation, such that numerous SDG targets have potential relevance. We also acknowledge that these findings are subject to some key choices made during the development of our approach (e.g. to not assign weights to the drivers from each country), and we discuss the implications of these choices later in our Discussion section.

To provide a visual overview of our data we present a bivariate heat map (Fig 4) which depicts the current status of each country for each target (ranging from 'poor' (blue) to 'good' (green)) in combination with the likelihood of progress (ranging from 'unlikely' (light shade) to 'likely' (dark shade)). Also shown in these figures are cases where targets are not linked to an ongoing driver and either present a potential future risk or opportunity (orange cells) or are not expected to have an imminent impact (beige cells). Our intention is that the assessments presented in this figure can be easily cross-referenced with the policy implications given in Fig 3. We also present our results in the form of maps that combine results from all targets of the same type ('risk' (Fig 5), 'opportunity' (Fig 6) or 'enabling' (Fig 7)) to derive metrics of 'cumulative impact'. While these maps do not imply that different components of the development agenda act additively in terms of their risks or benefits to forests, they do convey additive complexities from a wider range of socio-economic factors, all of which should be considered by conservation and policy-making agencies.

In the following three sections we provide summaries of our findings for each of the risk, opportunity and enabling targets considered. We also provide country-level assessment summaries for individual risk, opportunity and enabling targets in S5, S6 and S7 Tables, respectively, as well as summaries of key assessment outcomes for individual risk, opportunity and enabling targets in S8, S9 and S10 Tables, respectively. Although the following sections typically summarise our findings either by region or by all countries combined, we note here that greater utility may in fact be gained by considering assessments on a country-by-country basis, and we provide an illustrative example of this in our Discussion.

Risk targets

Africa emerges as the region with a greater variety of emerging risks to forests from anticipated development. One major contributor to this is that energy infrastructure across much of Africa, while not recorded as posing a current risk, is expected to undergo significant progress in the coming years. In other regions, energy infrastructure is a more common existing threat, but our data suggest comparatively less significant latent threats from some energy-related SDG targets in these regions compared with Africa. For risk targets 7.1 and 7.b (electricity access and energy infrastructure, respectively) 70% and 100% of African countries were assessed as having 'poor' status (compared with 0% and 69% in Asia/Pacific and 0% and 40% in LAC). Notable improvements in these two targets were recorded for 95% and 60% of

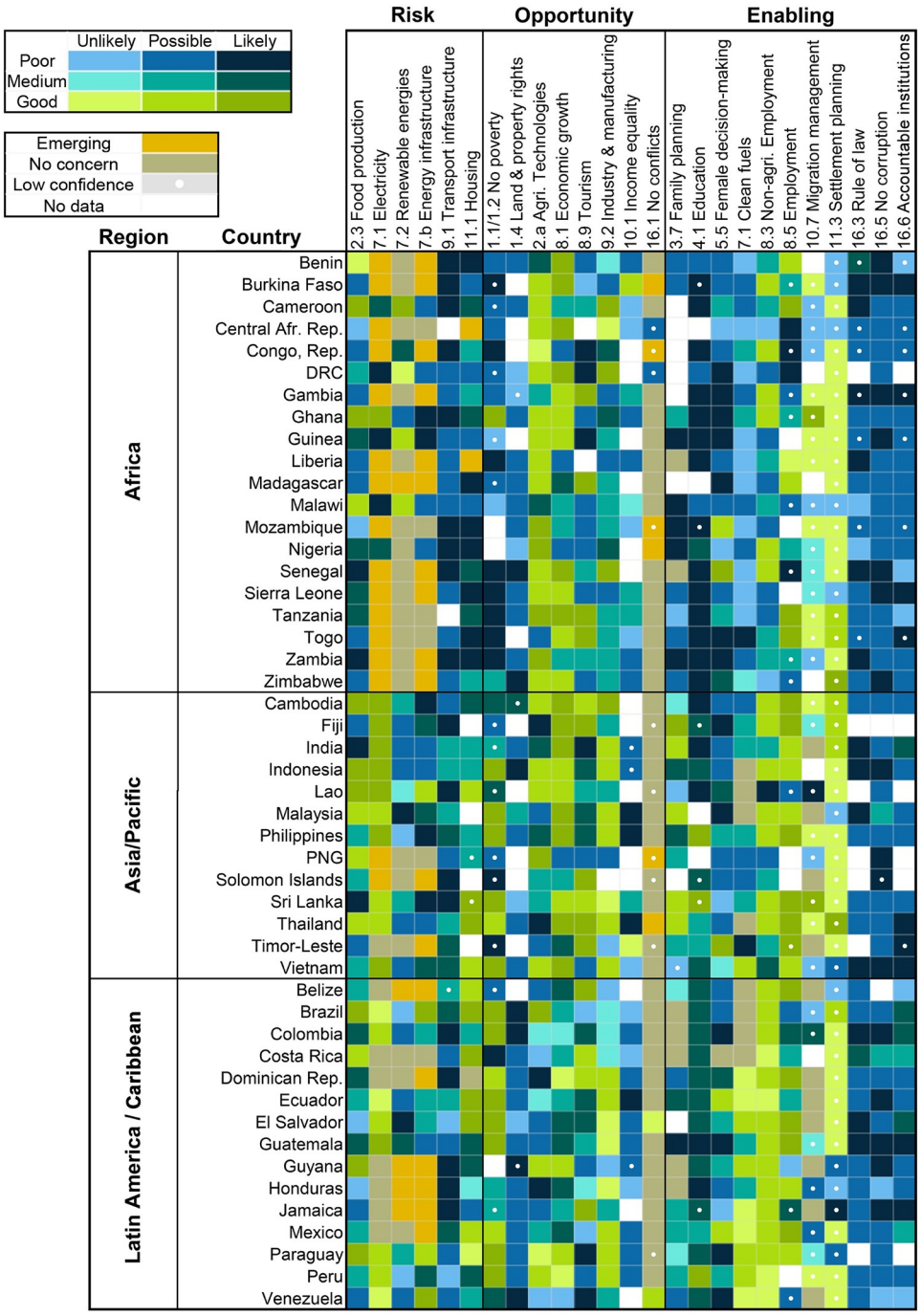

Fig 4. Country assessment summaries for all 25 development indicators included in this work. Legend axis showing current target status (ranging from blue to green) is based on indicator data for the most recent years available. Legend axis showing likelihood of imminent change (ranging from light to dark) is based on a combination of recent trend in each indicator over a 10-year period and level of priority assigned to each target by countries in their national development strategies. Emerging risks/opportunities are cases where targets are not linked to existing drivers, but where a target's status was assessed as 'poor' or 'medium', and likelihood of imminent change was assessed as 'possible' or 'likely'. Cases marked as 'no concern' show enabling targets that are not linked to existing drivers, or risk/opportunity targets not linked to existing drivers and with current status assessed as 'good' and/or imminent change assessed as 'unlikely'. White dots show cases where assessments of either status or trend are based on information gathered from the literature review, rather than from the primary source data used in other cases.

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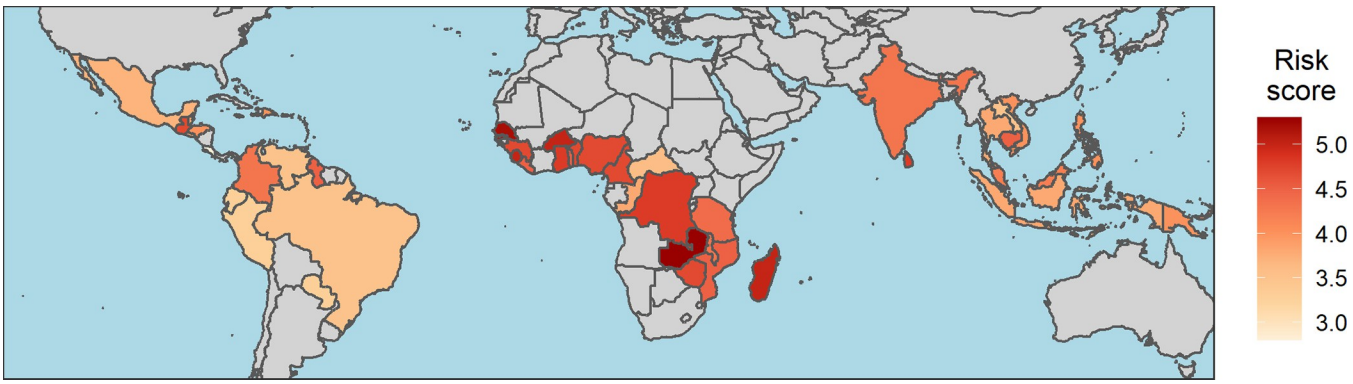

Fig 5. Cumulative risk scores for each country. Maximum possible score per country is six. See Materials and methods for details of how these scores were derived. Grey colour shows countries not included.

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African countries, compared with 92% and 85% in Asia/Pacific and 47% and 93% in LAC. Among African countries, 100% and 90% are prioritising these targets, compared with 85% and 77% in Asia/Pacific and 20% and 47% in LAC. This picture differs slightly for matters of renewable energy (risk target 7.2), which is neither a current threat nor expected to show imminent progress across much of Africa, but is already posing risks in the other two regions, and is expected to progress further in many cases.

Risks from infrastructure associated with transport (risk target 9.1) appear to be high across all three regions, although scope for potential progress is notably higher in Africa (where 95% of countries have 'poor' status) than in Asia/Pacific (46%) and LAC (73%). Recent improvements in this target have been achieved in around 50% of countries in each region, and further improvements are being treated as a priority in 95%, 100% and 80% of countries in Africa, Asia/Pacific and LAC, respectively.

