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Climate-smart land use requires local solutions, transdisciplinary research, policy coherence and transparency

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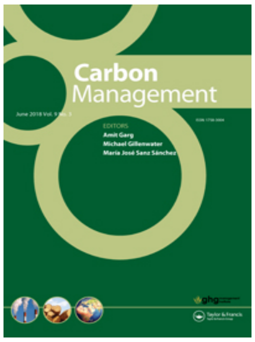

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Climate-smart land use requires local solutions, transdisciplinary research, policy coherence and transparency

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ABSTRACT

Successfully meeting the mitigation and adaptation targets of the Paris Climate Agreement (PA) will depend on strengthening the ties between forests and agriculture. Climate-smart land use can be achieved by integrating climate-smart agriculture (CSA) and REDD+. The focus on agriculture for food security within a changing climate, and on forests for climate change mitigation and adaptation, can be achieved simultaneously with a transformational change in the land-use sector. Striving for both independently will lead to competition for land, inefficiencies in monitoring and conflicting agendas. Practical solutions exist for specific contexts that can lead to increased agricultural output and forest protection. Landscape-level emissions accounting can be used to identify these practices. Transdisciplinary research agendas can identify and prioritize solutions and targets for integrated mitigation and adaptation interventions. Policy coherence must be achieved at a number of levels, from international to local, to avoid conflicting incentives. Transparency must lastly be integrated, through collaborative design of projects, and open data and methods. Climate-smart land use requires all these elements, and will increase the likelihood of successful REDD+ and CSA interventions. This will support the PA as well as other initiatives as part of the Sustainable Development Goals.

KEYWORDS
Climate policy; climate-smart agriculture; deforestation; food security; REDD+

Introduction

The ambitious goals set at the 21st conference of parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris have since been discussed in Bonn and Marrakesh. The Road Map for Global Climate Action notes a long-term move in focus from mitigation action toward adaptation [1], which will also be reflected in funding allocation [2]. The Marrakesh Action proclamation promises actions in the agriculture sector, primarily ensuring food security and enhancing the ability to deal with climate change impacts on agriculture [3]. There was further progress on agriculture in Bonn; the links between agriculture and climate change were included as a discussion point, with options such as increasing soil carbon mentioned [4]. At the same time, the Paris Climate Agreement (PA) features forest-based mitigation as a key mitigation strategy as well as working to secure food production. This presents a potential conflict between forests and agriculture.

The land-use sector is unique in its large potential for negative emissions, besides climate engineering options such as carbon capture and storage [see 5], and therefore must be fully utilized. The focus on food security and food production in the PA must leverage the potential synergies between adaptation and mitigation, which will support forest protection [6]. A crucial point of entry relates to linking existing concepts that address climate change mitigation and adaptation in the land-use sector, such as climate-smart agriculture (CSA) and REDD+. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible [7]. REDD+, a

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forest-based mitigation mechanism, aims to reduce emissions from deforestation and forest degradation, and to conserve forests and enhance forest carbon stocks by reducing pressure from drivers of deforestation and by managing forests sustainably. The agricultural drivers of deforestation, and their links to food security, should also be well understood. Commercial agriculture, which is often the result of large-scale land acquisitions, can have a large impact on forests [8], and can lead to food insecurity for smallholders [9]. Smallholder farming, in contrast, has a large role to play in terms of food security [10]. These key differences must be addressed when planning interventions.

The primacy of food production is clear in global strategies, not only in the PA (and the main text of the UNFCCC) but also in the Sustainable Development Goals [11]. With the increasing global population, this focus is crucial, as population increases are not matched by food production increases [12], and in Africa, population growth is expected to be the dominant driver of food insecurity, above climate change [13]. As such, the focus of CSA leans toward food security and adaptation, with mitigation being pursued only 'where possible'; a shift from earlier definitions in which it was described as a mandatory component [14]. In addition, the mitigation potential of agriculture and forests varies greatly from country to country [15], as well as the motivation within a country to focus on one or the other of the aims [16]. A major challenge in reconciling the two is the different accounting bases for food production relative to consumer demand, and area-based carbon balance in land use. For this reason, this paper focuses on the forest-sparing potential of interventions in the agricultural sector that seek to increase food production, one element of food security [17].

