Resource extraction and infrastructure threaten forest cover and community rights

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Mineral and hydrocarbon extraction and infrastructure are increasingly significant drivers of forest loss, greenhouse gas emissions, and threats to the rights of forest communities in forested areas of Amazonia, Indonesia, and Mesoamerica. Projected investments in these sectors suggest that future threats to forests and rights are substantial, particularly because resource extraction and infrastructure reinforce each other and enable population movements and agricultural expansion further into the forest. In each region, governments have made framework policy commitments to national and cross-border infrastructure integration, increased energy production, and growth strategies based on further exploitation of natural resources. This reflects political settlements among national elites that endorse resource extraction as a pathway toward development. Regulations that protect forests, indigenous and rural peoples' lands, and conservation areas are being rolled back or are under threat. Small-scale gold mining has intensified in specific locations and also has become a driver of deforestation and degradation. Forest dwellers' perceptions of insecurity have increased, as have documented homicides of environmental activists. To explain the relationships among extraction, infrastructure, and forests, this paper combines a geospatial analysis of forest loss overlapped with areas of potential resource extraction, interviews with key informants, and feedback from stakeholder workshops. The increasing significance of resource extraction and associated infrastructure as drivers of forest loss and rights violations merits greater attention in the empirical analyses and conceptual frameworks of Sustainability Science.

extractive industry | infrastructure | deforestation | rights | climate

The expansion of large- and small-scale agriculture has been identified as a primary driver of forest loss and degradation and related global greenhouse gas (GHG) emissions (1). In contrast, the impacts of extractive industry and infrastructure expansion, and especially the links between the two, have received less explicit treatment. The relationships between the protection or violation of human rights and the associated conservation or conversion of forests in the context of such economic projects have also received little analytical attention, particularly in Sustainability Science. This paper presents evidence on the current and projected significance of extractive industry and associated infrastructure investment to argue that Sustainability and Land System Science should be more explicit in addressing the relationships among resource extraction, rights, and land use in empirical and conceptual analyses of forest loss and emissions.

Investment in the global mining and hydrocarbon sectors (hereafter referred to as "resource extraction") continues to be significant (2). The world's remaining areas of extensive humid and semiarid forest are sites of significant known and potential mineral, oil, coal, and natural gas reserves. These forest areas are also set to receive significant investment in infrastructure designed to support resource extraction and the large-scale cultivation of oil palm, soybeans, sugar cane, and other crops (3–5). In 2014, the G20 (Group of 20: an international forum for the governments and central bank governors from Argentina, Australia, Brazil, Canada, China, the European Union, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, the United Kingdom, and the United States) committed to invest up to an additional $90 trillion in global infrastructure by 2030 and in 2016 committed to link infrastructure master plans across world regions (6). In Kalimantan and Sumatra (Indonesia), the volume of foreign direct investment directed toward infrastructure development and extractive industry is five times greater than international funding for forest conservation through mechanisms such as REDD+ (efforts to reduce emissions from deforestation and forest degradation) in

Significance

While infrastructure expansion has been broadly investigated as a driver of deforestation, the impacts of extractive industry and its interactions with infrastructure investment on forest cover are less well studied. These challenges are urgent given growing pressure for infrastructure investment and resource extraction. We use geospatial and qualitative data from Amazonia, Indonesia, and Mesoamerica to explain how infrastructure and extractive industry lead directly and indirectly to deforestation, forest degradation, and increasingly precarious rights for forest peoples. By engaging in explicit analyses of community rights, the politics of development policy, and institutions for transparency, anticorruption, and the defense of human rights, Sustainability Science could be more effective in examining deforestation and related climate-change impacts and in contributing to policy innovation.

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the very same regions. This scenario suggests that threats to forest cover from resource extraction and infrastructure will increase and that there is an urgent need to revise legislation, policy, and institutions ahead of this coming avalanche of investments. These forests are often areas of long-term occupation and use by indigenous and traditional peoples. Frequently, these are contested landscapes even before the incursion of new investment in infrastructure and resource extraction. Such investment exacerbates existing conflicts and creates new ones (7, 8), reflected in the most extreme cases by the killings of environmental defenders. Globally, 200 such killings were reported in 2016, and 207 were reported in 2017, the majority linked to contestations over mining, logging, hydropower, agro-industrial, and infrastructure projects (9–11).

Important parts of the world's remaining humid tropical forest are concentrated in Amazonia, Indonesia (Sumatra, Kalimantan, and Papua), and Mesoamerica [Central America and Southern Mexico (12)]. Here we ask what is the impact of investment in resource extraction and infrastructure on forest loss and on rights violations of forest-dependent populations in these regions; what are possible future impacts of such investments; and what are the factors driving these future impacts? We focus on transportation and power-generation infrastructure and on minerals mining and hydrocarbons development. We hypothesize that there is frequently a link between the shape and direction of infrastructure development and resource extraction priorities, especially given the transportation and energy demands of resource extraction. We also hypothesize that levels of protection of human and community rights related to expanding infrastructure and extraction provide an important indicator of possible deforestation trends in the future. We consider the role of national political settlements (agreements among national elites regarding the distribution of opportunities and power in society) and resulting development-policy agreements in driving patterns of investment and rights protection. We do not address the important macroeconomic effects of oil and mineral dependence on deforestation rates (13).