Risks associated with and improving access to housing (risk target 11.1) appear more severe in Africa than in the other two regions. Although levels of recent progress in this target have been similar across all regions (observed in 50%, 46% and 53% of countries in Africa, Asia/Pacific and LAC, respectively), proportions of governments prioritising this target are marginally higher in Africa (90%), compared with Asia/Pacific (69%) and LAC (80%). Most significantly, however, the extent of potential improvements to be made in this target are significantly higher in Africa (where 95% of countries were assessed as having 'poor' status)

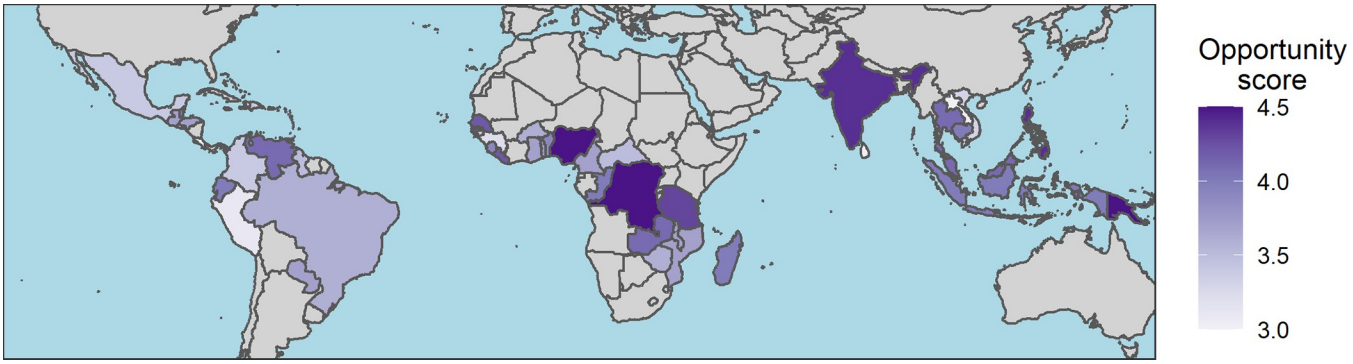

Fig 6. Cumulative opportunity scores for each country. Maximum possible score per country is six. See Materials and methods for details of how these scores were derived. Grey colour shows countries not included.

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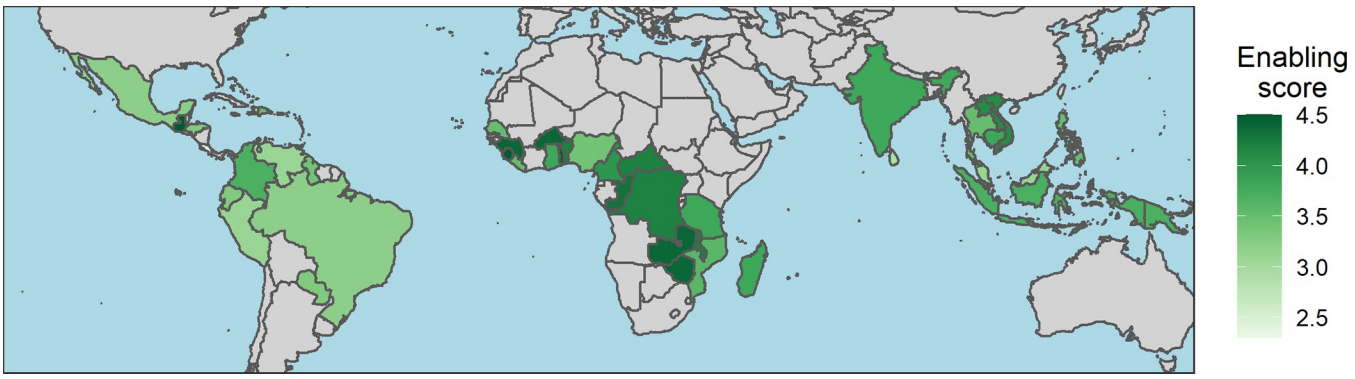

Fig 7. Cumulative enabling scores for each country. Maximum possible score per country is six. See Materials and methods for details of how these scores were derived. Grey colour shows countries not included.

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than in Asia/Pacific and LAC (where 0% and 7% of countries have 'poor' status, respectively). In two African countries (Central African Republic and Liberia), housing infrastructure was not recorded as a current driver, but in both cases our assessment identified this as a potential emerging risk.

Our findings on increased agricultural productivity (risk target 2.3) convey a complex picture, with few clear patterns emerging within or between regions. As has been widely noted elsewhere [33,34] risks to forests from agriculture are of high immediate relevance across the tropics. Accordingly, we recorded at least one of the two drivers associated with target 2.3 (small-scale agriculture and commercial agriculture) in all countries in this assessment. Although relatively low proportions of countries were assessed having 'poor' status for this target (55%, 31% and 27% of countries in Africa, Asia/Pacific and LAC, respectively), we note that this target is unbounded, having no defined endpoint to indicate 'success', and so high current productivity is, in this case, less indicative of reduced likelihood of further increases. Approximately 50% of countries from each region were recorded as having made notable progress in this target in recent years, and 80%, 92% and 73% of countries from Africa, Asia/Pacific and LAC were respectively assessed as prioritising increases in agricultural outputs. The four countries with the greatest potential and highest likelihood of progress in this target are India, Senegal, Sri Lanka and Zambia, but our findings suggest that risks to forests from agriculture could continue across much of the tropics.

In combining all of the risks described above (Fig 5), we find that seven of the nine countries with the highest cumulative risk scores are in Africa. These countries (in decreasing order of risk) are Zambia, Senegal, Burkina Faso, Madagascar, Sierra Leone, Congo, Ghana, Sri Lanka and the Solomon Islands. Countries with the lowest cumulative risk scores are predominantly located in mainland Latin America. These countries (in increasing order of risk) are Costa Rica, Ecuador, Paraguay, Peru, Brazil, Lao and Venezuela. We anticipated that cumulative risk scores based on status and trend data (see Materials and methods) would show a positive relationship with past changes in forest cover. Regression analysis verified this positive relationship ($\beta = 2.026$), although the model was not statistically significant ($R^2 = .10$, $F(1, 46) = 5.04$, $p = .254$), and we consider reasons for this in our Discussion section.

Opportunity targets

Our assessments of eight opportunity targets, which could either aggravate or help to mitigate drivers, showed fewer clear patterns than the two other target types (risk and enabling). Two exceptions to this are matters of poverty reduction (targets 1.1 and 1.2) and matters of

improving rights of ownership of property and land (target 1.4). Poverty reduction, which can encourage beneficiaries to reduce forest-damaging activities such as illegal logging, but also to increase consumption of forest products or expand practices such as agriculture [35], is being treated with high priority among a large share of the countries assessed (85%, 77% and 87% of countries in Africa, Asia/Pacific and LAC, respectively). Differences between regions emerge, however, when considering recent progress, which has been observed more commonly in Asia/Pacific (92% of countries) and LAC (77%) than in Africa (50%), but still has much greater potential to make significant impacts in Africa (where 90% of assessed countries have 'poor' status) than in Asia/Pacific (31%) and LAC (7%).

Improving property and land rights can induce landowners to either clear forests (or sell land to a third-party who may clear them) or to aid their protection [36–38]. Proxy data used to assess this target [39] were incomplete for 11 countries (five each in Africa and Asia/Pacific, and one in LAC). Notwithstanding these data gaps, among countries with sufficient data, high proportions of countries still have significant room for improvement in this area (100%, 75% and 100% of Africa, Asia/Pacific and LAC countries were assessed as 'poor', respectively), and reasonably large proportions have made notable recent progress (47%, 67% and 93% of Africa, Asia/Pacific and LAC countries, respectively). However, assessments concluding that (further) progress in this target is 'likely' were relatively less common, owing to the fact that few governments are prioritising this target in their national strategies (assessed as high priority in 40%, 31% and 27% of Africa, Asia/Pacific and LAC countries, respectively).

Investments into agricultural technologies and research (target 2.a), which we assess based on funds provided by the UN's International Fund for Agricultural Development, may result in risks to forests due to further agricultural expansion, but can also benefit forests, for example if agricultural intensification means that less land is required to produce the same yields [40]. We found that investments into agricultural technologies and research are already high in many countries, and especially so in Africa and Asia/Pacific compared with LAC. Although this target still appears to be a priority among many governments (81% of countries assessed), only 17 (35%) countries have seen recent improvements in this area, while 27 (56%) countries have seen declines. This means that our assessments of this target are largely uncertain as to whether investments will increase in the coming years (28 countries (58%) were assessed as 'possible', compared with 14 countries (29%) assessed as 'likely').

Assessments of economic growth (target 8.1) found that high proportions of countries are prioritising this target (Africa 95%, Asia/Pacific 100%, LAC 67%). Approximately half of all countries (46%) have improved in recent years, and existing rates of growth are relatively high across most countries (only 10% were assessed as having 'poor' status for this target). Altogether, this suggests that further economic growth is 'possible' across a large swathe of the tropics, but that existing rates of growth may be approaching their maxima. Past work on the links between economic growth and forests provides a complex picture, largely suggesting that initial growth in economically weaker countries typically results in loss or degradation of forests, but once higher economic status is achieved, rates of loss/degradation can (but are not guaranteed to) decline [41]. One of the most important factors influencing this outcome is the specific way(s) in which a country seeks to achieve growth, and two further opportunity targets are known to play key roles, namely growth of the tourism (target 8.9) and industry/manufacturing (target 9.2) sectors. Tourism, which can both encourage forest conservation to attract visitors, but also deplete forests to make way for necessary infrastructure and to meet increased demand on forest resources [28], is being widely prioritised (Africa 75%, Asia/Pacific 85%, LAC 73%), but has shown more notable recent improvements in Asia/Pacific (77% of countries) compared with Africa (45%) or LAC (53%). Countries with the greatest potential for growth in tourism are more numerous in Africa (55% of countries) than Asia/

Pacific (23%) or LAC (40%). Growth in industry and manufacturing can be damaging due to associated infrastructure, pollution and influxes or workers, but can also produce beneficial impacts if it allows a shift away from employment in agriculture or other damaging activities. This target is a notably higher priority among African (90%) and Asia/Pacific (77%) countries than among LAC countries (40%), but across all three regions, the potential for future progress was assessed as 'high' in only 17% of countries. Similarly, recent progress was recorded in only 17% of countries, suggesting that imminent risks and benefits from this target may be lower than for other areas of development.

Risks and benefits associated with reducing income inequalities (target 10.1) operate largely in the same way as for reducing poverty (see above). This target was the most data deficient of all targets considered, with one or more data elements missing for 14 (29%) countries. Using available data, we found that large proportions of countries have high potential for progress in this area (64%, 75% and 100% of countries in Africa, Asia/Pacific and LAC, respectively). However, relatively fewer have made significant progress in recent years (43%, 40% and 67% of countries in Africa, Asia/Pacific and LAC, respectively), and fewer still are prioritising this target (25%, 38% and 20% of countries in Africa, Asia/Pacific and LAC, respectively). Overall, despite high potential for progress in this area across the tropics, only four countries (11% of those with available data) were assessed as 'likely' to make imminent progress, suggesting that the associated risks and benefits are less likely to manifest in the near-term than for other areas of development.

