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Towards sustainable and just forest recovery: research gaps and potentials for knowledge integration

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eTOC

High hopes are placed on forest recovery for mitigating climate change and benefitting local communities, but severe ecological and social concerns prevail over its impacts on the ground. We propose that further linking two interdisciplinary research fields, land system science and political ecology, helps addressing these concerns. For five knowledge areas we discuss problems related to lacking knowledge integration, identify specific contributions by the two fields, and outline future research directions to advance ecologically sustainable and socially just forest recovery.

Summary

Forest recovery is central for addressing major sustainability challenges such as climate change and biodiversity loss. While positive assessments prevail over the global ecological forest restoration potential, critical research highlights limited potentials and even detrimental local impacts, particularly in the Global South. Here we argue that knowledge integration across land system science (LSS) and political ecology (PE) can contribute to addressing this contradiction and advance knowledge about ecologically sustainable and socially just forest recovery. We identify five key areas where knowledge integration is promising: (1) developing multi-dimensional forest definitions, (2) linking forest land to users and interests, (3) identifying reforestation failures and successes, (4) associating drivers and impacts across places and scales, and (5) including justice dimensions in assessments of socio-ecological forest recovery potentials. For each knowledge area, we review key contributions by LSS and PE, and outline future research directions to address ecologically sustainable and socially just forest recovery.

Keywords

Land system science, political ecology, transdisciplinarity, justice, conflict, reforestation, afforestation, forest transitions, conservation, climate change mitigation

Introduction

Forest recovery is a central aim for combatting major sustainability challenges such as climate change[1] and biodiversity loss[2]. While deforestation is an ongoing trend in the global tropics[3,4], a growing number of studies has identified large reforestation potentials, in particular with regard to their contribution to climate change mitigation.[5,6] Forest recovery has also become a policy pillar in global to national climate change mitigation plans, including the United Nations REDD+ program („Reducing Emissions from Deforestation and Forest Degradation"). Tree planting is part of many corporate climate actions[7], as well as a key component of sustainability strategies involving nature-based solutions[8]. Forest conservation is frequently expected to bring co-benefits for local communities. For instance, the Sustainable Development Goals emphasize how forestry measures are an „investment in people and their livelihoods, especially the rural poor, youth and women“ (see https://sustainabledevelopment.un.org/topics/forests).

This positive perception on the potential role of forest recovery to benefit people and the planet has been increasingly countered by critical research concerned with the ecological feasibility and the social impacts of large-scale reforestation and forest conservation. Debates on the ecological feasibility revolve around the realistic potential for reforestation in terms of climatic suitability of land areas[9] and the expected carbon sequestration potential[10]. Among the negative social outcomes, land conflicts over industrial tree plantations have been identified across the Global South[11]. Reforestation initiatives promoted in the context of climate change mitigation policies have been linked to livelihood loss in many national and local contexts[12,13]. There is also growing concern over the negative social impacts of expanding conservation areas, which frequently target forests, on the livelihoods of customary land users[14].

We argue that further knowledge integration across land system science (LSS)[15] and political ecology (PE)[16] has much to offer to enhance a nuanced understanding of sustainable and just forest recovery processes. Both fields address, in different ways, the complexities of social and environmental factors shaping forest recovery, as pointed out in an extensive review article detailing the explanatory claims of political ecology and land change science, the major precursor of land system science[17]. LSS has a tradition in mapping land system change (in particular: land use and land cover change), focusing on socio-ecological phenomena such as ecosystem services, land-atmosphere processes, land governance and urban-rural teleconnections.[15] Rooted in land change science, many LSS studies adopt a post-positive approach relying on empirical methods, modelling and testing, which creates interfaces to analyses of the natural world, such as biogeochemical fluxes, or biodiversity trends, and, in principle, allows applicability of methods at multiple scales.[17] PE on the other hand, rooted in critical social sciences, frequently adopts constructivist or post-marxist perspectives, and focuses on power relations, conflict and justice concerns associated to specific resource uses. PE thus addresses land characteristics such as tenure, access and diverse forms of material and cultural land uses, and establishes interconnections between political processes and environmental outcomes, including conflicts and social injustices related to land-use change.[17] While the two fields importantly cross-fertilize each other, the distinct viewpoints and epistemologies hamper a straight-forward integration of approaches.[17,18] Zimmerer[19], for example, describes how the integration of empirical methods into PE may even pose ‘professional risks’, as it may provoke antagonistic reactions by colleagues who are unsupportive of such integrative efforts.

Here we argue that further knowledge integration from PE and LSS into forest recovery research is a risk worth taking, because it has the potential to advance knowledge on sustainable and just forest recovery pathways. In fact, integration is already occurring in important areas and ‘hybrid research’ is emerging that, while not reconciling distinct epistemologies, fosters "an understanding and appreciation of divergent approaches"[17]. Rather than seeking full integration of knowledge systems, such research acknowledges productive tensions, or "fruitful frictions"[19] that provoke mutual learning and guide careful and selective integration of methods and approaches with the purpose to address specific problems in original and meaningful ways.

In this Perspective, we identify where further knowledge integration across PE and LSS is promising for enhancing our knowledge about sustainable and just forest recovery pathways. We draw attention to five knowledge areas in which we consider a selective integration of knowledge and methods to be productive (Figure 1), based on emerging contributions at the interface of the two fields, or on identified research gaps: (1) developing multi-dimensional forest definitions, (2) linking forest land to users and interests, (3) identifying failures and successes of forest recovery, (4) associating drivers and impacts across places and scales, and (5) including justice dimensions in assessments of socio-ecological forest recovery potentials.

The identification of key areas for knowledge integration was initially informed by our own research experience on forest recovery processes in different interdisciplinary contexts (including LSS and PE), and then refined in an iterative way through a literature review (see Experimental Procedures section). For the discussion of these knowledge areas, we provide a narrative review that (1) describes the problem arising from a lack of knowledge integration, (2) discusses particular contributions to addressing this problem by LSS and PE, and (3) highlights, based on research at the interface of the two fields wherever available, in which concrete ways further knowledge integration appears promising. Given the diversity of PE and LSS research and their sometimes blurred boundaries, the specific contributions highlighted here are not intended to indicate strict topical divisions between the fields, but tendencies and strengths in approaching forest recovery concerns that bear potential for further cross-fertilization.