The starting point for the analysis is the need to reconcile competing claims on land for climate mitigation (including forest protection and biofuel production) and for food production. Since deforestation is closely linked with agriculture [18,19], REDD+ will fail if agricultureal expansion into forests persists [20,21]. A review of REDD+ readiness documents reveals that most forest-related policies tend to overlook agricultural drivers of deforestation [22]. Initiatives that increase production on existing agricultural land can, in a planned economy, reduce the need to expand agriculture into, for example, high-carbon landscapes (forests, woodlands, wetlands). In a market economy, however, the land-sparing effects of intensification may only be achieved if it induces commodity prices to drop to a level where expansion and less-intensive production become uneconomic uses of land and labor; otherwise, increasing profits from yield improvements can lead to increased land acquisition for agriculture. This can, however, be avoided, if agricultural intensification (undertaken with CSA principles) is coupled with forest protection mechanisms (e.g. policies or interventions that directly address the agriculture drivers) to ensure that forest-sparing actually occurs [23,15,24–26]. While REDD+ may operate with area-based ('simple') scaling rules, global markets for agricultural commodities imply more complex scale relationships for CSA, and hence for the way REDD+ and CSA are related to each other [27]. These feedbacks at different scales call for an exploration of how REDD+ and CSA could be linked, and what the mutual synergies and trade-offs might be. This article proposes an approach in which not all agricultural expansion is avoided, but in which emissions from agriculture-driven deforestation are minimized, and food security is protected.

Support to develop solutions that reduce deforestation may be found in the emerging science on the dependence of hydroclimates on vegetative cover [28], which further highlights the links between CSA and REDD+. For example, those interventions to secure food production and those to protect forests can be mutually beneficial: forests provide numerous ecosystem services that can increase the adaptive capacity of agriculture, which reduces vulnerability to climate change [29,28]. Forest-generated humidity, soil stability and soil fertility maintenance are crucial services for agriculture, but also support communities by providing drinking water and reducing risks such as landslides and flooding. Additionally, forest products provide safety nets for local communities when agricultural yields decline because of climate change impacts [30], further supporting the goal of securing food production [31,32].

A roadmap for transformational change

Currently, there is a lack of coherent policies, and conflicting incentives, in the agriculture and forest sectors, implying that emissions reductions can only be realized through a deep transformational change. Transformational change is a move away from business as usual and is likely to include a shift in practices, a change in commodities, innovative policies, and/or financing actions [33]. The authors envisage that changes can be applied incrementally or stepwise; however, major changes across sectors and at all levels will be required [33,34].

To address the challenge of competition for land, while promoting forest-based mitigation efforts without compromising food production, this paper proposes an area-based integration of REDD+ and CSA at intermediate (e.g. local government or 'jurisdictional') scales, to enhance synergies and reduce trade-offs. The authors argue that the costs of not integrating will lead to competition for land and other resources, inefficiencies in monitoring and conflicting agendas, which leads to less success in reducing forest loss and in protecting food security. An integrated approach requires:

- Practical local solutions that integrate CSA and REDD+ and reduce emissions at the landscape scale;
- Transdisciplinary research approaches and priorities, in the agricultural, forest and social sciences and in non-scientific communities;
- Policy coherence at (inter)national and local levels;
- Transparency in reporting and engagement.

Practical local solutions

The definition of what is and what is not CSA is important if economic incentives and policy recognition matter. This article proposes that practices should only be classed as CSA when they, in addition to enhancing food security and increasing resilience, achieve reductions in greenhouse gas emissions (mitigation) at the landscape level (including, importantly, the life cycle of the product), and avoid expansion of agriculture into forests, which should be avoided where possible. Sa *et al.* [35] used a similar definition for activities that mitigate climate change and advance food security in South America. They stated these activities must have 'low carbon dioxide (CO_2) emissions from land use (LU) and land use change (LUC) in response to agricultural best management practices' [35]. Only activities that meet these criteria were considered suitable by the authors to contribute to the low-carbon agriculture (LCA) strategy as part of Brazil's program on low-carbon agriculture [36]. The activities identified were diverse, and included restoration of degraded pasture, biological N fixation and plantations of commercial forests. In all the scenarios assessed by the study, food production increased. In order for this to occur, the expansion of agricultural land was required. In these cases, emissions from the expansion event should be estimated and used to guide decision-making as to whether and where agriculture should expand.