Mechanisms through which reducing violence and conflict (target 16.1) can impact forests are complex, often involving a multitude of factors. For example, while ending a conflict may alleviate forest pressures relating to displaced peoples, armed groups residing in forests and/or the breakdown of the rule of law, it may concurrently allow other damaging activities to begin or resume, including agricultural expansion or increased exploitation of forest resources from formerly hostile environments [42–45]. This target is only considered relevant in four countries where ongoing violence or conflict was recorded as a current driver (Central African Republic, Democratic Republic of Congo, El Salvador and Venezuela). In both of the African cases, the current status of this target was assessed as 'poor', and in the two South American cases the status was recorded as 'good'. In all four cases, the likelihood of progress in this target was assessed as 'possible'. Six additional countries were assessed as either 'poor' or 'medium' with regards to this target, and as either 'possible' or 'likely' to make imminent progress, and in these cases a final assessment of 'possible emerging opportunity' was made. These six countries include four in Africa (Burkina Faso, Republic of Congo, Mozambique and Nigeria) and two in Asia/Pacific (Papua New Guinea and Thailand).

In combining data for all opportunity targets described above (Fig 6), we find that the countries with the highest cumulative opportunity scores (in decreasing order of opportunity) are Congo, Nigeria, PNG, India, the Philippines, Fiji, Jamaica, Tanzania, and the Solomon Islands. Countries with the lowest cumulative opportunity scores (in increasing order) are Costa Rica, Lao, Sri Lanka, Peru, Guinea, Vietnam, Colombia, Dominican Republic, and Mexico. Regression analysis comparing cumulative opportunity scores based on status and trend data (see Materials and methods) against recent changes in forest cover found a very slight positive relationship ($\beta = 0.693$), although the model was not statistically significant ($R^2 = .002$, $F(1, 46) = 0.11$, $p = .737$), which is perhaps unsurprising, given the varied nature of impacts associated with opportunity targets.

Enabling targets

Similar to our assessment of risk targets, Africa again emerges as the region with the greatest potential and the greatest likelihood of making impactful progress in targets that can help

enable forest conservation (Fig 4). Enabling targets that differ most notably between Africa and the other two regions relate to family planning (target 3.7), access to education (target 4.1), female representation in decision-making (target 5.5), and clean fuels (target 7.1), which all typically have greater potential for progress in Africa than elsewhere, and in many cases were assessed as more likely to actually improve.

Access to family planning is beneficial for forests in cases where population growth is an underlying driver of forest change [46], which we recorded in all but seven countries (Brazil, Colombia, Costa Rica, Guyana, Honduras, Liberia and Senegal). Although one or more data elements for this target were missing for eight countries, based on those with available data, and excluding countries where population growth is not an implicated driver, access to family planning was assessed as currently 'poor' in 92% of countries in Africa, compared with 17% in Asia/Pacific and 33% in LAC. Recent trends in this target are encouraging (assessed as improving in 67% of countries in both Africa and Asia/Pacific, and 78% in LAC). However, the level of priority awarded to this target varies between region, with 56%, 38% and 20% of countries from Africa, Asia/Pacific and LAC assigning high priority, respectively.

A well-educated population is increasingly recognised as an enabling condition for successful conservation, particularly as it can facilitate alternative livelihood options that are less damaging to forests, and can promote general awareness of the benefits of conservation [25,47,48]. Our assessments of target 4.1 (increase access to primary and secondary education) found that, irrespective of their current status, 42 countries (91% of those with available data) were assessed as 'likely' to make additional progress. Scope for potential progress is much greater in Africa (17 of the 18 countries with available data were assessed as 'poor') compared with Asia/Pacific and LAC where, barring a few exceptions, countries' statuses were more typically assessed as 'medium'.

Increasing women's representation in decision-making positions (target 5.5) has been shown to have positive implications for forests in its own right [49], and is also indicative of a socio-political setting with inclusive and participatory decision-making processes, which is generally thought to be beneficial for forests [50,51]. Our findings identified relatively high numbers of countries with currently 'poor' performances in this target, especially in Africa (75%) compared with Asia/Pacific (69%) and LAC (53%). Recent progress in this target has been encouraging, with 37 countries (77% of all assessed) making recent improvements. However, only 24 (50%) countries are prioritising this target, and only 18 (38%) countries were assessed as 'likely' to make further progress, including nine in Africa (45% of all assessed), four in Asia/Pacific (31%) and five in LAC (33%).

Target 7.1 calls, in part, for better access to clean fuels (but note that this target was split and also considered as a risk target), which we link to countries where domestic fuel production (typically wood and charcoal) is an acknowledged driver of forest change. This driver was recorded in all but nine countries (five in Asia/Pacific: Indonesia, Lao, Malaysia, Sri Lanka and Thailand, and four in LAC: Belize, Brazil, Colombia and Costa Rica). Among the 39 countries where this target is relevant to forests, we find conspicuous differences between regions in terms of current status. In Africa, 17 countries (85% of those assessed) were assessed as 'poor'), compared with four in Asia/Pacific (50% of countries where this target is relevant) and zero in LAC. Across all three regions, imminent progress was assessed as 'likely' in only two countries (Togo and Timor-Leste), compared with assessments of 'possible' in 21 countries (54% of those where the target is relevant) and 'unlikely' in 16 countries (41%).

Higher levels of employment (target 8.5), especially in non-agricultural sectors (target 8.3) can, through the provision of alternative livelihoods, reduce forest impacts from agriculture [52,53], as well as pressures from illegal logging and overharvesting of NTFPs [54,55]. Assessments of the current status of these targets show similar patterns across regions, with 10, 10

and 28 countries assessed as 'poor', 'medium' and 'good', respectively, for target 8.3, and equivalent values of 11, 9, and 25 (plus three unknown) for target 8.5. Differences emerge, however, when considering the likelihood of future progress in these two targets. For example, while future progress in target 8.5 was assessed as 'likely' for 20 countries (47% of those with available data), for target 8.3 this was only the case for two countries (4%), Lao and Vietnam. This is largely because almost all assessed countries are prioritising employment in their development strategies, but only the two mentioned above are explicitly aiming to reduce the relative share of agriculture in overall employment.

In countries where human migration (whether internal or from abroad) is considered a driver of forest change, well-planned and managed migration policies (target 10.7) can help to alleviate the associated impacts [56,57]. One or more drivers associated with this target were recorded in all African countries considered (100%), nine Asia/Pacific countries (69%) and eight LAC countries (53%). Among the 31 countries with complete data and for which this target is relevant, the status of this target was assessed as 'poor', 'medium' and 'good' for 11 (35%), 7 (23%) and 13 (42%) countries, respectively. Imminent progress in this target was assessed as 'likely' for only four countries (Colombia, Ghana, Lao and Sri Lanka) and as 'unlikely' in 25 countries (81% of those with migration-related driver(s) and complete data).

Despite limited empirical evidence, it is widely asserted that more participatory and integrated approaches to human settlement planning (target 11.3) can reduce forest loss/degradation from urbanization and other associated infrastructure [58,59]. Assessments of this target suggest that many countries are already performing well in this target, with 36 (75%) and 12 (25%) countries assessed as having 'good' and 'poor' statuses, respectively (note that data limitations for this target meant that assessments of 'medium' status were not possible; see S2 Table). Only three countries (Jamaica, Thailand and Zimbabwe) were assessed as 'likely' to make additional imminent progress in this target, and a much larger share (36 countries, or 75%) were assessed as 'unlikely to make progress.

We considered three targets from SDG 16 relating to matters of high-level governance, including improved law enforcement (target 16.3), reduced corruption (target 16.5) and increased institutional transparency and accountability (target 16.6). These targets are increasingly recognised as providing the enabling conditions necessary to reduce forest loss/degradation due to illegal activities or those which circumvent environmental regulations or safeguards [60–64]. Among all countries considered, current statuses were assessed as 'poor' for large proportions of all three of these targets, including 40 countries for target 16.3 of (95% of those with available data), 44 countries for target 16.5 (96%), and 36 for target 16.6 (86%). In terms of likelihood of imminent progress in these targets, assessments of 'possible' were most common for all three, followed by assessments of 'likely', and assessments of 'unlikely' comparatively few. For target 16.3, 17 countries (40% of those with available data) were assessed as 'likely' to make improvements, 24 (56%) as 'possible', and two (5%) as 'unlikely'. For target 16.5, 16 countries (34% of those with available data) were assessed as 'likely' to make improvements, 29 (62%) as 'possible', and two (4%) as 'unlikely'. For target 16.6, 13 countries (30% of those with available data) were assessed as 'likely' to make improvements, 25 (58%) as 'possible', and five (12%) as 'unlikely'.

In combining data for all enabling targets described above (Fig 7), we find that the countries with the highest cumulative enabling scores are predominantly in Africa. These are (in decreasing order): the Gambia, Sierra Leone, Guatemala, Togo, Guinea, Zimbabwe, Burkina Faso, Zambia, DRC and Central African Republic. Countries with the lowest cumulative enabling scores are predominantly in mainland Latin America. These are (in increasing order): Costa Rica, Belize, Sri Lanka, Venezuela, Malaysia, Peru, Brazil, Mexico, Ecuador and Honduras. We anticipated that cumulative enabling scores based on status and trend data (see

Materials and methods) would show a negative relationship with past changes in forest cover. Regression analysis verified this negative relationship (β = 2.026), and the model was statistically significant (R^2 = .03, F(1, 46) = 1.33, p = .029).

Discussion

For 48 tropical countries, our assessments highlight potential risks, opportunities and enabling conditions for forest conservation that could arise in the short to medium term, based on their anticipated development trajectories. Individual country assessments show variation in the make-up of their component target-level assessments, yet some broad patterns are evident. Of particular note is the observation that for the majority of targets, assessments of 'unlikely' imminent progress were less frequent than assessments of 'possible' or 'likely'. Exceptions to this include targets 10.7 (migration management), 11.3 (participatory settlement planning) and, for Africa only, the clean fuels aspect of target 7.1. Given that these are all enabling targets, we urge governments to make greater efforts to address these, both for the forest-specific and the wider benefits they provide. As has been noted elsewhere [65,66], creating appropriate enabling conditions is of paramount importance if the risks to forests from progress towards sustainable development are to be effectively managed.

Assessments of the likelihood of progress for each target assessed are more similar between regions (at least in terms of the proportions of countries in each category) than assessments of the magnitude of potential progress. Specifically, we see that, with few exceptions, African countries currently require greater progress in order to achieve many of the targets assessed in this work, suggesting that the latent impacts associated with the different target types (risk, opportunity or enabling) are greater in magnitude there than elsewhere.