The contested nature of forests and the violation of rights in forest landscapes challenge Land System Science and other traditions within Sustainability Science to offer analyses of land-cover change that (*i*) build models of land change in which rights understood broadly (i.e., not only as tenure rights but also as citizenship and human rights) occupy an analytically central position and (*ii*) find ways of addressing the relationships between forest loss, community rights, and drivers of land-cover change in ways that facilitate a rigorous public discussion of diverse pathways toward human and environmental flourishing in forest-rich regions. Addressing the first challenge will allow analyses that contribute to rights-based pathways to sustainability; addressing the second opens channels from science to policy that pass through the public sphere and relationships of democratic accountability. Contextual factors also make this an opportune moment to engage in such work. These include donor discussions of sustainable infrastructure aligned with the delivery of sustainable development goals and climate-change mitigation (14); civil society activism around national climate-change commitments; national efforts to secure Organization for Economic Cooperation and Development membership; high-level discussions of the need for comprehensive approaches to business and development, especially related to extractive industry; and the fallout of international corruption scandals that pressure business and government to enhance transparency in the contracting of infrastructure and extractive industry investments.

Resource Extraction, Infrastructure, Forests, and Emissions

Our analysis draws on much previous work establishing the relationship between changes in land use and land cover and GHG emissions (15). By examining the relationship between infrastructure, resource extraction, and forest loss, we may also draw conclusions about the pathways through which these sectors drive climate change and about the institutional and sociopolitical interactions that underpin these relationships (Fig. 1).

Infrastructure's contributions to emissions are better studied than the contributions of resource extraction (5, 16–20). The greatest impacts are indirect, and much of the forest loss and land-cover change that sustainability scientists document as resulting from agricultural expansion and in-migration are facilitated by the construction of roads, railways, port facilities, and waterways (1, 3, 21–23). Although dams are often invoked as important elements for reducing reliance on fossil fuel-based energy (16), the infrastructure expansion required to build dams, in addition to the release of methane from submerged vegetation, may result in a net contribution to emissions in tropical zones (18, 24). Furthermore, infrastructure relies on cement, the third largest single source of anthropogenic GHG emissions (25).

While some mineral extraction will be key for the deployment of new energy technologies for low-carbon futures (26–28), resource extraction also contributes to increases in emissions. Mining and hydrocarbons operations emit GHGs directly, including through heavy machinery use, flaring of associated gases, and dependence on increasingly energy-intensive technologies to enable the development of deeper and more remote seams. Ocean shipping of extractives releases GHGs and other toxic air pollutants. The end use of many of the products of these sectors, especially hydrocarbons, accounts for substantial shares of GHG emissions globally. By comparison, the direct contribution of resource extraction to GHG emissions through impacts on land-cover change and forest loss is relatively modest; however, the indirect impacts are more extensive, as indicated by our regional case studies (*SI Appendix*). The effects on forest degradation and loss reach well beyond the mine site. The mine and associated infrastructure encourage in-migration, new human settlements, and other economic activities that involve forest clearing (29, 30). In cases where coal deposits are mined from beneath dense, humid forest (as in Kalimantan and Sumatra), the contribution of this coal to increased emissions comes both from its burning and from the clearance of forest and consequent loss of a carbon sink.

Infrastructure and natural resource extraction are often linked synergistically. The possibility of resource extraction can strengthen the financial case for investment in access and energy infrastructure, while the presence of such infrastructure renders investment in resource extraction more viable (31). Mega-projects of resource extraction in remote forest locations, such as the S11D iron ore project in the Brazilian Amazon, the IndoMet Coal Project in Kalimantan, or the Cobre-Panama copper mine in Panama, also include investment in large-scale access and energy infrastructure. These synergies drive legal and institutional reforms that change how forests are governed and have led to reductions in protected-area status, weakened the protection of indigenous and traditional peoples' territories, diluted environmental assessment procedures, and increased deforestation rates (32, 33).

As infrastructure and the resource extraction and agricultural investment enabled by new infrastructure make new claims on forests, they enter into direct competition with prior land uses, including forest conservation and territorial claims. The relative pressure of these different activities on forest cover depends on underlying drivers: economic conditions affecting the relative returns to each form of land use; policy drivers favoring one land user over another; and political relationships determining the power of different land users and stakeholders to influence policy drivers (34, 35). Land speculation processes that typically follow or even anticipate the announcement of possible large-scale investments in infrastructure or resource extraction also contribute to forest clearance and rights violations (19, 36).

How much forest is cleared depends on the sets of rights and rights holders that control the use of forest lands. Rights claims over forests are disputed through different mechanisms: policy