With regard to social aspects of forest recovery, we focus on justice, conflict, and the role of specific actors involved, i.e. customary groups or social movements. We take a trivalent perspective to justice that considers distributional aspects, such as who benefits from certain land uses, as well as procedural issues, such as involvement in forest governance, and recognition, concerned with how different cultural identities and related forest uses are valued and respected.[20,21] The most important ecological dimensions we address relate to major global sustainability challenges, focusing on the carbon sink function of forest recovery connected to mitigating global climate change[1], but including also biodiversity conservation[2]. Geographically, we mainly address forest recovery processes in the Global South. Analyses of deforestation are included only if they draw conclusions for forest recovery or illustrate methodological or conceptual contributions that could be applied to forest recovery research.

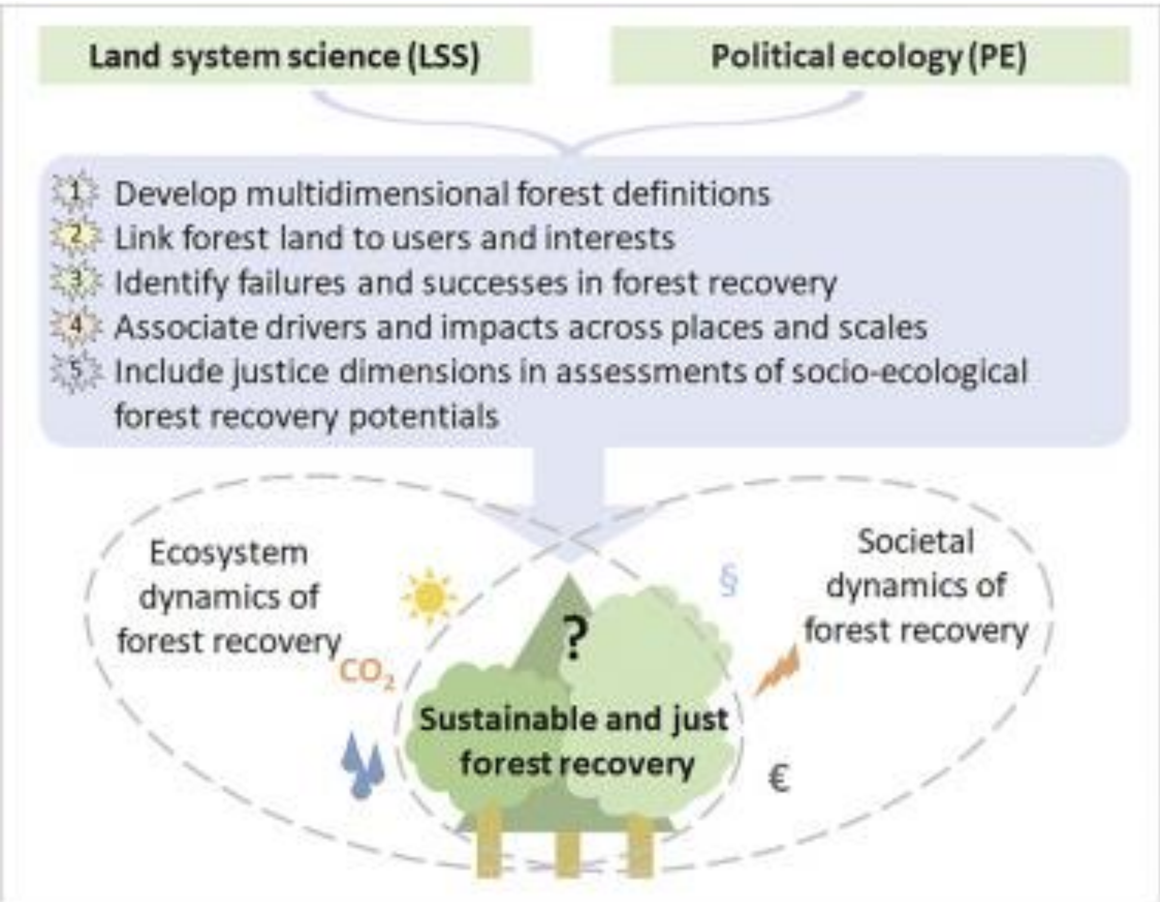

Figure 1: Knowledge areas for sustainable and just forest recovery research.

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Develop multidimensional forest definitions

The choice of a particular forest definition sensitively shapes ecological and social outcomes of forest recovery efforts on the ground.[22–24] International agreements on climate change mitigation refer to forests as minimum areas of 0.5–1 ha with a tree canopy cover of more than 10–30%, comprised of trees higher than 2–5m.[25] However, this definition does not capture important ecological and social qualities of forests and may obscure declines in carbon stock, biodiversity loss, and livelihood impacts related to forest change. These impacts can be grasped in interdisciplinary approaches, and we argue that knowledge integration from LSS and PE can inform on suitable dimensions for monitoring forest change (Figure 2).