Specific risks to forests that could warrant attention over the coming years include ongoing threats from agricultural production, transport infrastructure and urban infrastructure, which all look likely to make further progress in many countries across all regions (including countries that are already performing well in these areas). Energy infrastructure could also pose risks to forests across many tropical countries, though in many cases such threats are yet to emerge. We note that in Africa, possible emerging risks are more typically associated with providing access to electricity and other energy types, while in LAC, possible emerging risks from renewable energies were identified more frequently. While it would be improper to suggest that countries should not strive to achieve progress in these areas, appropriate safeguards, which are often facilitated by sound planning, management and governance frameworks (as per many of the enabling targets considered herein), will be essential in order to minimize any environmental damage caused [19,67,68].

Across all countries, assessments of opportunity targets show greater heterogeneity than those for risk and enabling targets, yet some broad patterns are still evident. For example, poverty reduction and economic growth are clearly high priorities among many countries, and much progress has been made in both areas in recent times. Conversely, assessments of property/land rights and income inequalities showed that much progress remains to be made in these areas, and that in many countries this is less likely to occur than for other targets. As with risk targets, the achievement of opportunity targets is unquestionably desirable, but we encourage those responsible for delivering progress to pursue pathways that support, rather than inhibit, environmental conservation. Ways to achieve such outcomes are innumerable, but examples might include the pursuit of target 8.9 (sustainable tourism) through well-managed ecotourism that facilitates poverty reduction and economic growth [69], strengthening of land and property rights (target 1.4) for individuals and communities in combination with appropriate conservation incentive programmes [70], or the promotion of agricultural

technologies (target 2.a) that allow sustainable intensification of otherwise low-yielding, extensive farming practices [71]. Achieving opportunity targets in ways that benefit, rather than damage the environment will, in many cases, require appropriate enabling conditions to first be created, so that resulting planning, management and governance frameworks can help to ensure the most sustainable progress possible.

Assessments of enabling targets show that the majority of countries still have much progress to make on matters of rule of law, corruption and institutional transparency, but that some progress can be expected in these areas in many cases. For a number of other enabling targets, we found that Africa is lagging behind the other two regions considered in many cases. Despite this, across all regions we expect to see progress in many areas, and especially in matters of education, female decision-making, and increased employment. Exceptions include matters of clean fuels (Africa only), reduced agricultural employment, migration management and participatory settlement planning, which were all assessed as generally less likely to make imminent progress. As the benefits associated with a number of enabling targets typically manifest through the mediation of impacts from other target types (e.g. reducing corruption can help prevent infrastructure projects from bypassing safeguards) we recommend that these targets be treated with the greatest priority. It is also worth noting here that SDG targets pertaining directly to matters of the environment are also all enabling in nature, but were not included in this work as our intention was to focus on matters that can affect forests indirectly. Progress in environment-related targets will be essential to stem the loss and degradation of forests and other natural systems, but achieving these additional, less conspicuously relevant targets will also be highly important to ensure that direct conservation measures are as effective as possible [72–74].

The relationships underpinning this work are typically relevant to the conservation of existing forests, but consideration of anticipated development trajectories is equally as important when planning for the restoration of lost or degraded forests [75], which we encourage. We further encourage similar applications in other development-related contexts. A key starting point for such assessments is to synthesise knowledge of the direct and underlying factors that can facilitate or limit success in achieving a given development outcome. Fortunately, such information exists for a wide range of topics featured among the SDG's targets, including both environmental (e.g. wetland conversion [76], illegal fishing [77,78]) and non-environmental (e.g. poverty reduction [79,80], maternal mortality [81,82], sustainable tourism [83,84]) issues. In many cases, and as was demonstrated in this work, this knowledge could be readily used to select key SDG targets to assess how ongoing national development trajectories could affect the development outcome in question, and to facilitate identification of appropriate policy responses. For development outcomes where the factors that facilitate or limit success are currently unknown, we encourage efforts address these knowledge gaps (e.g. through literature reviews and meta-analyses). By combining the growing understanding of interactions among development targets with data indicating anticipated progress (or lack of) in key areas, we can develop a more holistic understanding of likely outcomes across a range of development themes, and act accordingly to ensure that areas of development operate in harmony rather than in discord.

When considering interactions among the SDGs, whether pertaining to forests or otherwise, it is important to keep in mind the different contexts that exist between locations [4,7]. Although the results presented in this paper have largely been summarised either by region or by all countries combined, important insights can be gained by considering assessments on a country-by-country basis. The fact that no two countries are identical in their constituent assessments is indicative that appropriate responses to the findings presented will differ between countries. To illustrate this we might compare interpretations between two arbitrary

countries, say Zambia and Malaysia. In Zambia, risks to forests could arise from ongoing improvements in agricultural production, transport infrastructure and housing, while in Malaysia, these are less of an issue, and deployment of renewable energies was identified as a greater potential risk. In Zambia, opportunities will arise from poverty reduction and improved agricultural technologies, both areas with significant scope and high likelihood of progress. In Malaysia, these targets are expected to show progress, but with much less scope for potential gains, and instead, matters of tourism and income equality, both expected to show significant progress, are more relevant. Concerning enabling targets, both countries are set to make significant progress in matters of female decision-making, and rule of law, and neither country is expected to make the desired progress in matters of institutional transparency. However, few other similarities are evident, mainly as Zambia is lagging behind in many areas (most notably clean fuels and reducing corruption), while Malaysia is already performing relatively well in most other enabling targets. Such differences will necessitate different responses on the part of national-level policymakers and development/conservation agencies to guide national development in a forest-friendly direction, and we therefore encourage interpretation of our findings at this more in-depth level, including through follow-up discussions with stakeholders and experts (see below) to verify whether the potential for forest-related outcomes is relevant in their specific context.

The assessment framework presented in this paper requires very little technical expertise to apply and interpret, and is readily applicable across different locations and scales, which are all characteristics considered desirable among decisionmakers [16], and mean that it is likely to be especially useful in cases where limited time, resources, capacity or system-specific knowledge pose a constraint. Nevertheless, the approach has some limitations that are important to consider. Despite showing the anticipated relationships in terms of direction, our analyses regressing forest cover change against the cumulative scores for each of the three target types generally had low explanatory power. Among other reasons (e.g. the fact that our response variable does not consider forest degradation), this is likely due in large part to several key assumptions that were made in the absence of knowledge of specific contextual elements. In this demonstration we assumed that all recorded drivers within a given country are of equal importance, and that links between drivers and SDG targets are uniform across countries, neither of which are likely to be true. Although we still feel that our approach can be informative in its own right (e.g. to identify sectors between which dialogue and collaboration could help to address the ongoing issue of silos within the sustainable development community [85]), such assumptions constrain the degree to which policy recommendations can be made directly from our findings, and again reiterate that inputs from knowledgeable experts and stakeholders on these contextual matters would be of great benefit, as is the case in the majority of future-oriented approaches [86]. As was stated at the outset of this paper, our approach is intended as a complement to existing techniques, which in most cases will involve a process of stakeholder and expert consultation, providing an opportunity to address these and other assumptions.

The list of drivers used in this work is limited to human-driven, national-level factors (see Materials and methods), yet we should not underestimate the importance of other factors that play roles in the loss and degradation of forests, including human-driven factors (e.g. global commodity prices, foreign policies and resource demands, or levels foreign investment) and natural factors (e.g. climate change). Although we acknowledge the importance of such factors [87–91], their inclusion would be challenging, not least because they are typically stochastic and/or beyond the control of any single government. Similarly, we focused on a subset of SDG targets with the best-documented links with drivers of forest change (and with sufficient data availability). Notable omissions from our assessments include matters of access to vocational

and tertiary education (target 4.3), and access to finance and markets by small-scale enterprises (target 9.3), for which good evidence exists to suggest beneficial and damaging impacts on forests, respectively [92,93]. Our omission of certain drivers and development targets means that our assessments are not wholly representative of the myriad ways in which sustainable development may affect tropical forests. Nevertheless, we cover many of the major issues surrounding the forest impacts of sustainable development, and hence provide an informative and comprehensive overview of the outlook over the coming years. Moreover, given the simplicity of our approach, the inclusion of additional indicators (e.g. once useable data become available) in future applications of this framework would present few challenges.

To a limited extent, our assessments intrinsically cover multi-target interactions (impacts arising from the interplay between two or more targets). For example our inclusion of target 4.1 (access to education) assumes that benefits to forests from this target will manifest, at least in part, through changes in poverty levels (targets 1.1 and 1.2) and employment status (targets 8.3 and 8.5) [94]. However, interactions of this nature were not explicitly investigated in this work. To do so would require a much deeper understanding of how two or more targets can interact to result in environmental impacts, which is currently lacking, at least compared with the more straightforward two-target interactions considered in this work. As knowledge of multi-target interactions continues to grow, the inclusion of such factors in assessments such as this, which aim to identify emerging risks and opportunities, could well represent a valuable area of inquiry. In the meantime, however, a limited understanding of these more complex interactions should not inhibit consideration and appropriate actions to address interactions that are better understood, which was the underlying motivation for this this paper.

Materials and methods

Selecting focal countries

From an initial list of 96 countries (excluding dependent territories) falling within or largely within the tropical zone, we excluded those considered 'high income' by the World Bank [95], as such countries are expected to have less scope for imminent development progress and are therefore of less interest in this regard. We excluded countries with less than 20% total natural forest cover in 2018, based on data compiled by the Food and Agriculture Organization of the United Nations (FAO) and made available as part of the World Bank's Development Indicators [96] (development progress in these countries is less likely to impact upon forests compared to those with higher forest cover). Lastly, we excluded countries that had not published a Voluntary National Review (VNR) of recent progress towards achieving the SDGs, as these documents were a key data source for this work. This resulted in a list of 50 remaining countries for investigation, though we subsequently excluded a further two countries (Saint Lucia and Vanuatu) due to a lack of useable indicator data. The total estimated forest cover of the initial 96 countries and for our subset of 48 is 18,067,728 km^2 and 15,224,221 km^2, respectively, meaning that, notwithstanding dependent territories, our assessments are relevant to countries containing around 84.3% of all tropical forests. Our subset of 48 countries comprised 20 countries from Sub-Saharan Africa, 13 countries from the Asia/Pacific region, and 15 countries from the LAC region.

Assessing national-level drivers of deforestation and forest degradation

As there is currently no repository for storing or providing data on national-level drivers, our approach drew upon available literature, including peer-reviewed articles and other high-level reports. We used a series of four searches (country name, plus each of the terms "deforestation", "forest change", "forest degradation" and "forest drivers") in both Google and Google

Scholar, excluding publications prior to 2015 and, in each case, inspected the first 50 results for relevant information. For each country, we also specifically sought the following documents, which all typically present summaries of national-level drivers: (i) World Bank 'Country Forest Notes' [e.g. 97]; (ii) CIFOR working papers from their 'Context of REDD+' series [e.g. 98]; and (iii) REDD+ preparation documentation (predominantly, but not exclusively national 'Readiness Preparation Proposals'), made available by the Forest Carbon Partnership Facility [99].