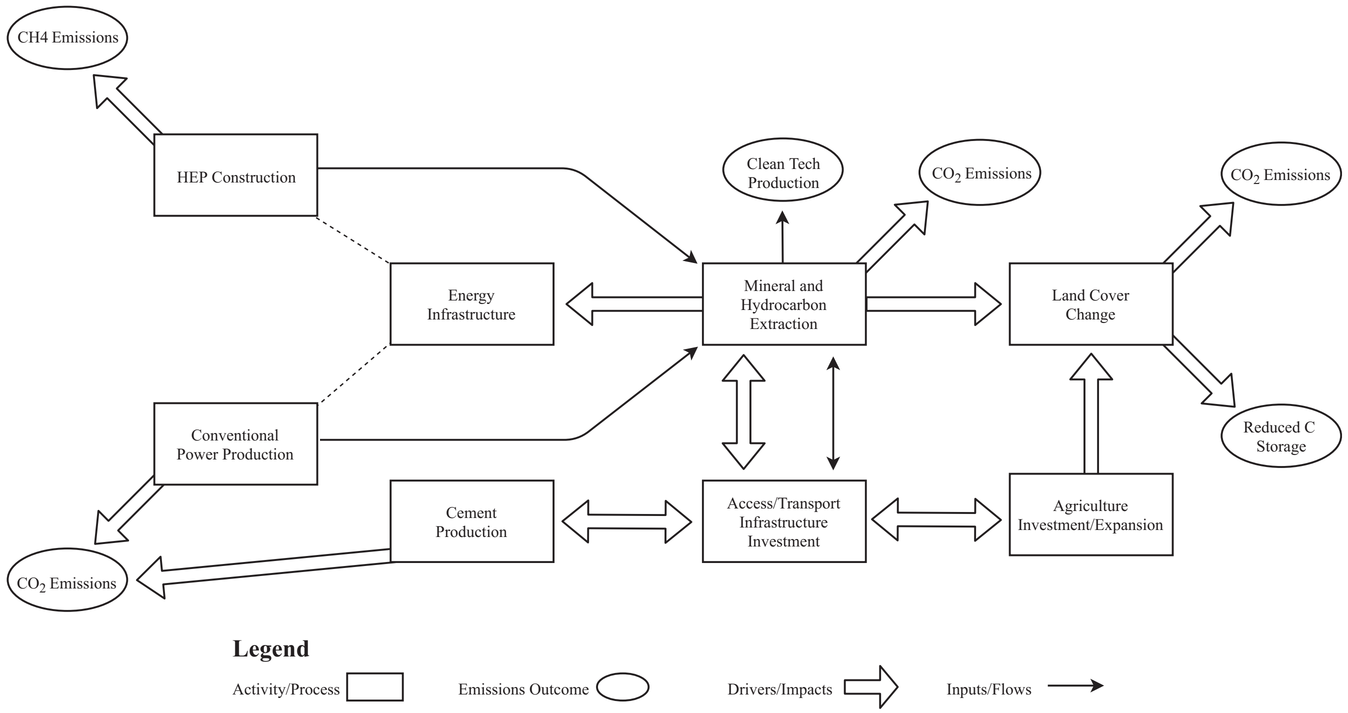

Fig. 1. The relationships among extraction, infrastructure, and emissions.

efforts to redefine rights in favor of a particular type of land user; the use of legal and litigation procedures to contest policy and protect rights through the courts; and efforts to frame public and policy debate in favor of specific rights and rights holders. Research shows that direct, titled control of resources by indigenous peoples and communities can reduce deforestation and carbon emissions, as can the existence of protected areas (37, 38). In addition to being an inherent good in itself, protection of the human, citizenship, and resource-tenure rights of these peoples is therefore a critical instrument for sustaining

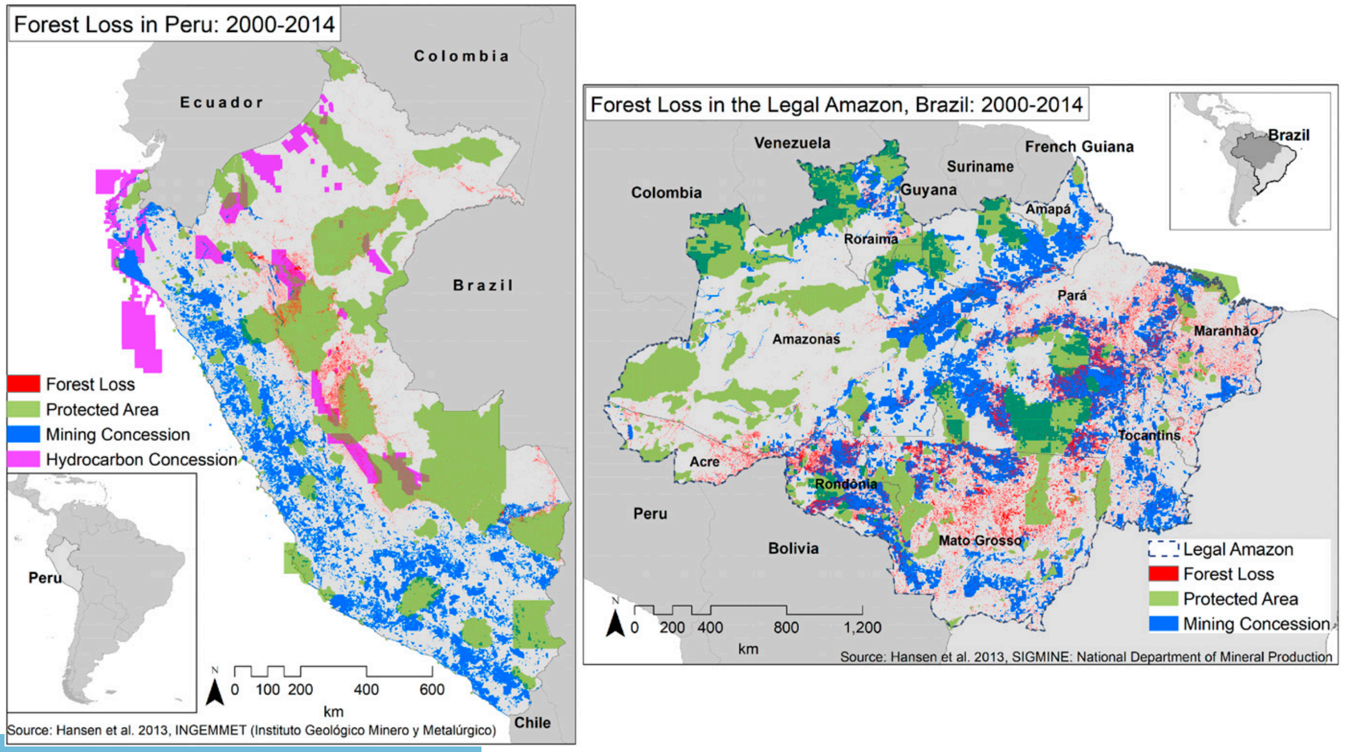

Fig. 2. Deforestation, extraction, and land use in Brazil (*Right*) and Peru (*Left*).

forests (20, 37, 39–42). However, the existing legal frameworks for human rights and forest protection have consistently proven insufficient to counter the sometimes violent claims to land and resources, especially those made by more powerful actors in concert with some elements within national and local governments (9, 10, 43).

Results

Spatial Patterns of Forest Loss and Resource Extraction by Region.