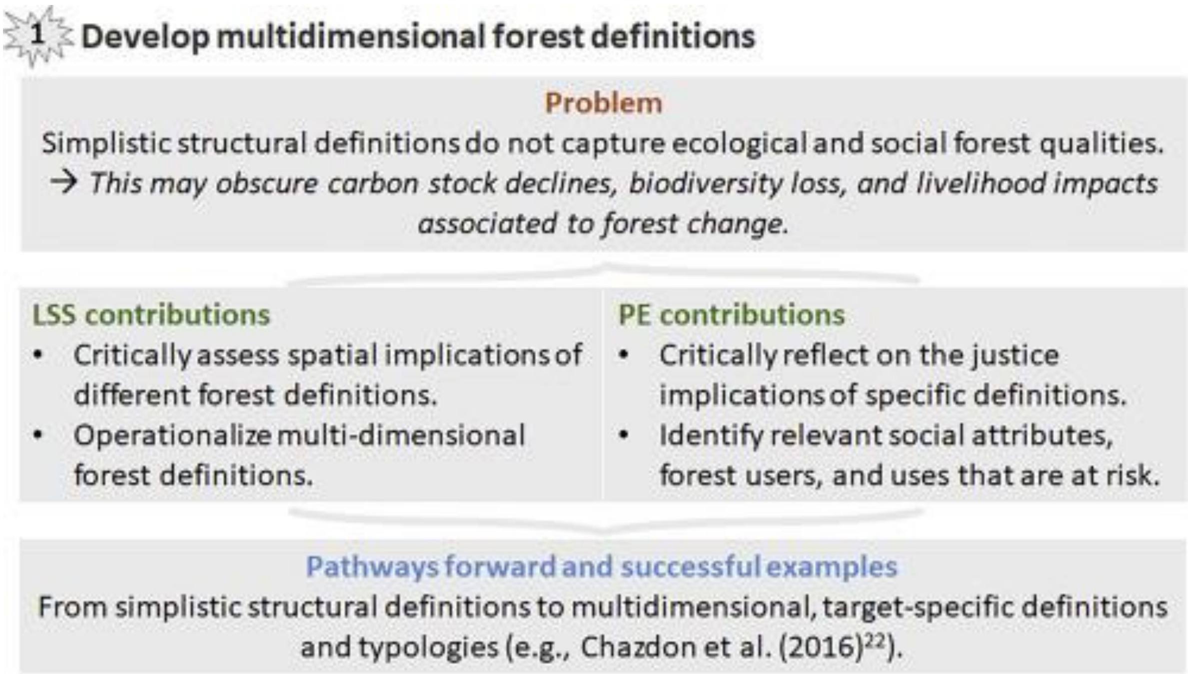

Figure 2: Knowledge Area 1 - Develop multidimensional forest definitions.

Several studies from the field of conservation ecology have highlighted how structural forest definitions may foster ecological degradation.[26,27] The central concern of these studies is that policies targeting forest conservation for climate change mitigation do not distinguish between natural forests and plantations, allowing conversions of old-growth forests into monocrop tree plantations that technically remain forests despite severe ecological degradation, such as biodiversity loss. LSS studies have shown that such political reforestation targets resulted in a shift from primary forest to forest plantations in different geographical contexts.[28,29]

Furthermore, the low threshold for forest cover allows for selective logging of up to 70-90% in closed-canopy forests, leading to carbon losses, without being considered deforestation.[23] These important ecological changes remain invisible in forest assessments based on such structural definitions.[30] More nuanced definitions are required that consider diverse ecological aspects, as well as a more holistic perspective that understands forests embedded in both ecological and social landscapes.[22]

Forest definitions also have major social implications: they reflect particular management objectives, social values and needs attached to forests. The structural definitions underlying those applied by the UNFCCC were initially developed to monitor and manage forests as sources of timber, no matter whether they were planted or natural forests. Thus, they reflected the interests of the timber, plantation and pulp industries but not those of other groups, for instance, Indigenous people relying on forests materially and culturally.[22] This has provoked social consequences, particularly for forest-dependent communities whose access to livelihood resources and cultural sites is threatened when forests are converted to tree plantations, or for adjunct land users facing adverse social-environmental impacts of tree plantation expansion, such as pollution, wildlife loss and other issues.[31] Environmental movements summarized their profound social concerns over the prevailing use of structural forest definitions with the slogan ‘tree plantations are not forests’, and urged the FAO through mass petitions to revise its definition.[32] These concerns are exacerbating in the context of climate change mitigation policies, where several studies document the profound social problems resulting from the accelerated expansion of tree plantations, endorsed by the UNFCCC as reforestation.[12,13,33]

All forest definitions will require practicable compromise, and no single forest definition will be able to capture all socio-ecological aspects. However, a multidimensional conceptualization of forests is needed for management, monitoring and restoration within current mitigation efforts that must be informed by the multiple social and ecological functions that specific forest landscapes provide.[22,34] Definitions used in the governance, restoration and monitoring of forest landscapes must be informed by what is at risk.[23] Definitions in the global Forest Resource Assessments, distinguishing 'natural' and 'planted' forests[4] offer only a very rough distinction in this direction. Monitoring the carbon sequestration of forest change should move away from binary definitions of very few different types of forest, 'other wooded land', and non-forested areas. Such comprehensive assessments are common in LSS. Building on remotely-sensed data, studies develop and operationalize non-binary land classifications, distinguishing different levels of e.g. carbon stocks[3,35] or tree cover[36,37].

For understanding social aspects of forest change, as well as the implications that specific forest definitions have for different user groups, it is necessary to look at who is at risk, why and how, which are issues at the core of PE.[16] Attention must be paid to peoples' access schemes to forests that in turn shape their vulnerability.[38] The only social distinction made in national reports of the Forest Resource Assessment is on public vs. private forests. A consistent international distinction between different forms of customary, small-scale and large-scale corporate forest ownership and access rights, partly existing in national forest inventories, would be a first step towards monitoring of social changes and informing policies to avoid 'social degradation'. Combining social and ecological attributes into a typology of land-use categories suitable for climate change mitigation and biodiversity conservation that is widely accepted, useful in monitoring and technically also operational, remains a key challenge and research gap.

Link forest land to users and interests

Adequately linking a physical piece of forest land to people using or wanting to use it is a precondition for avoiding conflicts resulting from competing land use claims.[39] Several studies report conflicts in the forestry sector that resulted from inadequate forest classifications and improper identification of the actual land users.[33,40] Knowledge about who uses which forest land for what is therefore a prerequisite for preventing conflict and developing socially just forest recovery initiatives. Such identification can build on concepts and methods being debated and developed in both LSS and PE (Figure 3).