Calculating the emissions intensity of crops is a useful tool to understand the impact of production and also to set targets for mitigation [37]. Different outcomes in terms of the best options for mitigation can be found using different accounting methods [38], so using a number of approaches and comparing results can be useful for decision makers. The 'carbon debt' when establishing oil palm plantations in Indonesia has been discussed by van Noordwijk *et al.* (Figure 1) [38]. In this case, an optimal fertilizer level is determined by the production levels at which net emission savings per unit of biofuel are maximized. These figures are then compared to the carbon debt of clearing land – including draining of peatlands, and the loss of forests. The carbon debt and emissions from fertilizer were the dominant factors in the whole life-cycle assessment – showing how important the impacts on the forest sector are for mitigation efforts in agriculture. Palm oil produced on peat soils, and in some cases mineral soils, was found not to meet the current

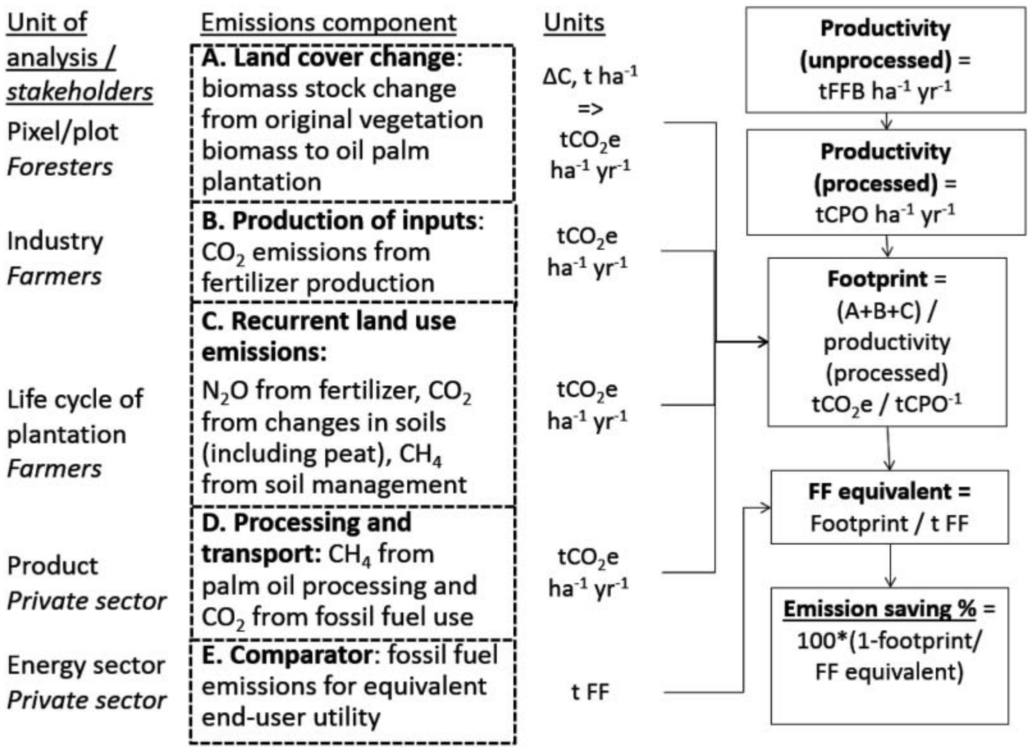

Figure 1. Information flow in an assessment of the emission footprint per unit palm oil, and a subsequent step to estimate the percentage emission saving in biofuel use (adapted from van Noordwijk *et al.* [38]). FFB: Fresh fruit bunches; CPO: Crude palm oil.

EU emissions threshold for biofuel production, which requires at least 35% emissions savings compared to fossil fuels.

In van Noordwijk *et al.* [38], an optimum fertilizer application rate can be identified for a given relationship between fertilizer and yield. Attention to other management choices can, however, shift the relationship between fertilizer and yield, and current fertilizer use on smallholder oil palm farms can be excessive and inefficient [39].