Amazon. To date there is no direct relationship between resource-extraction activity and forest loss in the Amazon basin (Fig. 2), with the following principal exceptions. In Brazil, the “arc of deforestation” extending from Pará across Mato Grosso and Rondônia is characterized by the presence of exploration concessions and operating mines in Eastern Pará and in Rondônia. Another 1.5 million ha of forest in Pará and Maranhão, including in quilombola and indigenous communities, have been lost due to charcoal making in support of the iron complex at Gran Carajás (44). The curvilinear area of deforestation in Southeastern Peru is the consequence of extensive artisanal and small-scale gold mining (ASGM) in Madre de Dios (45).

Currently 327 oil or gas blocks are available for bidding or are under exploration in the Amazon Basin (covering some 108 million ha). Mining concessions cover a further 160 million ha, ∼21% of the basin’s total area (46). Most protected areas and indigenous territories are threatened by hydro-power/waterway development, mining, oil and gas, and road investment. Overlaps of mining and other resource extraction rights with protected areas represent a real future risk either from degazettement of protected areas or simply from increased local pressure on forest cover (47, 48). In Brazil, applications for and approvals of mining concessions have moved steadily west- and northwards, and the state of Amazonas, the principal remaining area of primary forest in the Brazilian Amazon, is now ringed on three sides by mining concessions or requests for concessions. Infrastructure plans show a similar extension further into the currently forested areas of the basin (Fig. 3).

Indonesia. Between the years 2000 and 2014 in Sumatra, 71.8% of deforestation occurred within oil palm, logging, mining, tree plantation, or other industrial natural resource concessions (49, 50). Only 2% of this forest loss occurred within coal-mining concessions (Fig. 4), although the rates of deforestation within coal concessions are similar to those within other types of concession and the rates increase substantially when coal concessions overlap with other concessions (50). Much forest targeted for investment is inhabited by and claimed by indigenous and local communities (51).

Active coal mining affects 1.74 million ha of forest land according to the Indonesian nongovernmental organization Auriga, and future permits threaten 8.6 million ha, around 9% of Indonesia’s remaining total forest cover (52). Over 1.1 million ha of designated “conservation” and “protection” forest is currently allocated to coal-mining permits. Approximately 3.9 million ha of all coal-mining permits are located in Papuan forests (*SI Appendix*, Fig. S2). Some 3.45 million ha of Kalimantan’s forests are designated as coal-mining concessions. Over 45% of East and South Kalimantan has been allocated for mining, mostly for coal, and between 2009 and 2011 one-quarter of all deforestation in Kalimantan was due to the clearance of forest within coal-mining concessions (53). ASGM is also a growing threat to Indonesia’s forests, with approximately one million ASGM miners across the archipelago (54, 55), with particular concentrations in conservation areas. The strategic environmental assessment of Indonesia’s 2011–2025 development strategy, based on infrastructure and natural-resource extraction concluded that the strategy could put US$490 billion of natural capital at risk annually, although actual impacts were deemed likely to be lower (56).

Mesoamerica. Across Honduras, Guatemala, and El Salvador, only 0.96% of forest loss between 2001 and 2014 occurred in concessions with operating mines. Conversely, the Cobre Panama concession

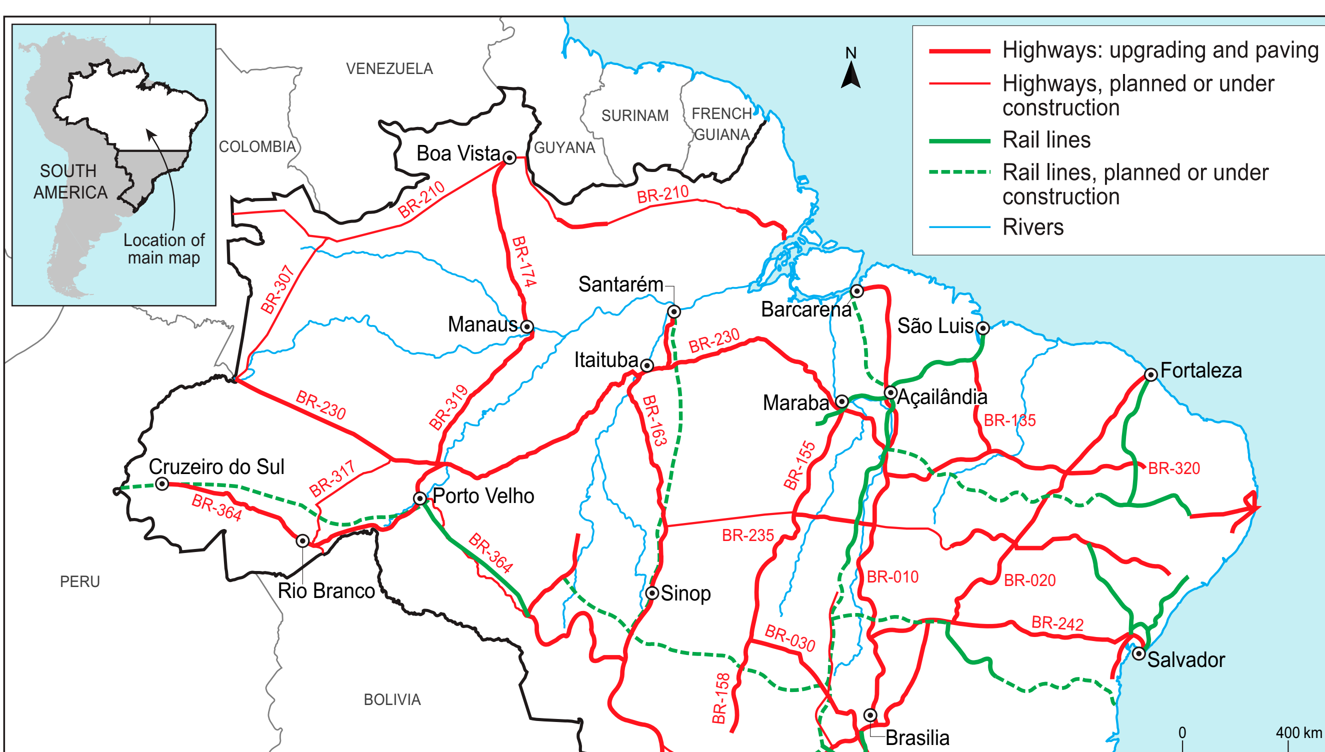

Fig. 3. Planned infrastructure expansion in the Brazilian Amazon.