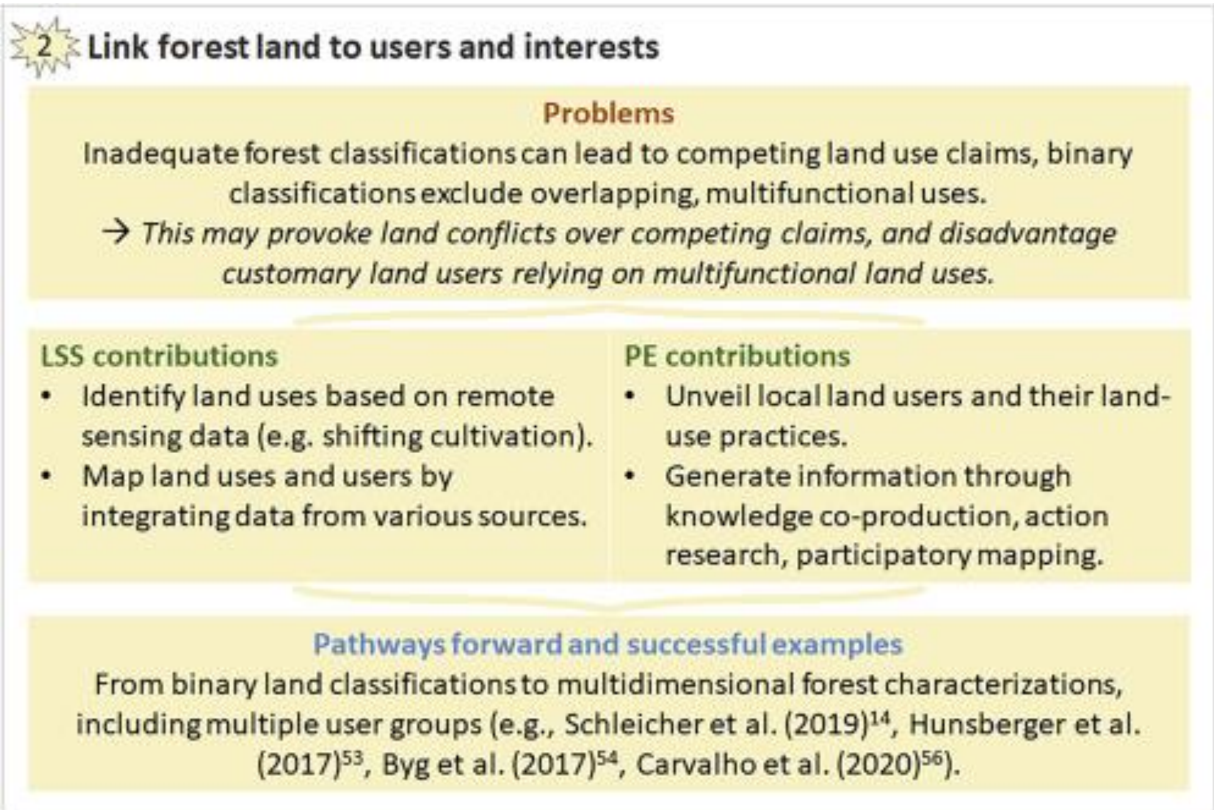

Figure 3: Knowledge Area 2 - Link forest land to users and interests.

LSS has a strong tradition in linking land to people, because one of its core interests is in understanding land system dynamics at the interface of biophysical and human subsystems.[41] Integrated conceps used in LSS like 'land functions', denoting the "wide range of goods and services"[42] provided by land, or 'ecosystem services', describing the "benefits people obtain from ecosystems"[43] bridge ecological and socetial dimensions of land systems and, by enabling identification of functions or services relevant to specific actors and interests, offer entry points for addressing issues of justice or conflict in the context of forest recovery. Relevant conceptual contributions from PE on the other hand focus on the diverging interests of different forest users, and the impact of power relations on the potential benefit of forest change for different actors. 'Green grabbing' describes the appropriation of resources for environmental ends, with often detrimental effects for local populations.[44] This concept is useful to link land cover, such as forests, to specific actors who expect benefits from its protection, while other actors, such as customary land users, get excluded from this land. In this context, the negative impacts of forest restoration programs such as REDD+ projects have been highlighted, they may exacerbate existing inequalities by benefiting political elites while excluding other social groups from access to local resources.[45]

Also empirically and methodologically, both LSS and PE contribute to better tackling the challenges of linking land to people in cases when standard land classifications fail to acknowledge multifunctional forest use. In particular, LSS has contributed to better mapping shifting cultivation based on advanced analyses of remote sensing data, and thus helped identify the importance of forest resources to local livelihoods otherwise not documented.[46,47] Recently, a proposal to spatially link illicit activities to land uses using remote sensing data was made by Tellmann et al.[48], which might be applied to trace e.g. illicit cultivation or logging activities within forests. Several works in PE on the other hand pinpoint that inadequate land classifications disadvantage moving populations, such as shifting cultivators[49] or pastoralists[50], as well as the complex livelihood patterns of peasants. Beyond their permanent agricultural plots, peasants depend on frequently unmapped access to forest livelihood resources, such as non-timber forest products (NTFPs) and wildlife from surrounding forests or savannas[51]. PE unravels that some forest uses, such as NTFPs, are virtually 'invisible', but nevertheless vitally important for local livelihoods.[52]

Further knowledge integration across LSS and PE is promising to better understand who uses which forests and in what ways. At local levels, a number of different contributions have recently pushed this frontier: Hunsberger et al.[53] proposed the combination of a landscape perspective, collaborative action research and knowledge co-production with local actors to uncover local histories of land uses as well as local understandings of justice. Participatory mapping has proven to be a valuable tool to integrate information on both social and ecological forest characteristics and diverging interests among different users.[54,55] Interview-based research also enables identification who uses which land for what purpose, regardless of whether these uses are considered in standard land classifications or detectable by remote sensing methods.[56,57]

Less work in this direction is available at national and global levels, but important progress has recently been made. For example, Leijten et al.[58] map the global forest area that may be covered by corporate zero deforestation commitments based on specific biophysical criteria, and consider potential leakage effects. Fa et al.[59] integrate Indigenous Land maps with maps of Intact Forest Lands and show that at least 36% of intact forest lands are within Indigenous peoples' lands.[60] They argue that recognition of Indigenous rights is therefore critical to mitigate deforestation. Similarly, Schleicher et al.[14] demonstrate that 1 billion people would be affected if half the terrestrial land surface was put under conservation, as proposed by international conservationists. Combining approaches from PE that uncover multiple interests in forests, with mapping of land uses associated to specific user groups appears as a promising area for future methodological innovation.

Identify failures and successes in forest recovery

The failure and success of concrete reforestation initiatives depends on both ecosystem and social dynamics. Thompson[61] illustrates this for the case of mangrove reforestation in Thailand, where failures have occurred due to a mix of ecological factors, such as tidal inundation, algal accumulation, or invasion by barnacles, as well as political and institutional aspects, including how ecological knowledge was used, or how decisions on siting, planting techniques and monitoring have been made, shaped by the different interests and power relations across involved actors. A thorough understanding of reforestation successes and failures must draw on both ecosystem and political-ecological analyses. While literature is available that addresses institutional and stakeholder dynamics in reforestation projects[62], as well as the economic preconditions of reforestation[63], bridging LSS and PE can further enhance knowledge about the interplay of ecosystem dynamics, socio-economic and institutional processes, and informal and non-institutionalized processes, shaping reforestation failures and successes (Figure 4).