Similarly, Sa *et al.* [35] assessed emissions associated with land-use change over time using the concept of ecosystem carbon payback time (ECPT). ECPT considers how long the annual savings from the LCA activities (in comparison with non-LCA) can repay the debt of conversion (e.g. clearing the forest in the conversion to agriculture). ECPT, expressed in years, represents the time that the intervention has to be effective in order to offset the land use and land use change emissions from the intervention. Implementing activities in areas with the lowest ECPT is a way of minimizing the impact, and the restoration of degraded pastures was found to be one of the most advantageous scenarios, although it still had an ECPT of 56 to 188 years [35]. In the case of Sa *et al.* restoration of pastures was achieved by application of fertilizers, lime and gypsum (accounting for associated emissions related to their application), as well as altering species composition and introducing forage management to increase the carrying capacity. The restoration of grazing land has also been implemented as a National Appropriate Mitigation Action (NAMA), and has been estimated to fulfil 10–12% of pledged emission reductions for the year 2020, due to land spared from deforestation [40]. Restoration of pastures can be a promising tool to reduce agricultural expansion into forests (see e.g. [40], although pasture activity has been found to have mixed impacts on deforestation [41]), and should therefore be considered a priority mitigation action in the agriculture sector. However, in many cases, degraded land has marginal potential for production, even after costly rehabilitation. Lal [42] suggested that agriculturally marginal and degraded soils should be avoided for this purpose (and could be set aside for nature), and that lands with potential for higher yields could be restored, for example those in areas of sub-Saharan Africa and South Asia where there is potential for tripling or quadrupling of yields. Over 1.3 billion people, however, use degraded agricultural land, particularly in the drylands [43], and in general larger soil C sequestration rates can be achieved from interventions to increase C sequestration in degraded soils than from other soils [44]. There are a number of GHG mitigating practices that can be implemented to restore degraded and marginal land, such as the use of cover crops, avoiding overgrazing, using crop residues and organic composts and agroforestry; however, employing these is not always straightforward [45]. The conditions under which yields in sub-Saharan Africa and South Asia could be increased while sparing land should be investigated, utilizing the existing body of evidence on successful CSA interventions [7; see also e.g. 35,38,39,42]. The dichotomy between forest and agriculture itself may prevent the emergence of optimal solutions, as for example in a landscape where fodder for dairy cows can be derived from any part of the landscape [46].

The sink capacity of forests can provide a large and cost-effective contribution toward climate change mitigation [47]. However, agricultural systems can also provide mitigation benefits, as well as contributing to forest sparing. In fact, a recent global study of trees in agricultural lands suggested a considerable carbon stock that has so far been ignored in the accounting [48]. Agroforestry and soils represent a sink potential and technologies such as biogas digesters a promising mitigation potential, and measures related to these potentials have been implemented without compromising agricultural production [49]. Agroforestry has one of the highest land-based potentials to sequester carbon [50,21,51], and provides the adaptation benefits aimed at by CSA. It is also reversible, however, so land can be converted back to treeless agriculture should local priorities change. Reducing emissions from soils storage is possible through a number of management interventions such as increasing inputs that contain C, avoiding over-fertilization of crops, and altering irrigation and tillage regimes [44]. This has received recent attention, for example through the Soils for Food Security and Climate 4‰ Initiative [42,52]. Knowledge gaps exist, however, for example in soil C sequestration processes, turnover and stabilization [45], as do potential trade-offs between soil C sequestration and N_2O emissions [53], making it controversial not least because it is easily reversible. There is currently also an active debate on the potential of the 4-per-mille initiative, and whether the claims (of offsetting 30% of global GHG emissions [44]) are feasible. Although the difficulties of engaging large numbers of people who are using agricultural lands around the world, and the technical challenges in monitoring and verifying results, are discussed [44], other points such as the feasibility of including currently unmanaged rangelands, time to reach carbon equilibrium and depth at which soils can be managed are still being debated [54, among others]. However, identifying areas with the potential to increase soil C stocks at a rate of 4‰ could contribute to climate mitigation efforts, and soils remain an important consideration in the context of this paper, in their role in forest-sparing and food security.

Although interventions exist that not only deliver increased production within a changing climate (food security), but also avoid land-use change (particularly from forests or other high carbon landscapes), robust and inclusive methods to identify which ones can provide the largest mitigation benefits must be used.