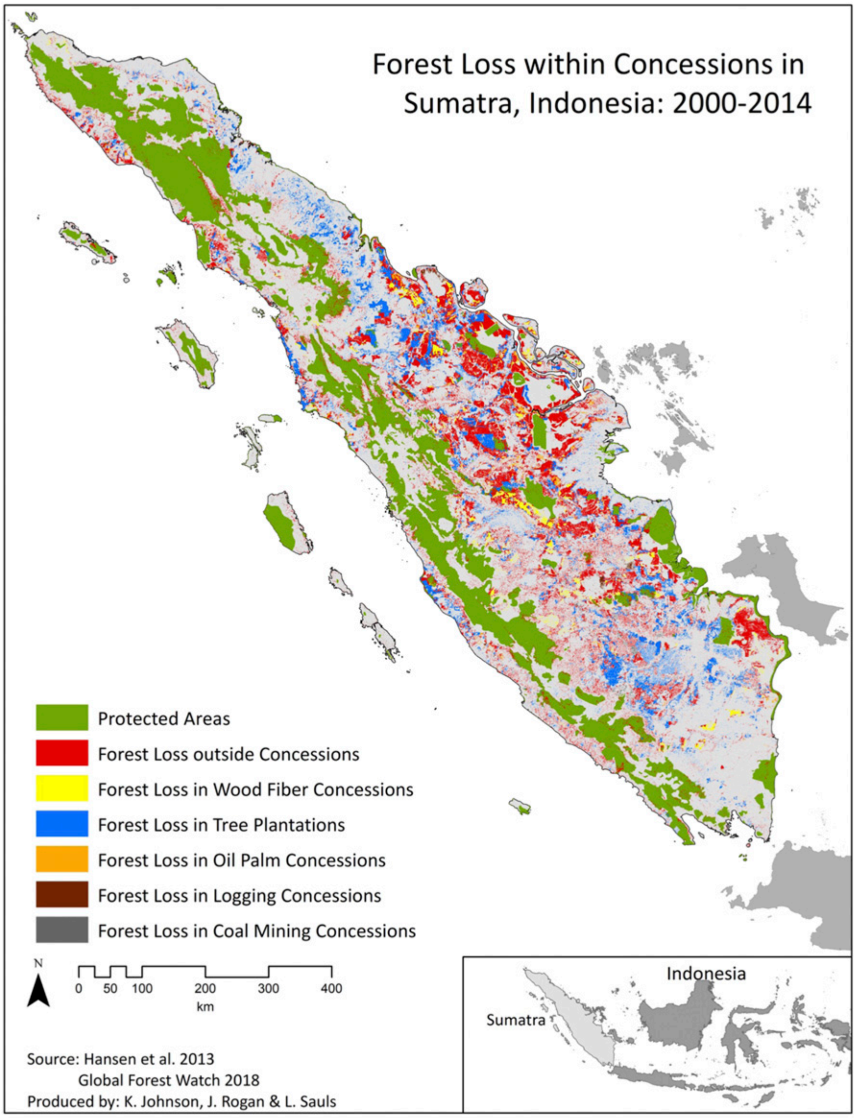

Fig. 4. Deforestation, extraction, and land use in Sumatra, Indonesia.

affects 13,600 ha of mostly dense rainforest (57). The mine and associated infrastructure will increase Panama's national GHG emissions by 8% (58). Infrastructure–resource extraction interactions have driven forest loss in the Petén, Guatemala, where road expansion, some directly related to oil extraction, has correlated directly with forest clearing since the 1980s (59, 60). Local leaders attribute forest loss to the rapid and uncontrolled settlement made possible by these roads. Hydropower projects affect forested areas and exacerbate tensions over environmental degradation and land rights, as demonstrated by the violence and murder surrounding the Aguas Zarcas hydroelectric conflict in Honduras in 2016.

Substantial areas of Guatemala, Honduras, Mexico, Nicaragua, and Panama are affected by mineral and hydrocarbon concessions (Fig. 5 and *SI Appendix*, Fig. S3), and governments have passed legislation promoting resource extraction. Mining concessions and mining reserves in Nicaragua covered 10.5% of the national territory by 2015, with substantial overlaps with protected area forests near the border with Honduras, including in the Bosawas Biosphere Reserve (61). A proposed natural gas pipeline connecting US and Mexican gas supplies with Guatemala, Honduras, and El Salvador would cross communal lands and areas already concessioned for mining in the western portion of Guatemala, suggesting future synergies among infrastructure, resource extraction, and forest loss (62).

Converging Patterns of Resource Extraction and Forest Loss. In the period 2000–2014, the aggregate direct effects of mining and oil and gas extraction on forest cover and quality were limited: Overall, there is no clear spatial relationship between forest loss and resource extraction. There are, however, important subnational exceptions to this pattern in the results noted above. Particularly significant cases have included coal mining in Sumatra and Kalimantan (49), iron ore mining and charcoal and pig iron production in Brazil (30), and ASGM in Madre de Dios, Peru (45, 63), along rivers in the Brazilian and Colombian Amazon (64, 65), across Kalimantan (66), and in Nicaragua (67).