The societal processes enabling reforestation are a major topic in LSS, debated as ‘drivers’ or ‘pathways’ of forest transitions. Work here builds on theoretical approaches that discern ideal-type pathways associated to socio-economic or political factors enabling reforestation.[64] Originating from a focus on long-term studies of forest change in industrialized countries[65,66], major socio-economic drivers of forest recovery, such as agricultural intensification[67] and growing income or socio-economic wellbeing[68] are increasingly documented in quantitative

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assessments of reforestation in the Global South[69,70]. Complementary, case-specific analyses, including more qualitative methods, highlight the influence of political and institutional dimensions.[71] In particular, the historical context of forest governance[72] and institutional legacies[73] have been demonstrated to impact dynamics of forest change.

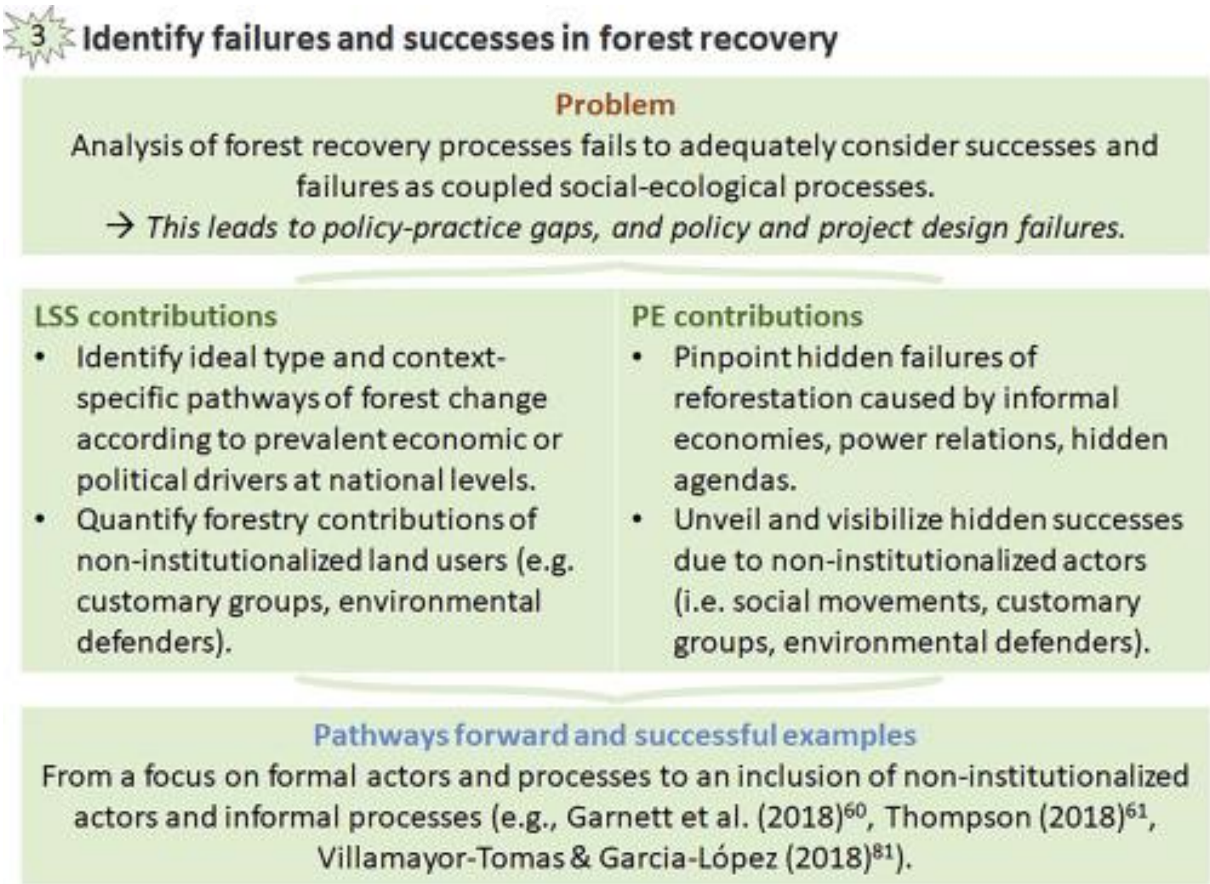

Figure 4: Knowledge Area 3 - Identify failures and successes in forest recovery

PE contributes to the understanding of processes enabling or disabling various forms of reforestation, not only by addressing the social outcomes, such as justice concerns, but also by shedding light on informal actors, power relations and illicit processes frequently overseen. The relevance of hidden agendas, informal and illicit processes in shaping forests on the ground manifests for example in Cambodia, whose recent political history has been deeply entrenched with the development of the illicit timber sector.[74] While the officially demarcated conservation areas contain some of the most valuable timer resources, they are being logged at a rapid pace by political elites involved in the multi-million dollar shadow economy.[75] Structural forest definitions further support this process, because they enable Cambodia's political elites and timber industries to conduct selective logging, and to replace natural forests containing high value timber stocks by tree plantations that are globally accepted as forests.[12] Illicit activities and clientelist relations between the state and the logging industry mark forest governance not only in Cambodia, but occur in many countries targeted for reforestation. They must be taken into account to avoid naïve policy recommendations that do not meet local realities.[76]

PE also sheds light on 'hidden successes' of forest recovery, by addressing the contributions of customary resource users and non-institutionalized actors such as social movements to forest conservation, which are not officially labelled as conservation or climate change mitigation actions.[77] Coined by Martinez-Alier[78] as 'environmentalism of the poor', the roles of these actors in environmental protection have been highlighted by PE for decades.[79] For example, shifting cultivators, frequently blamed by governments and domestic policies for hindering climate change mitigation, can play an important role in sustainably managing tropical forests.[80] Social movements in general can be key in promoting and defending sustainable use of commons against outside threats.[81] Specifically, forest movements, such as for example the Cambodian Prey Lang Community Network (PLCN), actively protect the forests upon which their livelihoods depend against illegal loggers and outside encroachers.[82] Only recently, the UN Human Rights council formally recognized the role of such 'environmental defenders' for sustainability.[83]

Combining further the insights from LSS and PE can contribute to a better understanding of both evident and hidden successes and failures of forest conservation policies. The study of shifting cultivation is a good example of such knowledge integration. Interdisciplinary approaches have illustrated how too narrow perspectives fail to understand the role of shifting cultivation in climate change mitigation[84], and have shed light on the conditions under which shifting cultivators are able to contribute to carbon storage and biodiversity conservation[80,85]. Similarly promising research links Indigenous lands and land use practices with a quantitative analysis of forest change, highlighting the importance of reckognizing indigenous land uses and involving indigenous groups in forest conservation.[59,60]

Within current debates on the role of environmental defenders for sustainability[83], further knowledge is needed to better understand the role of forest defenders for forest recovery globally. While PE has provided important answers to the questions of why and how customary users and social movements protect the environment such as their forests, little has been done to actually track and quantify these contributions. LSS methods, such as the analysis of remote sensing data, can help address these questions by unveiling and monitoring historical and current landscape transformations associated to informal processes and non-instituionalized actors that do not appear in any statistics or official reports (see [48]).