We reviewed each document for relevant information, recording each direct and underlying driver reported, including those reported as likely to emerge in the near future. We did not include drivers related to fire events or climate change, nor those that are not typically influenced by the focal country (e.g. timber market prices or levels foreign direct investment), which are all beyond the scope of this work. We also did not include drivers relating to formal government policies, as, given that government policies form a key source of information for this work, we would risk making circular arguments. At this initial review stage, all drivers were recorded in their raw form, as specified in the source documents. Subsequently, all recorded drivers were grouped into logical categories (33 in total, see S1 Table) to provide consistency and comparability between countries. With few exceptions, all documentation reviewed used similar terminology and classification schemes to describe drivers, and so this process presented few challenges.

We did not attempt to assign relative weights or levels of importance to drivers, as, in most cases, the complexities surrounding causes of forest change, even at national levels, make this unfeasible. Though our approach was not exhaustive, it can be considered comprehensive, and in the majority of cases, individual drivers were reported across multiple documents, suggesting that our searches captured the most important contributing factors.

Selecting SDG targets

Initial selection of SDG targets was based on Carr et al. [26], who identified 63 targets as having potentially damaging, beneficial or mixed implications for forests (corresponding with our categories of 'risk', 'opportunity' and 'enabling' targets, respectively). From these, we excluded targets for which implications were deemed uncertain (i.e. reported as 'low confidence' by the authors) or where the original findings were based on highly specific contexts, not applicable to a multi-country assessment such as this (e.g. the authors' findings on target 16.4 related specifically to efforts to reduce organised crime in Colombia). To further confirm these target-forest relationships, we also consulted Katila et al. [27], who provided a qualitative, expert-driven assessment of the impacts of achieving the SDGs on forests. Where, for a given target, one source suggested beneficial or damaging impacts and the other suggested mixed impacts (as was the case for target 8.9, on tourism), the target was placed in the opportunity category. In one case (target 6.1, water access) the two sources disagreed entirely, with one suggesting negligible impacts and the other damaging, and so we chose to not include this target. Because Katila et al.'s assessment was not systematic in nature, not all targets were necessarily considered in their work. As such, in cases where the Carr et al. study cited impacts for a target that was not mentioned by Katila et al., the former was taken as the default option.

As targets 4.1 (access to primary and secondary education) and 4.2 (access to pre-primary education) are expected to be closely related, we only included the former, which had better data availability. Two targets (4.3 on technical and vocational education and 9.3 on access to credit and markets) were not included due to a lack of available indicator data to inform assessments. Targets 1.1 and 1.2 (poverty measured using international and national scales, respectively) were combined into a single assessment, and two separate assessments were

made for target 7.1 (access to modern energy services); one on access to electricity and another on clean fuels (see details in S2 Table). Despite being assessed by Carr et al. [26] as having impacts with low associated confidence, we included assessments of access to family planning (target 3.7), responsible migration policies (target 10.7), inclusive and participatory settlement planning (target 11.3), and accountability/transparency of institutions (target 16.6). These targets can all be linked with commonly cited underlying drivers of forest change [58,100–102], and so were deemed informative in our context. Overall, we considered 25 indicators, relevant to 24 SDG targets (see S2 Table).

Establishing linkages between drivers and SDG targets

In many cases, the links between SDG targets and drivers of forest loss/degradation are straightforward. For example, plans to increase agricultural output (target 2.3) could result in the emergence or worsening of drivers relating to agricultural expansion, while efforts to address corruption (target 16.5) will likely help to address cases where corruption is a known underlying driver. In many other cases, however, these links are less clear, and so to establish linkages for the purpose of this assessment, we again drew upon the published literature. When assessing the national-level drivers for each of the 48 countries considered in this work, many of the documents reviewed described ways that specific drivers could be mitigated or aggravated by suggested interventions or anticipated changes. This was especially the case for documentation associated with REDD+ (e.g. Readiness Preparation Proposals and synthesis reports), which commonly give detailed breakdowns of identified national-level drivers, including suggested solutions and/or anticipated changes that could cause them to worsen. This information was then compared with the official SDG targets and indicators [17] to determine which of the SDG targets best aligned with the solutions/changes that were identified as having implications for a given driver.

The documents used to select SDG targets for inclusion in this work also contained useful information in this regard. The review by Carr et al. [26], which was conducted by several authors involved in this work, provided a large body of literature containing much information on the specific mechanisms through which individual targets can affect forests, which was often readily linked to specific drivers. The book by Katila et al. [27] also provides detailed descriptions of how each SDG is expected to interact with forests, often making or (inferring) explicit links with drivers. Information gathered from these sources was cross-referenced with our list of drivers, and all linkages recorded.

Information gathered through the above processes were summarised (S1 and S2 Tables) for consideration by co-authors, and any contentious links were excluded. A matrix showing all links used to conduct this assessment is provided in S3 Table. We acknowledge that our assessment of the links between SDG targets and drivers in this way may not have captured the full range of complexities, but nevertheless feel that our approach was thorough, and should have captured the most important relationships. We also acknowledge that many of our recorded linkages may not apply in all countries and contexts. However, as our intention is to indicate *possible* ways that anticipated development progress could affect forests, which we hope will be further discussed among experts with more detailed contextual knowledge, we prefer to be inclusive, allowing exclusion of a particular relationship deemed irrelevant at a later point, rather than to exclude potentially relevant relationships, which could be later overlooked.

Assessing SDG target indicators

For each target, and for each country, we aimed to assess three features: (i) the current status, designated into categories of either 'poor', 'medium' or 'good', (ii) the recent trend, using

categories of either 'declining', 'stable' or improving' and (iii) the level of priority assigned by national governments, using categories of either 'low', 'medium' or 'high'.

For elements (i) and (ii) we first sought data directly pertaining to the official SDG indicators [17], made available on the UN's Global SDG Indicators Database [103] and by the World Bank [96], the latter often being more data rich, and so used preferentially where data for the same indicator were available from both sources. In cases where targets or indicators are multi-faceted in nature, we purposefully chose indicators most closely related to the forest impacts identified by Carr et al. [26]. For example, for target 1.4 ("*By 2030*, *ensure that all men and women*, *in particular the poor and the vulnerable*, *have equal rights to economic resources*, *as well as access to basic services*, *ownership and control over land and other forms of property*, *inheritance*, *natural resources*, *appropriate new technology and financial services*, *including microfinance*") we were specifically interested in matters relating to "control over land and other forms of property", which was identified by the authors as playing a key role in matters of deforestation and forest degradation. In cases where data from our preferred source were unavailable or insufficient, we identified alternative data sources thought to adequately reflect the target in question. Additional sources included: the Physical Property Rights component of the International Property Rights Index [39] for target 1.4 (control over land and other forms of property); FAO data on national levels of agricultural production [104] for target 2.3 (increase food production); data from the World Justice Project [105], which includes a range of indices relating to matters of national-level governance, for targets 16.1 (no conflicts), 16.3 (rule of law) and 16.7 (institutional transparency); and Transparency International's Corruption Perceptions Index [106] for target 16.5 (reduce corruption).

For all targets/countries, we collated information for the most recent years available (excluding cases with no data available for 2015 or after) as well as for 10 years (or as close as possible) prior to the most recently available value. Information on all targets/indicators considered in this work, including data sources, is provided in S2 Table.

For indicators with defined endpoints (i.e. those based on bound indices or where a 0% or 100% outcome is desired) we calculated the global (using all countries with available data) standard deviation (SD) from this endpoint. We then considered national-level distances from the defined endpoint, and assessed values less than the global SD as 'good', those greater than one SD but less than two SDs as 'medium', and those greater than two SDs as 'poor'. Where indicator endpoints are less well defined (e.g. proportion of total GDP derived from tourism for indicator 8.9.1), we assigned our own success thresholds based on reasonable assumptions of desirable target values (see S2 Table), and applied this same approach. While this approach may attract criticism for use of somewhat arbitrary values, other approaches (e.g. comparing country-level values to global averages [107]) are limited by the fact that reference values may not be indicative of the levels that countries wish to achieve (i.e. if global performance for a given target is currently poor), and so our approach is preferred. Assigning categories that characterise recent change (i.e. 'declining', 'stable' or improving') in a given indicator faces similar challenges, again because there are no pre-established thresholds with which to distinguish between stable and either declining or improving (given that some level of change, even if very small, can be expected in the majority of cases). We calculated the percentage change between the latest available data value and the corresponding value from 10 years previous (extrapolating from intermediate values as required), and with few exceptions (see S2 Table) considered absolute changes of less than five percent as 'stable'. Although use of ordinal categories may mask some of the between-country variation present in the raw data, it does allow straightforward comparison between countries and indicators. Future applications of this framework could potentially capture a wider extent of the variability by using more than three categories, but for the sake of interpretability, we opted for a more simple approach.

Assessments of the priority assigned to each target by governments used official national development plans as well as the most recent Voluntary National Reviews of the SDGs [108]. Targets explicitly stated in these documents as being a priority and/or with detailed information on how the target will be achieved were considered 'high' priority. Targets receiving mention, but lacking details on how they will be achieved were considered 'medium' priority. Targets not mentioned at all were considered 'low' priority. An improving trend in a given indicator does not guarantee that improvements will continue, and, similarly, governments simply stating that a particular target is a high priority does not necessarily mean that they will honour this. As such, we combined these two components to derive a measure of likelihood of imminent change using the following logic: for targets exhibiting recent progress and considered high government priority, imminent change was considered 'likely'. For targets where only one of the above was true, imminent change was considered 'possible', and for targets where neither of the above was true, imminent change was considered 'unlikely'.

In cases where a given target was not linked to an acknowledged country driver, two assessment outcomes were possible: for opportunity and risk targets with current statuses assessed as either poor or medium and with imminent progress assessed as either possible or likely, the category or 'possible imminent opportunity/risk' was assigned. For enabling targets, and for opportunity and risk targets not meeting the above criteria, we assigned the category of 'not currently relevant'.