The indirect impact of resource extraction on forest loss exceeds the direct impact because of the interaction between resource extraction and infrastructure investment, which leads to increased forest loss and extensive forest degradation. Access infrastructure built for resource extraction increases the footprint of that extraction, enables in-migration of agricultural colonists, and signals that the government intends for those areas to be developed and settled. The Petén of Guatemala is a clear

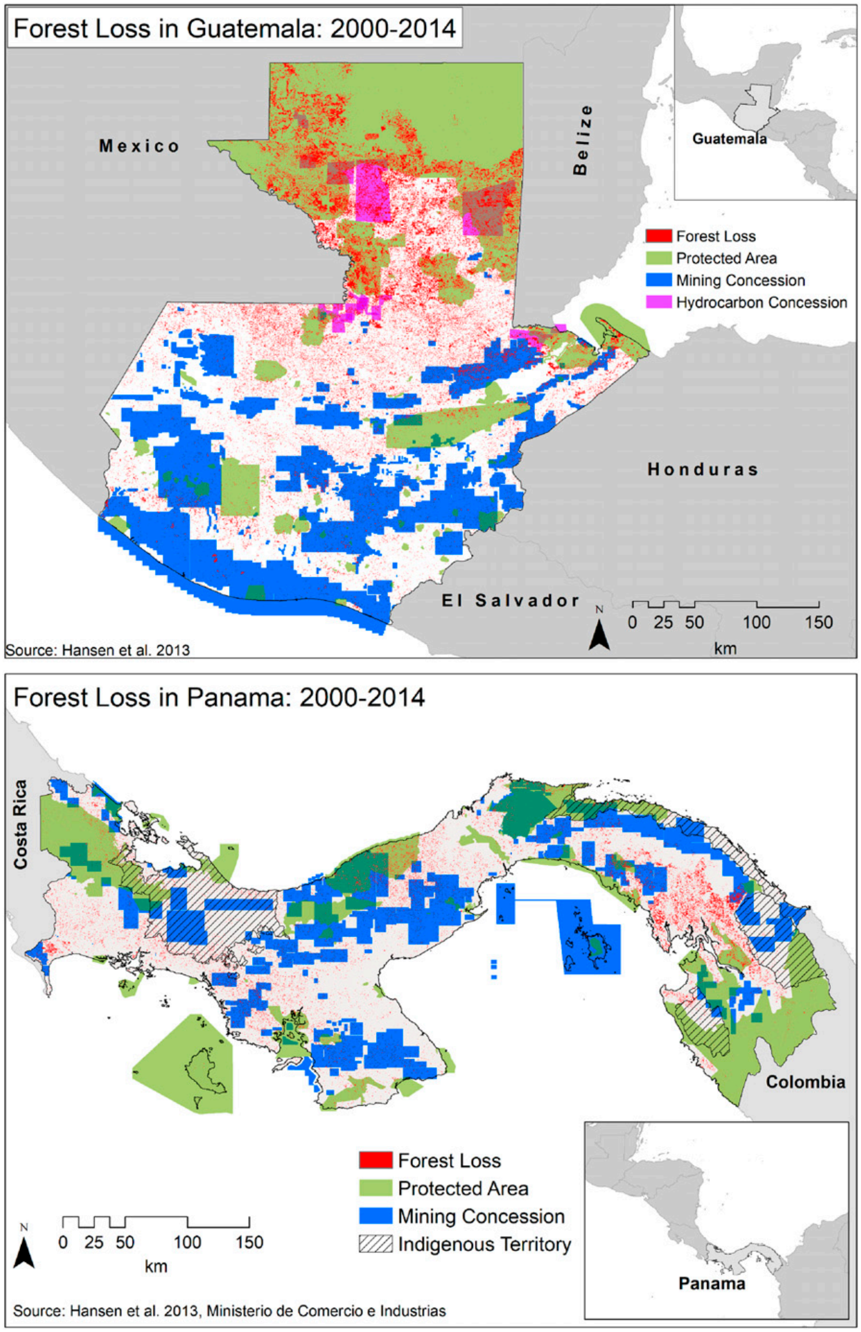

Fig. 5. Deforestation, extraction, and protected areas in Guatemala and Panama.

historical example of this relationship. The expansion of ASGM in Madre de Dios accelerated with the construction of the Southern Interoceanic Highway linking Brazil and Peru. Such cases are relevant for the assessment of future pressures on forest cover. While mining concessions in the northern edge of the Brazilian state of Amazonas are currently not viable, planned extension of waterways (Fig. 3 and *SI Appendix*) as part of multimodal transport systems will reduce bulk transport costs and increase pressure on Brazil's largest areas of intact forest. The designation of a "mining arc" covering 12% of national territory on the Venezuelan side of the border and placed under military control with the suspension of constitutional rights, may also reduce barriers to mineral development in the region. In Kalimantan, the enormous IndoMet coal concession will become viable if a planned rail link running through intact forest to a coastal port is realized.

Such past and projected interactions between infrastructure and expanded resource extraction speak to the impact of infrastructure on forest loss. Access and energy infrastructure have consistently enabled the expansion of the large- and small-scale agricultural frontier in forest areas. Agricultural conversion is the proximate driver of forest loss (21, 68), while infrastructure investment becomes "the driver of drivers" of forest loss. The synergy between access infrastructure and agro-industrial expansion is also reflected in the lobbying activities of agricultural investors. In Brazil, large-scale soybean farmers lobby directly for the government to facilitate investment in waterways, rail, and roads, and their representatives have become state governors, members of Parliament, and the Minister of Agriculture, positions from which they have continued to promote infrastructure investment (69). The *Lava Jato* (Car Wash) scandal, which began in Brazil but has led to legal proceedings against senior politicians and businesses across much of Latin America, has exposed the pathways through which extraction and infrastructure offer extensive opportunities for corruption and illegal behavior involving significant private capture of resource rents. While the crisis has led to intensified demands for transparency in public–private interactions, its adverse effect on investment induces further pressure to weaken forest protections to facilitate additional extraction and infrastructure projects to fill these gaps in public investment. This can also offer further opportunities for corruption.