Associate drivers and impacts across places and scales

Forest recovery in specific places is usually the result of ecological and societal processes interacting across places and scales. One problem arising from this, known as leakage, is that environmental policies targeting a particular country may result in displacing environmental burdens beyond national boundaries. For example, Ingalls et al.[86] trace how REDD+, while supporting forest recovery in Vietnam, indirectly displaces deforestation to Laos and Cambodia, by provoking large-scale land deals for forest-risk commodities in these countries.

A related problem is that case-specific knowledge on the social justice implications of particular reforestation policies or practices has not been generalized to global levels. Currently, we observe a certain scale-related bias, where global studies of forest change tend to overlook social justice dimensions, whereas local case studies that address socio-political aspects of forest change focus less on ecological implications. LSS and PE offer approaches to address both problems: to link and quantify reforestation drivers and impacts across places and scales, and to upscale knowledge from single cases to systematic and generalized knowledge (Figure 5).

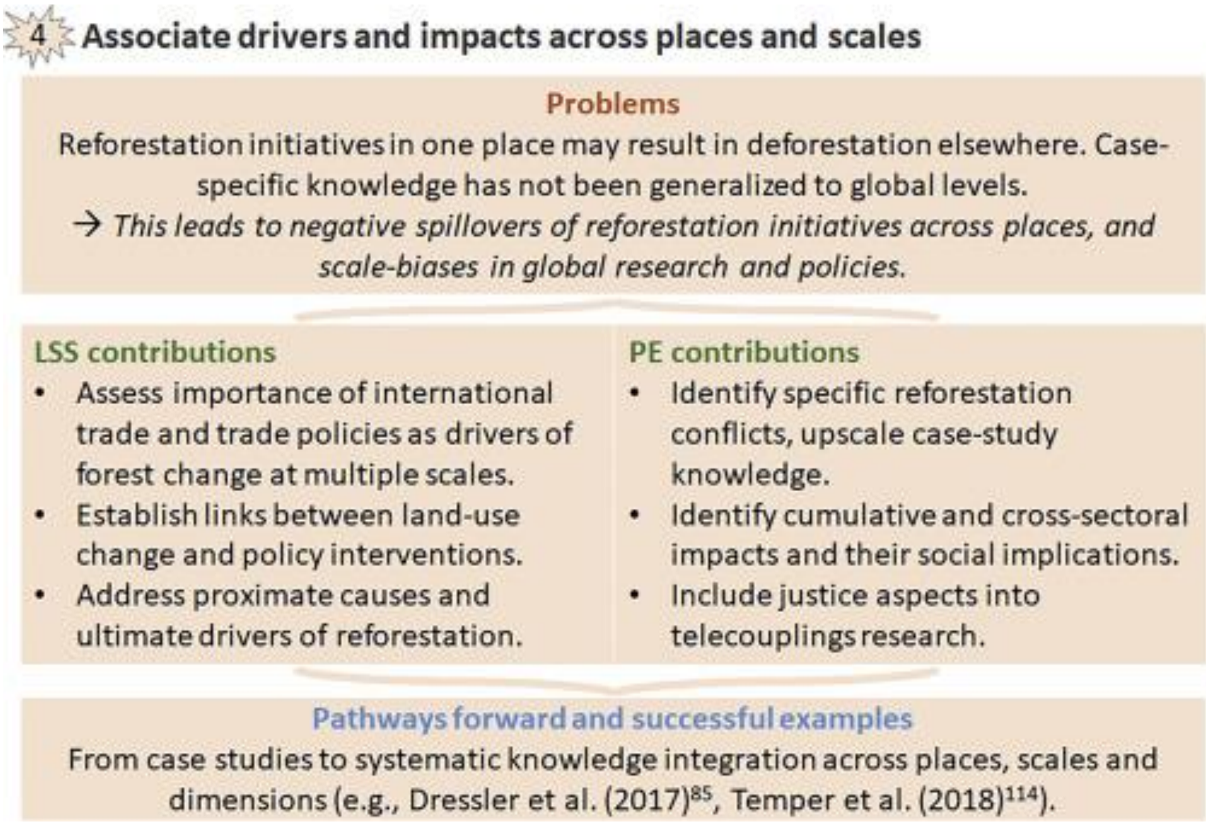

Figure 5: Knowledge Area 4 - Associate drivers and impacts across places and scales

LSS has its roots in understanding spatial patterns and dynamics of land use change at multiple scales.[41] A particular strength of LSS is its ability to consistently depict land use and land cover change across scales, forest recovery being one of them. National-level analyses for several countries and regions, experiencing net-reforestation after long periods of deforestation, have shown spatial patterns of reforestation based on remote-sensing data products.[87,88] Ecological characteristics, like the type of forests recovering[28], carbon stock changes in forests[89,90], and biodiversity effects[91] can be addressed with such approaches, and linked to global contributions of forests e.g. to ecosystem carbon storage[35] and biodiversity[92].

Telecouplings, i.e. the "socioeconomic and environmental interactions over distances"[93] have become an important topic of forest recovery analysis in LSS in recent years[94]. The displacement of deforestation beyond national boundaries via imports of wood or forest-risk commodities has been identified as enabling factor for reforestation at national[95] and global scales[96]. Interventions in international supply chains have been shown to impact the slow-down of deforestation in the Amazon[97], and similarly, policy interventions reduced the rate of palm-oil expansion in Indonesia[98].