Deriving and comparing indicative, combined scores

To derive cumulative scores for each target type, individual targets were scored as follows: for current status, good = 0, medium = 1, poor = 2; for trend, declining = 0, stable = 1, improving = 2; and for priority, low = 0, medium = 1, high = 2. Values for all targets in each category (risk, opportunity or enabling) were summed (with scores of zero given to enabling and opportunity targets without recorded target-driver links), and final country values for each category derived by taking the mean of all values for each target with complete available data. Minimum and maximum possible scores are zero and six, respectively. The nature of this scoring process means that higher scores can result where countries have significant progress to make in order to achieve targets, where observed progress has been achieved in the last decade, or where targets are being treated with high priority by governments, and combinations of all three of these criteria result in the highest possible scores. As noted earlier, high cumulative scores are not necessarily indicative of a higher intensity of expected forest outcomes (whether positive or negative), but rather a greater complexity of factors that governments, conservationists and development agencies will need to consider in order to achieve development trajectories that are conducive to forest conservation. All maps were produced in R version 4.2.1 [109], using country boundary data sourced from Natural Earth (www.naturalearthdata.com) [110], which are in the public domain.

We also examined whether cumulative target values from each target category (risk, opportunity and enabling) were associated with changes in forest cover in the recent past. Given that our assessment framework is essentially 'forward looking', some modifications were required to apply it in a more historic sense. Scores for each country/target category were derived in a similar fashion to above, but with scores for the 'status' component reversed (i.e. poor = 0, medium = 1, and good = 2), so that higher scores reflect better current status as opposed to high potential for significant progress. We also excluded the 'priority' component in this case, as this was not expected to be associated with any past impacts on forests. Resulting values were regressed (using standard linear regressions) against measures of percentage tree cover loss between 2010 and 2020 derived from [111], which broadly aligns with the timeframe

covered by the rest of our study. Our expectation is that risk targets should have a positive relationship with percentage tree cover loss, enabling targets a negative relationship, while opportunity targets could have either, if any relationship is evident at all.

Supporting information

S1 Table. Driver categories used in this analysis. Includes the total number of countries reported as having forests affected by each driver, and explanations of SDG targets associated with each driver. Drivers are presented from highest to lowest numbers of countries in which they were recorded in this work. In this work, for all acknowledged drivers in a given country, all associated targets of relevance are reported upon. In cases where risk or opportunity targets are not triggered by an existing driver, but are assessed as likely to show imminent progress, we report these as 'possible emerging risks' (see Materials and methods, main report).
(PDF)

S2 Table. SDG targets included in this analysis. Includes links with drivers of forest loss or degradation (highlighted bold for cross-referencing with S1 Table), indicator data used to perform analyses, any notes or caveats associated with indicator data, and values used to assign categories of current status.
(PDF)

S3 Table. Summary matrix showing all links between drivers (rows, listed alphabetically) and SDG targets (columns) used in this work.
(PDF)

S4 Table. Drivers recorded for each country. Countries are presented in descending order by total number of recorded drivers. Y = driver ongoing, F = expected future driver. Values given in the final column were used to create the map in S1 Fig.
(PDF)

S5 Table. Assessment summaries of risk targets for all countries. For each cell in columns 2 to 7, the first value indicates status (0 = good, 1 = medium, 2 = poor), the second value indicates trend (0 = declining, 1 = stable, 2 = improving) and the third value indicates priority (0 = low, 1 = medium, 2 = high). Underscores show missing data values. Asterisks show cases where one or more data elements is lower confidence. Also shown are the mean risk scores, used to produce Fig 5, and values derived from the status and trend assessments, used to perform regression analysis against tree cover change (see Materials and methods in main article).
(PDF)

S6 Table. Assessment summaries of opportunity targets for all countries. For each cell in columns 2 to 9, the first value indicates status (0 = good, 1 = medium, 2 = poor), the second value indicates trend (0 = declining, 1 = stable, 2 = improving) and the third value indicates priority (0 = low, 1 = medium, 2 = high). Underscores show missing data values. Asterisks show cases where one or more data elements is lower confidence. Also shown are the mean opportunity scores, used to produce Fig 6, and values derived from the status and trend assessments, used to perform regression analysis against tree cover change (see Materials and methods in main article).
(PDF)

S7 Table. Assessment summaries of enabling targets for all countries. For each cell in columns 2 to 12, the first value indicates status (0 = good, 1 = medium, 2 = poor), the second value indicates trend (0 = declining, 1 = stable, 2 = improving) and the third value indicates

priority (0 = low, 1 = medium, 2 = high). Underscores show missing data values. Asterisks show cases where one or more data elements is lower confidence. Also shown are the mean enabling scores, used to produce Fig 7, and values derived from the status and trend assessments, used to perform regression analysis against tree cover change (see Materials and methods in main article).
(PDF)

S8 Table. Summary of key assessment outcomes for risk targets for all countries by region. Includes counts and proportions of countries with high potential for change (poor status), observed improving trend, and high government priority. Combined assessment summaries show numbers and proportions of countries of all combinations of potential for change (high = poor or medium status; low = good status) and likelihood of change (high = likely; low = unlikely or possible). Values in parentheses show total countries with unavailable data. Bold text shows cases where ≥50% of countries are within a given category.
(PDF)

S9 Table. Summary of key assessment outcomes for opportunity targets for all countries by region. Includes counts and proportions of countries with high potential for change (poor status), observed improving trend, and high government priority. Combined assessment summaries show numbers and proportions of countries of all combinations of potential for change (high = poor or medium status; low = good status) and likelihood of change (high = likely; low = unlikely or possible). Values in parentheses show total countries with unavailable data. Bold text shows cases where ≥50% of countries are within a given category.
(PDF)

S10 Table. Summary of key assessment outcomes for enabling targets for all countries by region. Includes counts and proportions of countries with high potential for change (poor status), observed improving trend, and high government priority. Combined assessment summaries show numbers and proportions of countries of all combinations of potential for change (high = poor or medium status; low = good status) and likelihood of change (high = likely; low = unlikely or possible). Values in parentheses show total countries with unavailable data. Bold text shows cases where ≥50% of countries are within a given category.
(PDF)

S1 Fig. Counts of recorded drivers of deforestation and forest degradation per country (from a possible total of 33). Grey colour shows countries not included. Underlying values used to create this map are given in S4 Table.
(TIF)

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References

1. Nilsson M, Griggs D, Visbeck M. Map the interactions between Sustainable Development Goals. Nature. 2016; 534: 320–322. https://doi.org/10.1038/534320a PMID: 27306173
2. Anderson CC, Denich M, Warchold A, Kropp JP, Pradhan P. A systems model of SDG target influence on the 2030 Agenda for Sustainable Development. Sustain Sci. 2021; 1–14. https://doi.org/10.1007/s11625-021-01040-8 PMID: 34659581
3. Pradhan P, Costa L, Rybski D, Lucht W, Kropp JP. A systematic study of Sustainable Development Goal (SDG) interactions. Earths Future. 2017; 5: 1169–1179. https://doi.org/10.1002/2017EF000632
4. Nilsson M, Chisholm E, Griggs D, Howden-Chapman P, McCollum D, Messerli P, et al. Mapping interactions between the sustainable development goals: lessons learned and ways forward. Sustain Sci. 2018; 13: 1489–1503. https://doi.org/10.1007/s11625-018-0604-z PMID: 30546483
5. Horvath S, Michael M, Kirchner M, Toth W, Germann V, Hundscheid L, et al. Handling a complex agenda: A review and assessment of methods to analyse SDG entity interactions. Environ Sci Policy. 2022; 131: 160–176. https://doi.org/10.1016/j.envsci.2022.01.021
6. Bennich T, Weitz N, Carlsen H. Deciphering the scientific literature on SDG interactions: A review and reading guide. Sci Total Environ. 2020; 728: 138405. https://doi.org/10.1016/j.scitotenv.2020.138405 PMID: 32388023
7. International Council for Science (ICSU). A guide to SDG interactions: from science to implementation. Paris: International Council for Science; 2017.
8. Fuso Nerini F, Tomei J, To LS, Bisaga I, Parikh P, Black M, et al. Mapping synergies and trade-offs between energy and the Sustainable Development Goals. Nat Energy. 2018; 3: 10–15. https://doi.org/10.1038/s41560-017-0036-5
9. Barquet K, Järnberg L, Alva IL, Weitz N. Exploring mechanisms for systemic thinking in decision-making through three country applications of SDG Synergies. Sustain Sci. 2021; 1–16. https://doi.org/10.1007/s11625-021-01045-3
10. Hegre H, Petrova K, von Uexkull N. Synergies and trade-offs in reaching the Sustainable Development Goals. Sustainability. 2020; 12: 1–24. https://doi.org/10.3390/su12208729
11. Lusseau D, Mancini F. Income-based variation in Sustainable Development Goal interaction networks. Nat Sustain. 2019; 2: 242–247. https://doi.org/10.1038/s41893-019-0231-4
12. Bali Swain R, Ranganathan S. Modeling interlinkages between sustainable development goals using network analysis. World Dev. 2021; 138: 105136. https://doi.org/10.1016/j.worlddev.2020.105136
13. Moyer JD, Bohl DK. Alternative pathways to human development: Assessing trade-offs and synergies in achieving the Sustainable Development Goals. Futures. 2019; 105: 199–210. https://doi.org/10.1016/j.futures.2018.10.007
14. Lucas PL, Hilderink HBM, Janssen PHM, KC S, van Vuuren DP, Niessen L. Future impacts of environmental factors on achieving the SDG target on child mortality—A synergistic assessment. Glob Environ Chang. 2019; 57: 101925. https://doi.org/10.1016/j.gloenvcha.2019.05.009
15. van Soest HL, van Vuuren DP, Hilaire J, Minx JC, Harmsen MJHM, Krey V, et al. Analysing interactions among Sustainable Development Goals with Integrated Assessment Models. Glob Transitions. 2019; 1: 210–225. https://doi.org/10.1016/j.glt.2019.10.004
16. Di Lucia L, Slade R, Khan J. Decision-making fitness of methods to understand SDG interactions. Nat Sustain. 2022; 5: 131–138. https://doi.org/10.1038/s41893-021-00819-y
17. IAEG U. Final list of proposed Sustainable Development Goal indicators. Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators (E/CN. 3/2016/2/Rev. 1). 2016.

Available from: https://sustainabledevelopment.un.org/content/documents/11803Official-List-of-Proposed-SDG-Indicators.pdf.