Converging Drivers. Across Amazonia, Mesoamerica, and Indonesia, similar policy drivers promote investments that will impact forest cover and emissions. Interviews and workshops (*SI Appendix*) identified the following drivers as important: commitments to regional integration of energy systems and energy security; a policy of economic growth based on the exploitation and export of natural resources; commitments to large-scale regional integration through infrastructure; policy, legal, and regulatory reforms to facilitate investment in previously protected areas, particularly in indigenous peoples' lands and conservation areas; and national elites committed to these models of growth. While such policies are not new, their implications for forests have become more serious: These drivers have already driven forest loss in earlier decades, so the remaining forest that they now threaten is substantially reduced in extent; the intensity and ambition of such policies has increased as countries seek to reach developed-country status; and in an attempt to grow out of economic crisis, Brazil has promoted further natural resource extraction in the Amazon. Globally, forest areas are being connected to new commodity markets, particularly in Asia, in addition to existing connections to markets in the Western Hemisphere.

Growth based on natural resources. Pressure on forest cover in these regions is driven by growth policies based on the use, transformation, and extraction of natural resources. Indonesia's framework national development plan, the MP3EI issued in 2011, identified six "economic corridors" spread across the archipelago. In five of these corridors, growth and investment strategies were oriented to focus on natural-resource industries and infrastructure. In Brazil, the three phases of the government's Growth Acceleration Program (PAC), launched in 2007 and running to 2018, emphasized the construction of highways, waterways, and hydroelectric power plants, with most of these in the Legal Amazon. In Mesoamerica, the Honduran government's strategic plan for 2014–2018 identifies hydroelectric energy as an investment priority and calls for a plan to promote investment in mining and petroleum exploration (70), while by 2016 gold had become one of Nicaragua's top three exports, with production concentrated along the edges of the forested Muskitia and with concessions overlapping protected forests (61).

Infrastructure and regional integration. Each region has an explicit plan for regional integration based on coordinated infrastructure investment. The Amazon region lies at the heart of the former Initiative for the Integration of Regional Infrastructure of South America (IIRSA), subsequently called "COSIPLAN" (South American Council for Infrastructure and Planning). IIRSA/COSIPLAN is a vision of multimodal transport systems integrating the continent and organized around 10 axes, four of which run across the Amazon basin. Waterways, rail lines, and roads make up 72% of Brazil's US$20 trillion Agenda for Priority Integration Projects. The MP3EI in Indonesia, now renamed but substantially similar under a new government, envisages roads, railways, and bridges integrating the islands of the archipelago. In Mesoamerica, the Mesoamerican Integration and Development Project (MIDP, formerly Plan Puebla-Panama) anticipates road- and energy-based integration of the isthmus, although in this case much of the planned investment has a more urban focus. In each region, planned infrastructure has synergistic relationships with expansion of the agricultural and resource-extraction frontiers. The role of infrastructure investment as a driver of forest-based emissions cannot be separated from its implications for the expansion of agriculture and resource extraction.

Regulatory and legal reform. Efforts to create institutional environments that favor investment in resource extraction and infrastructure characterize each region and have intensified in recent years (71, 72). After decades of efforts to establish social and environmental protections, those protections are now viewed as excessive obstructions to project approval. This effort to create rules that favor investment is an attempt to increase competitiveness and the ease of doing business and thus offset the effects of slowing rates of growth and falling commodity prices. It is also a response to private-sector lobbying both for investment incentives and for the weakening or elimination of sustainability safeguards. One set of reforms in Brazil eases resource extraction and infrastructure investment in previously restricted areas. In 2016 there were ∼140 proposals for legislative change in the Brazilian Congress that would affect indigenous and other groups' resource and territorial rights, including laws allowing mining investment inside these territories. Other reforms include constitutional and legal changes allowing private investment in Mexico's hydrocarbon sector; Indonesian efforts to seek to improve the country's ease of doing business index and facilitate public–private partnerships; and Nicaraguan legal reforms to ease the expropriation of land for large-scale investments in priority infrastructure.

Energy integration. Commitments to energy security through enhancing energy production and making possible its transmission across large distances, with consequences for forest cover, are apparent in all three regions. In Brazil, commitments to increase the domestic energy supply motivate plans for broad-based expansion of hydroelectricity production across the Amazon basin, although the future of these plans is now in some doubt (73). In Indonesia, the goal of increasing domestic electricity provision by 35 GW before 2019, in addition to 8 GW of on-going projects (74), includes substantial commitments to thermal power, and 38 GW of new coal plant capacity are either under construction or in the pipeline between now and 2025 (although some are delayed). This drives the demand for coal produced in Kalimantan and Sumatra, complementing export demands. In Mesoamerica, the possibility of a continuous link between the US and South American energy grids, coupled with plans for gas pipelines and hydropower, drive pressure on primary forest cover in the Darién Peninsula linking Panama and Colombia (75, 76).

Political settlements. Commitments to the above policy drivers have been relatively constant across governments of different persuasions. This suggests that behind these drivers are stable political settlements that transcend particular administrations (77, 78). While such settlements are hard to identify other than through their effects, the recently exposed network of corruption in Brazil and beyond has revealed how elites made agreements regarding the systematic, illegal distribution of benefits that were made possible by the sustained promotion of infrastructure investment and hydrocarbon extraction throughout Latin America (79). In Indonesia, the commitment to significant expansion of coal-based energy likewise transcends periods of government and reflects an agreement among economic and political elites to support increased coal mining in forested areas by investing in thermal electricity-generating plants (80, 81).

Conclusion and Implications for Sustainability Science

What happens to the forests of Amazonia, Indonesia, and Mesoamerica over the next two decades will depend on which claims over these forests prevail in these contests about land use.