Telecouplings research has, despite its focus on power relations in land system change, so far not sufficiently addressed issues of social justice, as recently claimed by Corbera et al.[99]. Similarly, calls for more contextual analyses of national reforestation processes are being made, arguing that biophysical processes of forest change should be better linked to political, institutional or cultural processes, including conflicts from diverging interests and unequal power relations.[100–102]

Conceptually, the distinction of proximate causes and ultimate driving forces, introduced by land change scientists almost two decades ago[103], offers important potential here. This distinction has been successfully applied in many studies on deforestation[104,105], enabling the localization of different drivers and identification of actors with diverging interests[106]. Applying this concept to cases of reforestation appears as a promising next step.

Studies from PE have demonstrated that forest recovery projects are embedded in socio-political processes unfolding at different scales and involve actors with diverging agendas. Key research topics include e.g., political implications of the growing attention to tree plantations[107], analyses of actors' interests and interactions across scales[108], conflicts playing out between local populations and national or international investors (e.g., in the context of tree plantations[11]) or national and international governance administrations (e.g., in the context of conservation efforts[109]). Baird and Barney[110] furthermore showed that project impacts go well beyond specific project boundaries and interact with other land uses, by pointing to the cumulative and cross-sectoral impacts of multiple projects in the same landscape, and their implications for customary users. Extensive empirical work has also been conducted analyzing the drivers and (unintended) social effects of reforestation under the REDD+ scheme, where international policies interact with local land uses. Most studies work at local scales and identify structural problems when international restoration schemes meet local realities.[111,112]

The case study approach adopted in many of these studies has yielded 'thick descriptions' with high internal validity of place-specific reforestation dynamics and impacts. However, little is usually said about the external validity of the case study and the generalizability of observed processes beyond the specific case. Questions such as how frequent a particular type of forest conflict occurs, or how many people or how much land are affected by specific forestry activities across geographic regions or globally, remain unanswered.

Upscaling case-specific insights and creating generalized knowledge is urgently needed to better address issues of social justice and conflict in the context of global forest recovery endeavors. Such generalizations cannot offer the rich contextual analysis of case studies, but unveal general tendencies and patterns with higher external validity. Important contributions towards upscaling case-specific knowledge are made by extensive literature reviews.[45,85,113]

Beyond this, we observe an increasing number of empirical data compilations established by researchers and non-governmental institutions that can inform future meta-analyses. Examples here include the global Atlas of Environmental Justice (EJAtlas), providing standardized information on environmental conflicts an justice mobilizations worldwide, including some on reforestation and forest conservation programs.[79,114] Similarly, the Land Matrix database provides information on international land deals for agriculture, including forestry related projects[115], and ID-RECCO[116] compiles information on a large number of REDD+ projects. These databases provide the empirical basis for developing functional typologies (e.g., types of conflicts over land, or success criteria of reforestation projects), and enable situating case-specific processes into larger regional and global contexts.

Include justice in socio-ecological forest recovery estimates

Studies on global forest carbon sequestration[117] and the potentials for forest recovery[5,8] fuel hopes that forests can substantially contribute to climate change mitigation[118]. Important empirical and methodological efforts are being conducted to better quantify ongoing trends in forest extent and carbon storage, especially in the tropics where forests continue to decline.[3,36] Nevertheless, disagreement among existing datasets on biomass stocks[35] and among different methodological approaches[119,120] prevail. Given the high uncertainty of global forest, tree cover and carbon stock datasets, research quantifying forest recovery potentials face substantial critiques. So far, criticism has addressed in particular the way in which biophysical constraints are considered, affecting potential forest area expansion and the amount of feasible carbon sequestration.[9,10,121]

However, forest recovery is deeply embedded in social processes[122], creating also social constraints. A social justice perspective, which recognizes that socially acceptable forms of

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reforestation require attention to diverse values attached to forest recovery, as well as to procedural and distributive concerns of multiple users affected by forest recovery processes, is rarely mentioned in assessments of global reforestation potentials.[123] The seedlings of a reforestation project will not grow if they are burnt or uprooted in acts of resistance by locals whose lives are negatively affected by the tree plantations (for a review of cases, see[11]). Livelihood needs, justice concerns, and conflict must therefore be incorporated in forest recovery potential assessments because these factors directly shape the possible forms of, and limits to, forest recovery. Insights from both LSS and PE can contribute to addressing this challenge (Figure 6).