18. Sayer J, Sheil D, Galloway G, Riggs RA, Mewett G, MacDicken KG, et al. SDG 15: Life on land–The central role of forests in sustainable development. In: Katila P, Pierce Colfer C, de Jong W, Galloway G, Pacheco P, Winkel G, editors. Sustainable Development Goals: Their impacts on forests and people. Cambridge: Cambridge University Press; 2019. pp. 482–509.
19. Laurance WF, Peletier-Jellema A, Geenen B, Koster H, Verweij P, Van Dijck P, et al. Reducing the global environmental impacts of rapid infrastructure expansion. Curr Biol. 2015; 25: R259–R262. https://doi.org/10.1016/j.cub.2015.02.050 PMID: 25754645
20. Laurance WF, Goosem M, Laurance SGW. Impacts of roads and linear clearing on tropical forests. Trends Ecol Evol. 2009; 24: 659–679. https://doi.org/10.1016/j.tree.2009.06.009 PMID: 19748151
21. Gibson L, Wilman EN, Laurance WF. How green is 'green' energy? Trends Ecol Evol. 2017; 32: 922–935. https://doi.org/10.1016/j.tree.2017.09.007 PMID: 29074270
22. Laurance WF, Sayer J, Cassman KG. Agricultural expansion and its impacts on tropical nature. Trends Ecol Evol. 2014; 29: 107–116. https://doi.org/10.1016/j.tree.2013.12.001 PMID: 24388286
23. Permanyer I, Smits J. Inequality in human development across the globe. Popul Dev Rev. 2020; 46: 583–601. https://doi.org/10.1111/padr.12343
24. Smith R, Muir R, Walpole M, Balmford A, Leader-Williams N. Governance and the loss of biodiversity. Nature. 2003; 426: 67–70. https://doi.org/10.1038/nature02025 PMID: 14603318
25. Godoy R, Contreras M. A comparative study of education and tropical deforestation among lowland Bolivian Amerindians: Forest values, environmental externality, and school subsidies. Econ Dev Cult Change. 2001; 49: 555–574. https://doi.org/10.1086/452515
26. Carr JA, Petrokofsky G, Spracklen D V, Lewis SL, Roe D, Trull N, et al. Anticipated impacts of achieving SDG targets on forests—a review. For Policy Econ. 2021; 126: 102423. https://doi.org/10.1016/j.forpol.2021.102423
27. Katila P, Pierce Colfer C, De Jong W, Galloway G, Pacheco P, Winkel G, editors. Sustainable Development Goals: Their impacts on forests and people. Cambridge: Cambridge University Press; 2019.
28. Brandt JS, Buckley RC. A global systematic review of empirical evidence of ecotourism impacts on forests in biodiversity hotspots. Curr Opin Environ Sustain. 2018; 32: 112–118. https://doi.org/10.1016/j.cosust.2018.04.004
29. De Castro TCS, Castro ACL, Soares LS, Lopes Silva MH, Silva Ferreira HR, Jesus Azevedo JWJ, et al. Social and environmental impacts on rural communities residing near the industrial complex of Sao Luis Island, State of Maranhão, Brazil. J Sustain Dev. 2017; 10: 249. https://doi.org/10.5539/jsd.v10n2p249
30. Parés-Ramos IK, Gould WA, Aide TM. Agricultural abandonment, suburban growth, and forest expansion in Puerto Rico between 1991 and 2000. Ecol Soc. 2008; 13. https://doi.org/10.5751/ES-02479-130201
31. Tomaselli MF, Timko J, Kozak R, Bull J, Kearney S, Saddler J, et al. SDG 9: Industry, innovation and infrastructure–Anticipating the potential impacts on forests and forest-based livelihoods. In: Katila P, Pierce Colfer C, De Jong W, Galloway G, Pacheco P, Winkel G, editors. Sustainable Development Goals: Their impacts on forests and people. Cambridge: Cambridge University Press; 2019. pp. 279–314.
32. Geist HJ, Lambin EF. Proximate causes and underlying driving forces of tropical deforestation. Bioscience. 2002; 52: 143. https://doi.org/10.1641/0006-3568(2002)052[0143:PCAUDF]2.0.CO;2
33. Benhin JKA. Agriculture and deforestation in the tropics: A critical theoretical and empirical review. Ambio. 2006; 35: 9–16. https://doi.org/10.1579/0044-7447-35.1.9 PMID: 16615693
34. Franks P, Hou-Jones X, Fikreyesus D, Sintayehu M, Mamuye S, Danso E, et al. Reconciling forest conservation with food production in sub-Saharan Africa: Case studies from Ethiopia, Ghana and Tanzania. London: IIED; 2017.
35. Wunder S. Poverty alleviation and tropical forests—What scope for synergies? World Dev. 2001; 29: 1817–1833. https://doi.org/10.1016/S0305-750X(01)00070-5
36. Naughton-Treves L, Wendland K. Land tenure and tropical forest carbon management. World Dev. 2014; 55: 1–6. https://doi.org/10.1016/j.worlddev.2013.01.010
37. Travers H, Winney K, Clements T, Evans T, Milner-Gulland EJ. A tale of two villages: An investigation of conservation-driven land tenure reform in a Cambodian Protection Forest. Land use policy. 2015; 43: 186–196. https://doi.org/10.1016/j.landusepol.2014.11.007
38. Barkmann J, Burkard G, Faust H, Fremerey M, Koch S, Lanini A. Land tenure rights, village institutions, and rainforest conversion in Central Sulawesi (Indonesia). In: Tscharntke T, Leuschner C, Veldkamp E, Faust H, Guhardja E, Bidin A, editors. Tropical rainforests and agroforests under global

change: Ecological and socio-economic valuations. Berlin, Heidelberg: Springer Berlin Heidelberg; 2010. pp. 141–160.

39. IPRI. The International Property Rights Index [Internet]. 2020 [cited 5 Mar 2021]. Available from: https://www.internationalpropertyrightsindex.org/.
40. Ewers RM, Scharlemann JPW, Balmford A, Green RE. Do increases in agricultural yield spare land for nature? Glob Chang Biol. 2009; 15: 1716–1726. https://doi.org/10.1111/j.1365-2486.2009.01849.x
41. Kaimowitz D, Angelsen A. Economic models of tropical deforestation: a review. Bogor: CIFOR; 1998.
42. Álvarez MD. Could peace be worse than war for Colombia's forests? Environmentalist. 2001; 21: 305–315. https://doi.org/10.1023/A:1012904318418
43. Draulans D, Van Krunkelsven E. The impact of war on forest areas in the Democratic Republic of Congo. Oryx. 2002; 36: 35–40. https://doi.org/10.1017/S0030605301000011
44. McNeely JA. Biodiversity, war, and tropical forests. J Sustain For. 2003; 16: 1–20. https://doi.org/10.1300/J091v16n03_01
45. Loucks C, Mascia MB, Maxwell A, Huy K, Duong K, Chea N, et al. Wildlife decline in Cambodia, 1953–2005: Exploring the legacy of armed conflict. Conserv Lett. 2009; 2: 82–92. https://doi.org/10.1111/j.1755-263x.2008.00044.x
46. Mavanza M, Grossman AA. Conservation and family planning in Tanzania: The TACARE experience. Popul Environ. 2007; 28: 267–273. https://doi.org/10.1007/s11111-007-0043-8
47. Burns TJ, Kick EL, Murray DA, Murray DA. Demography, development and deforestation in a world-system perspective. Int J Comp Sociol. 1994; 35: 221–239. https://doi.org/10.1163/002071594X00255
48. D'Silva E, Pai S. Social capital and collective action: Development outcomes in forest protection and watershed development. Econ Polit Wkly. 2003; 38: 1404–1415.
49. Leisher C, Temsah G, Booker F, Day M, Samberg L, Prosnitz D, et al. Does the gender composition of forest and fishery management groups affect resource governance and conservation outcomes? A systematic map. Environ Evid. 2016; 5: 1–10. https://doi.org/10.1186/s13750-016-0057-8
50. Bonatti M, Del Rio M, Rodriguez T, Morales Muñoz H, Eufemia L, Löhr K, et al. Key factors for effective design and implementation of sustainable land use systems to reduce deforestation and enhance peacebuilding in Colombia. Policy Brief No. 55. Cali: Alliance of Bioversity International and CIAT; 2021.
51. Di Gregorio M, Brockhaus M, Cronin T, Muharrom E. Politics and power in national REDD+ policy processes. In: Angelsen A, Brockhaus M, Sunderlin WD, Verchot L, editors. Analysing REDD+ challenges and choices. Bogor: CIFOR; 2012. pp. 69–90.
52. Shively, Martinez E. Deforestation, irrigation, employment, and cautious optimism in southern Palawan, the Philippines. In: Angelsen A, Kaimowitz D, editors. Agricultural technologies and tropical deforestation. CAB International, Wallingford, UK; 2001.
53. Rudel TK, Coomes OT, Moran E, Achard F, Angelsen A, Xu J, et al. Forest transitions: Towards a global understanding of land use change. Glob Environ Chang. 2005; 15: 23–31. https://doi.org/10.1016/j.gloenvcha.2004.11.001
54. Bouriaud L. Causes of illegal logging in Central and Eastern Europe. Small-scale For Econ Manag Policy. 2005; 4: 269–291. https://doi.org/10.1007/s11842-005-0017-6
55. Alemagi D, Kozak RA. Illegal logging in Cameroon: Causes and the path forward. For Policy Econ. 2010; 12: 554–561. https://doi.org/10.1016/j.forpol.2010.07.008
56. Carr D. Population and deforestation: Why rural migration matters. Prog Hum Geogr. 2009; 33: 355–378. https://doi.org/10.1177/0309132508096031
57. Maystadt JF, Mueller V, Van Den Hoek J, Van Weezel S. Vegetation changes attributable to refugees in Africa coincide with agricultural deforestation. Environ Res Lett. 2020;15. https://doi.org/10.1088/1748-9326/ab6d7c PMID: 33329757
58. Erazo JS. Landscape ideologies, indigenous governance, and land use change in the Ecuadorian Amazon, 1960–1992. Hum Ecol. 2011; 39: 421–439. https://doi.org/10.1007/s10745-011-9408-9
59. Valencia-Sandoval C, Flanders DN, Kozak RA. Participatory landscape planning and sustainable community development: Methodological observations from a case study in rural Mexico. Landsc Urban Plan. 2010; 94: 63–70. https://doi.org/10.1016/j.landurbplan.2009.07.018
60. Brunner J, Seymour F, Badenoch N, Ratner B. Forest problems and law enforcement In Southeast Asia: The role of local communities. Washington, DC: World Resources Institute; 1999.
61. Downs F. Rule of law and environmental justice in the forests: The challenge of "strong law enforcement" in corrupt conditions. Bergen: Chr. Michelsen Institute; 2013.