Forests cannot simultaneously serve as a frontier for further expansion of natural resource-based macroeconomic development, a global carbon sink, a source of livelihood and meaning for forest-dependent communities, and the refuge of increasingly threatened biodiversity. Among these different claims on forests, those from mining, hydrocarbon, and infrastructure-facilitated agro-industrial expansion appear likely to expand further into remaining forest stands if current drivers persist. This expansion reflects expressed policy commitments by national governments of different ideological persuasions, the asymmetric relations of power that influence policy definition, and sustained international demand for minerals, hydrocarbons, energy, palm oil, soybeans, and beef.

Contentions over land use and the extent to which the rights of forest defenders are protected are an integral part of determining which forms of land use prevail. Models that assess the influence of protected areas, indigenous territories, land-use consultations, and other institutions on land-cover change all make an implicit assumption that there are human agents who are capable of and are supported in implementing such institutions. If these human agents are subject to violence, intimidation, and murder, then such institutions will neither emerge nor persist and so will fail to affect land-cover change. The implication is that models of land-cover change and forest loss must incorporate questions of rights protection, impunity, and the rule of law alongside analysis of patterns of resource extraction and infrastructure.

This context presents a challenge to Sustainability Science. As the discipline has grown, tropical forest loss and resurgence have been among its primary concerns. However, this rich body of work on deforestation and the associated policy recommendations focus far more on agriculture and forestry than on resource extraction or associated large-scale infrastructure (82). There is even less analysis of the types of social and political relationships that have been created by these large-scale investments and which become self-perpetuating through lobbying and the reentrenchment of power relations. To the extent that Sustainability Science is a discipline explicitly committed to outcomes that promote human and environmental flourishing, violations of such rights should feature more explicitly in its analyses of forests for normative reasons. These themes should also receive greater attention for analytical reasons. They are integral parts of the explanation of forest dynamics.

At the same time, Sustainability Science is grounded in core principles: that securing sustainability requires bridging among knowledge systems; that science should influence policy promoting sustainability; and that this requires that science be salient, credible, and legitimate to the range of stakeholders who influence policy formation (83). In the relationships among resource extraction, infrastructure investment, and community rights in forested lands, these stakeholders have distinct and often opposed interests as well as unequal power to pursue those interests. In such a context, Sustainability Science may be able to secure credibility (by pursuing methods that different stakeholders can agree are defensible) and legitimacy (by maintaining independence and at the same time being transparent to each stakeholder). However, achieving salience with all stakeholders is more difficult, given that these stakeholders often have divergent views regarding the future use and governance of forests. The challenge is to conduct research oriented toward the protection of forest cover and community rights without being cast as either anti- or prodevelopment. Future sustainability will require roads, minerals, and energy, but it will also require extensive primary forests and biodiversity and, by definition, requires a flourishing of human rights.

Asymmetries of power among stakeholders drive forest loss and systematically disadvantage those users whose impact on forests is much lighter. This challenges Sustainability Science and its component parts such as Land Change Science (*i*) to analyze and understand the causal relations through which such asymmetries have these effects and lead to policy that favors forest loss, and (*ii*) to generate knowledge in ways that offset asymmetries. This implies conducting research in ways that contribute to (*i*) change in the terms of public debate about forests and forest communities, and (*ii*) the capacities and credibility of those institutions that defend the rights of forest users.

In the regions discussed in this paper, this finding suggests the value of collaboration with nontraditional partners [e.g., the Public Ministry and the National Indian Foundation (FUNAI) in Brazil, the Corruption Eradication Commission (KPK) in Indonesia, human rights defenders' offices in Mesoamerica, legal defense and indigenous rights organizations in civil society, and constitutional courts in all regions] in efforts to combat climate change. Sustainability transitions in these regions have as much need of institutions and resources to protect forest defenders and the professionals and organizations supporting them as they do of expert commissions to measure and model emissions releases. Collaborations with civil society research observatories that monitor interactions between resource extraction and infrastructure investment flows, forest governance, forest cover and tenure, and human rights are also important and can build on the work of existing research centers in each region, some of whose work is cited here. Such observatories can also identify and publicize financially unviable or pork-barrel projects. Research collaborations can build mutual capacities, share data, enhance visibility, and, where needed, provide backing in the face of political pushback. Concerted efforts to examine successful responses to address pressures on forests would offer the possibility for rigorous lesson-learning and broader policy and conceptual relevance. In the Amazon alone, examples of such responses include grassroots organizing and litigation in Sao Luis do Tapajos, indigenous and environmentalist organizations' prevention of hydroelectric projects proposed under the Peru-Brazil Energy Agreement, and conservation-based initiatives such as the Amazon Region Protected Areas Program and REDD Indígena.

The protection of forests and forest peoples' rights also requires new and different approaches to development (84) that prioritize these objectives while accommodating some resource-extraction and agroindustry priorities. Elements of such a model will include rigorous land-use zoning setting aside forest areas and forest-dependent community territory; energy-security strategies not based on removing coal from forest areas and involving reduced dam building and fossil fuel extraction; community-based forest management drawing on well-documented experiences, especially across Latin America (45, 85, 86); financial instruments for the reduction of forest conversion; commodity-chain regulation to promote responsible production (87, 88) coupled with the reassertion of social and environmental safeguards on investment; and a substantial community and human rights agenda. Land use futures in forest areas depend on whose land rights are enforced, and which land-rights defenders and proponents prevail. This in turn requires particular ways of conducting Sustainability Science that enable such an agenda while retaining legitimacy and credibility with large-scale resource extraction, infrastructure, and agroindustry investors as well as helping imagine futures in which no more forest is lost, violence against forest defenders ceases, and large-scale investment can secure at least some of its objectives. In this vision, Sustainability Science becomes a process of knowledge generation and constituency building as well as a powerful tool for reducing the historic inequalities of access and power that are a significant underlying driver for forest loss.

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