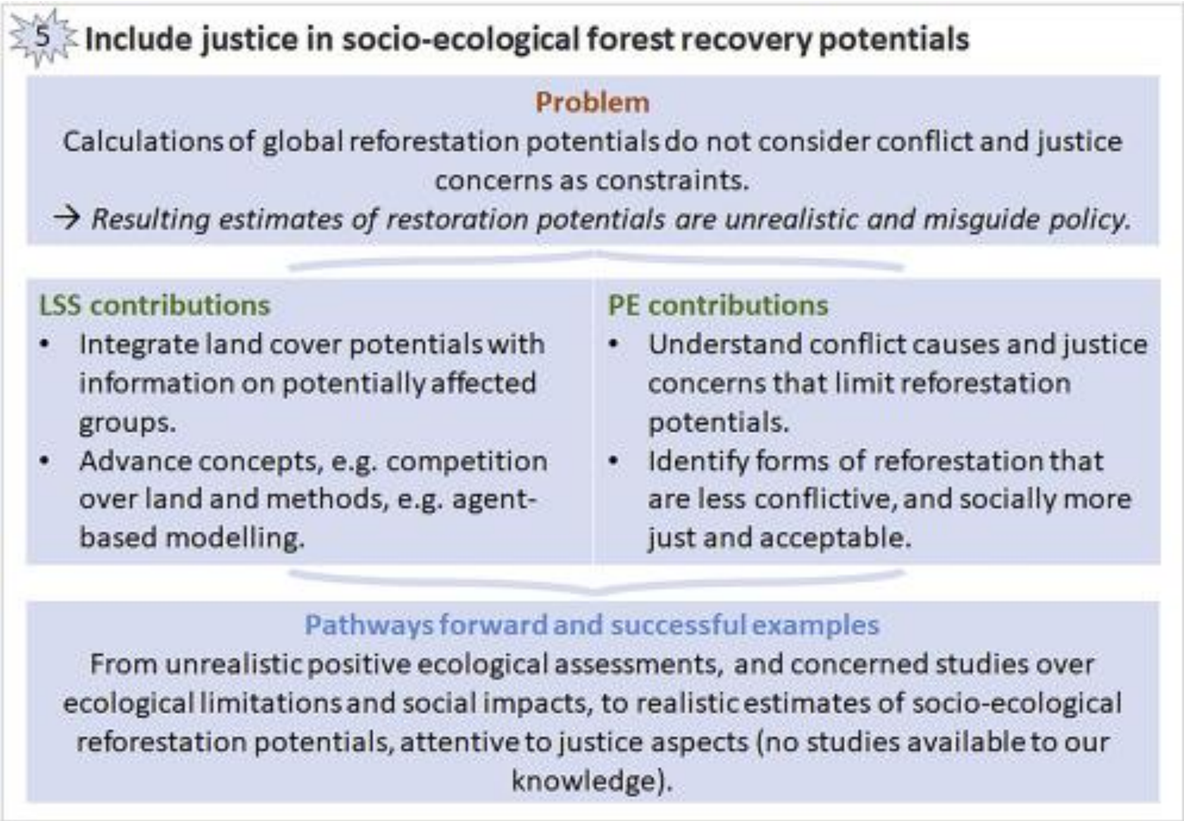

Figure 6: Knowledge Area 5 - Include justicein assessments of socio-ecological forest recovery potentials

Methodologically, ecological potentials have been linked to social issues by overlaying maps with ecological and social information. For example, the number of people potentially affected by forest recovery[124], or nature conservation in general[14], has been assessed this way. Similarly, Garnett et al.[60] use maps of Indigenous territories to identify areas that are under traditional management and subject to Indigenous Peoples' rights to land that must be respected to meet social and ecological conservation goals. Whether forestry initiatives in disputed areas actually lead to conflicts, or are seen by affected actors as beneficial, depends on multiple factors. Among them are the specific project characteristics, historical land uses, competing land claims, worldviews, local perceptions of justice, and also the resulting distribution of benefits and burdens across different actor groups. A PE lens can unpack the role of these factors, and by scaling up knowledge, enhance a global understanding of conflict triggers associated to different types of forest recovery initiatives. Also, debates from LSS might prove as fruitful entry points. For example, the concept 'competition over land'[125,126] can be useful to identify not only biophysical trade-offs, but also diverging interests by different groups of actors, and the social conflicts associated to them. Methodologically, agent-based modelling is a useful tool to operationalize in a formalized way the interests by different actors in the context of land use,[127] but has only rarely been applied to conflicts over forest recovery projects[128].

Insights on the socio-political dynamics associated to different forms of forest recovery are necessary to revise current estimates of global, regional and national reforestation potentials to more realistic ones, and to guide the forms of forest recovery initiatives towards projects that are socially just. For example, a recent study for Southeast Asia that integrated socio-economic aspects estimated that financial, land use and operational constraints reduce the biophysical reforestation potential by 82% to 99.7%.[129] Crucial knowledge gaps prevail regarding the integration of socio-economic aspects at the global level, and particularly, the inclusion of social justice aspects as constraints to forest recovery. While the latter requires to think about new methodological approaches that draw on LSS and PE insights, it is a promising path to unveil more sustainable and just potentials for forest recovery.

Concluding remarks

This Perspective started from the observation that overly positive estimates of forest recovery potentials to mitigate global climate change or biodiversity loss oppose evidence from more critical studies on the ecological constraints and potentially detrimental social impacts of forest conservation, particularly in the Global South. We propose that knowledge integration between LSS and PE offers productive potentials for addressing this contradiction, by (1) developing multi-dimensional forest definitions, (2) adequately linking forest land to users and interests, (3) identifying failures and successes of forest recovery, (4) associating drivers to impacts across places and scales, and (5) including justice dimensions in assessments of socio-ecological forest recovery potentials. In all five knowledge areas substantial knowledge gaps remain that we have outlined here. Yet, contributions are appearing that draw on insights, approaches and methods from LSS, PE and neighboring fields. These studies show a promising direction for further knowledge integration towards well-informed, ecologically sustainable and socially just forest recovery research.

With this contribution we aim at stimulating further inter- and transdisciplinary research to close these gaps, even if this requires going beyond established methodologies, well-known routes of scientific collaboration, or even pose ‘professional risks’. Research along the knowledge frontiers sketched out here is in our view indispensable for informing forest monitoring and governance at multiple levels. We are well aware that the issues addressed here are also profoundly political, and not only academic problems, which cannot be solved by research alone. Nonetheless, the research agenda proposed here can importantly inform negotiation processes around sustainable forest conservation, by making visible major societal and ecological trade-offs and concerns involved in forest recovery processes.

Experimental Procedures

Resource availability

Lead contact

Further information and requests should be directed to and will be fulfilled by the Lead Contact Simone Gingrich: simone.gingrich@boku.ac.at

Materials availability

This study did not generate new unique materials.

Data and code availability

This study did not analyze datasets.

Literature review approach

This Perspective is based on a review of about 230 publications that informed our arguments. The compilation of relevant research articles was based on three search strategies: articles we knew from our past work, articles from search results in main research databases (Google Scholar, Web of Science) based on keywords related to the five knowledge areas (e.g., keywords related to topical issues, such as “forest definitions,” “forest classification,” “reforestation failure,” “reforestation success,” “drivers forest recovery,” “telecoupling forest” and others, combined with keywords related to the discussed disciplines, such as "political ecology," "land change science," and "land system science"), and handsearched bibliographies of reviewed articles. We selected contributions from LSS and PE based on two criteria: articles that empirically or conceptually illustrate how knowledge integration can be successfully achieved, or articles that discuss social and ecological concerns resulting from insufficient knowledge integration in forest recovery research. Acknowledging that both LSS and PE are heterogeneous, and their boundaries are difficult to trace, we also included studies from neighboring fields, such as economic, physical, and critical geography, conservation ecology, or critical agrarian studies, if they met the above described selection criteria and scope. Due to limitations of space, we selected publications cited here principally according to their topical fit. In cases where several references were available to back up a statement or illustrate an argument, the final selection was based on the criteria of impact (with preference to more frequently cited papers), recency (with preference to more recent publications), and the gender balance in the authors list.

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Author contributions

A.S. and S.G. contributed equally to the conceptualization and writing of the paper. Literature from land system science was mainly reviewed by S.G., while literature from political ecology was mainly reviewed by A.S.

Declaration of interests

The authors declare no competing interests.

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