62. Sommer JM. Corrupt actions and forest loss: A cross-national analysis. Int J Soc Sci Stud. 2018; 6: 23–34. https://doi.org/10.11114/ijsss.v6i10.3534

63. Galinato GI, Galinato SP. The short-run and long-run effects of corruption control and political stability on forest cover. Ecol Econ. 2013; 89: 153–161. https://doi.org/10.1016/j.ecolecon.2013.02.014

64. Klaver D. Multi-stakeholder design of forest governance and accountability arrangements in Equator province, Democratic Republic of Congo. Gland, Wageningen: IUCN and Wageningen University & Research Centre; 2009.

65. Hou-Jones X, Franks P, Chung J. Creating enabling conditions for managing trade-offs between food production and forest conservation in Africa: Case studies from Ethiopia and Zambia. IIED Working Paper. London: IIED; 2019.

66. Kissinger G, Herold M, De Sy V. Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers. Vancouver: Lexeme Consulting; 2012.

67. Narain D, Maron M, Teo HC, Hussey K, Lechner AM. Best-practice biodiversity safeguards for Belt and Road Initiative's financiers. Nat Sustain. 2020; 3: 650–657. https://doi.org/10.1038/s41893-020-0528-3

68. Tayleur C, Balmford A, Buchanan GM, Butchart SHM, Ducharme H, Green RE, et al. Global coverage of agricultural sustainability standards, and their role in conserving biodiversity. Conserv Lett. 2017; 10: 610–618. https://doi.org/10.1111/conl.12314

69. Wunder S. Promoting forest conservation through ecotourism income? A case study from the Ecuadorian Amazon region. CIFOR Occas Pap No 21. Bogor: CIFOR; 1999.

70. Holland MB, de Koning F, Morales M, Naughton-Treves L, Robinson BE, Suárez L. Complex tenure and deforestation: Implications for conservation incentives in the Ecuadorian Amazon. World Dev. 2014; 55: 21–36. https://doi.org/10.1016/j.worlddev.2013.01.012

71. Kaimowitz D, Angelsen A. Policy Recommendations. In: Angelsen A, Kaimowitz D, editors. Agricultural Technologies and Tropical Deforestation. Wallingford, Bogor: CABI Publishing and CIFOR; 2001. pp. 403–412.

72. Yi Y, Borzée A. Human population and efficient conservation: Are humans playing ostriches and rabbits? J Asia-Pacific Biodivers. 2021; 14: 144–145. https://doi.org/10.1016/j.japb.2020.12.008

73. Korhonen-Kurki K, Sehring J, Brockhaus M, Di Gregorio M. Enabling factors for establishing REDD+ in a context of weak governance. Clim Policy. 2014; 14: 167–186. https://doi.org/10.1080/14693062.2014.852022

74. Rands MRW, Adams WM, Bennun L, Butchart SHM, Clements A, Coomes D, et al. Biodiversity conservation: Challenges beyond 2010. Science (80-). 2010; 329: 1298–1303. https://doi.org/10.1126/science.1189138 PMID: 20829476

75. International Tropical Timber Organization (ITTO). Guidelines for forest landscape restoration in the tropics. Yokohama: ITTO; 2020.

76. Van Asselen S, Verburg PH, Vermaat JE, Janse JH. Drivers of wetland conversion: A global meta-analysis. PLoS One. 2013; 8: 1–13. https://doi.org/10.1371/journal.pone.0081292 PMID: 24282580

77. Collins C, Nuno A, Benaragama A, Broderick A, Wijesundara I, Wijetunge D, et al. Ocean-scale footprint of a highly mobile fishing fleet: Social-ecological drivers of fleet behaviour and evidence of illegal fishing. People Nat. 2021; 3: 740–755. https://doi.org/10.1002/pan3.10213

78. Aghilinejhad SM, Gorgin S, van Uhm D, Joolaie R, Ghorbani R, Paighambari SY, et al. What are the drivers of the occurrence of illegal fishing and conservation barriers of sturgeons in the Caspian Sea? Aquat Conserv Mar Freshw Ecosyst. 2018; 28: 690–701. https://doi.org/10.1002/aqc.2897

79. Anyanwu JC, Anyanwu JC. The key drivers of poverty in Sub-Saharan Africa and what can be done about it to achieve the poverty sustainable development goal. Asian J Econ Model. 2017; 5: 297–317. https://doi.org/10.18488/journal.8.2017.53.297.317

80. Warr P. The drivers of poverty reduction. In: Coxhead I, editor. Routledge Handbook of Southeast Asian Economics. Routledge; 2014. pp. 325–348.

81. Hussein J, Bell J, Iang MD, Mesko N, Amery J, Graham W. An appraisal of the maternal mortality decline in Nepal. PLoS One. 2011; 6: 1–10. https://doi.org/10.1371/journal.pone.0019898 PMID: 21637836

82. Cameron L, Suarez DC, Cornwell K. Understanding the determinants of maternal mortality: An observational study using the Indonesian Population Census. PLoS One. 2019; 14: 1–18. https://doi.org/10.1371/journal.pone.0217386 PMID: 31158243

83. Dwyer L. Globalization of tourism: Drivers and outcomes. Tour Recreat Res. 2015; 40: 326–339. https://doi.org/10.1080/02508281.2015.1075723

84. Maxim C. Drivers of success in implementing sustainable tourism policies in urban areas. Tour Plan Dev. 2015; 12: 37–47. https://doi.org/10.1080/21568316.2014.960599

85. Bogers M, Biermann F, Kalfagianni A, Kim RE, Treep J, de Vos MG. The impact of the Sustainable Development Goals on a network of 276 international organizations. Glob Environ Chang. 2022; 76: 102567. https://doi.org/10.1016/j.gloenvcha.2022.102567

86. den Herder M, Khadka C, Pelli P, Wolfslehner B, Sandker M, Lindner M, et al. Scenario development to strengthen national forest policies and programmes: a review of future-oriented tools and approaches that support policy-making. Forestry Policy and Institutions Working Paper No 34. Rome: FAO; 2014.

87. Verburg R, Filho SR, Lindoso D, Debortoli N, Litre G, Bursztyn M. The impact of commodity price and conservation policy scenarios on deforestation and agricultural land use in a frontier area within the Amazon. Land use policy. 2014; 37: 14–26. https://doi.org/10.1016/j.landusepol.2012.10.003

88. Pendrill F, Persson UM, Godar J, Kastner T. Deforestation displaced: Trade in forest-risk commodities and the prospects for a global forest transition. Environ Res Lett. 2019; 14: 055003. https://doi.org/10.1088/1748-9326/ab0d41

89. Assa BSK. Foreign direct investment, bad governance and forest resources degradation: Evidence in Sub-Saharan Africa. Econ Polit. 2018; 35: 107–125. https://doi.org/10.1007/s40888-017-0086-y

90. Dale VH, Joyce LA, McNulty S, Neilson RP. The interplay between climate change, forests, and disturbances. Sci Total Environ. 2000; 262: 201–204. https://doi.org/10.1016/s0048-9697(00)00522-2 PMID: 11087026

91. Zhao Z, Li W, Ciais P, Santoro M, Cartus O, Peng S, et al. Fire enhances forest degradation within forest edge zones in Africa. Nat Geosci. 2021; 14: 479–483. https://doi.org/10.1038/s41561-021-00763-8

92. Ehrhardt-Martinez K. Social determinants of deforestation in developing countries: A cross-national study. Soc Forces. 1998; 77: 567–586. https://doi.org/10.2307/3005539

93. Pendleton LH, Howe EL. Market integration, development, and smallholder forest clearance. Land Econ. 2002; 78: 1–19. https://doi.org/10.2307/3146919

94. Hübler M. How to curb poverty-related deforestation? Appl Econ Lett. 2017; 24: 374–380. https://doi.org/10.1080/13504851.2016.1194959

95. World Bank. The World by Income and Region [Internet]. 2021 [cited 18 Jul 2021]. Available from: https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html.

96. World Bank. World Development Indicators [Internet]. 2022 [cited 18 Jan 2022]. Available from: https://databank.worldbank.org/source/world-development-indicators.

97. World Bank. Benin Country Forest Note. Washington, DC: World Bank Group; 2020.

98. Pham TT, Hoang TL, Nguyen DT, ào Thị LC, Ngo HC, Pham VH. The context of REDD+ in Vietnam: Drivers, agents and institutions. 2nd ed. Bogor: CIFOR; 2019.

99. FCPF. The Forest Carbon Partnership Facility [Internet]. 2021 [cited 21 Jan 2022]. Available from: https://www.forestcarbonpartnership.org/.

100. Bizzo E, Michener G. Forest governance without transparency? Evaluating state efforts to reduce deforestation in the Brazilian Amazon. Environ Policy Gov. 2017; 27: 560–574. https://doi.org/10.1002/eet.1776

101. Busch J, Ferretti-Gallon K. What drives deforestation and what stops it? A meta-analysis. Rev Environ Econ Policy. 2017; 11: 3–23. https://doi.org/10.1093/reep/rew013

102. Hugo G. Migration, development and environment. IOM Migration Research Series No. 35. Geneva: International Organization for Migration; 2008.

103. United Nations Statistics Division. Global SDG Indicators Database [Internet]. 2022 [cited 1 Mar 2022]. Available from: https://unstats.un.org/sdgs/indicators/database/.

104. FAO. FAOSTAT [Internet]. 2021 [cited 13 Mar 2021]. Available from: http://www.fao.org/faostat/en/#home.

105. World Justice Project. World Justice Project [Internet]. 2021 [cited 1 Mar 2021]. Available from: https://worldjusticeproject.org/.

106. Transparency International. The Corruption Perceptions Index [Internet]. 2021 [cited 25 Apr 2021]. Available from: https://www.transparency.org/en/cpi/2019/index/nzl.

107. Zeng Y, Maxwell S, Runting RK, Venter O, Watson JEM, Carrasco LR. Environmental destruction not avoided with the Sustainable Development Goals. Nat Sustain. 2020; 3: 795–798. https://doi.org/10.1038/s41893-020-0555-0

108. Sustainable Development Knowledge Platform. Voluntary National Reviews [Internet]. 2021 [cited 1 Mar 2021]. Available from: https://sustainabledevelopment.un.org/vnrs/.

109. R Core Team. R: A language and environment for statistical computing [Internet]. Vienna, Austria: R Foundation for Statistical Computing; 2022. Available from: https://www.r-project.org/.

110. Natural Earth. Natural Earth: Free vector and raster map data at 1:10m, 1:50m, and 1:110m scales [Internet]. 2022 [cited 2 Aug 2022]. Available from: https://www.naturalearthdata.com/.

111. Hansen MC, Potapov P V, Moore R, Hancher M, Turubanova SA, Tyukavina A. High-resolution global maps of forest cover change. Science (80-). 2013; 342: 850–853. https://doi.org/10.1126/science.1244693 PMID: 24233722