Transdisciplinary research approaches and priorities

Transdisciplinary research is vital to set priorities for climate change actions in the land-use sector. Research should recognize the varied interests of each actor by answering questions and delivering results that stakeholders find useful [55]. Approaches should account for the disconnect between the timescales at which various actors operate – for example, climate science considers longer timescales than those at which farmers, and also foresters, make decisions. Using backcasting to develop transition pathways is one way to evaluate options to achieve multiple sustainability objectives [e.g. 5]. In addition, models and tools should be able to assess the outcomes of various interventions related to adaptation, mitigation and food production [56–58]. Trade-offs for stakeholders are inevitable, and need to be evaluated (e.g. in the context of the landscape approach). Smallholder farmers are often key stakeholders who should be consulted, and who will then assess whether they are willing to engage in such interventions. Engel and Muller [59] discuss the potential for incorporating CSA into a payments for ecosystem services (PES) context (e.g. REDD+), and highlight the potential for PES to address reasons why some farmers do not adopt CSA. A PES approach was found to deal with issues such as an unwillingness to wait for medium- or long-term productivity and an aversion to risk, as short-term costs are often required [59]. Other barriers identified included lack of information, insecure tenure and weak property rights. These issues can be addressed by incorporating CSA into the framework of REDD+ projects. Securing tenure and community engagement are key processes for REDD+ implementation.

Landscape approaches could provide a platform for assessing the benefits and challenges of integrating mitigation and adaptation [27,60,61] (also for emissions accounting, as discussed previously). To involve and improve communication between stakeholders and researchers in the landscape, methods using both quantitative and qualitative data can be used (e.g. role playing games [62,63], and innovative participatory scenario planning [64]). Increasing availability of remote sensing data, emerging technologies and community-based monitoring can be the focus of research streams aiming to monitor results from both CSA and REDD+ together [65,66]. Measuring the impacts of ongoing initiatives is key to understanding how to implement a landscape approach.

To have the greatest impact, interventions in the agricultural sector that promote forest land-sparing should be implemented first in areas where most agriculture-driven deforestation and emissions from agriculture are occurring [67]. These were identified at the national level by Carter *et al.* [15]. Emission hotspots have been identified at a much higher spatial resolution by Roman-Cuesta *et al.* [68], through a collaborative effort from the forest and agricultural communities. Hotspots covering 25% of the tropical area are responsible for 70% of the tropical agriculture, forestry and other land use (AFOLU) emissions. All continents have hotspots, and they cover a variety of biomes across the tropics – so these make promising locations for interventions [68]. Typically emissions in hotspots are dominated by forest emissions (69%; e.g. fire, deforestation and wood harvesting), highlighting the important role of forests in mitigation, although livestock and paddy rice also produce high emissions (Figure 2).

One important point for research priorities from the example of Roman-Cuesta *et al.* [68] is that hotspot

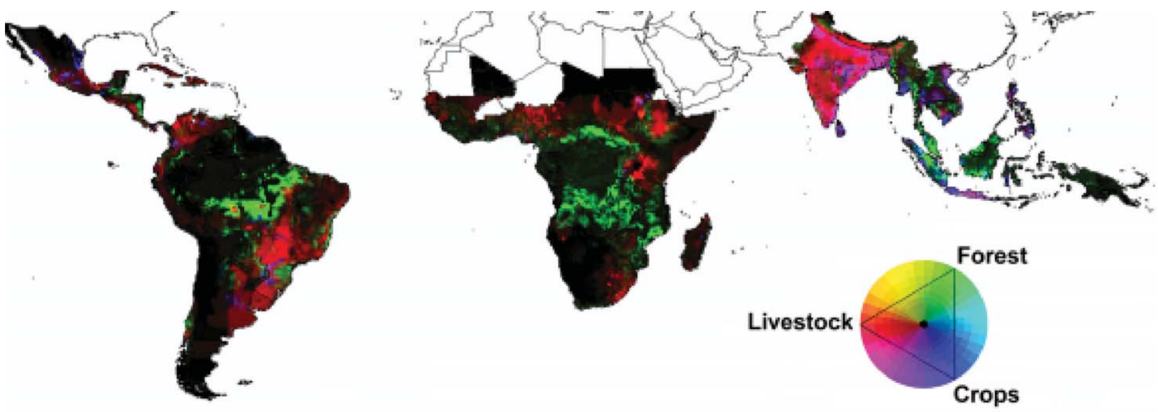

Figure 2. Contribution of the leading emission sources (grouped into forests, crops and livestock) % per pixel (0.5°), 2000–2005. Forest emission sources include fire, deforestation and wood harvesting. Crop emissions include paddy rice, cropland soil and croplands over drained histosols. Livestock includes enteric fermentation and manure management emissions. Colors represent the strength of the emissions for the three sources (e.g. fuchsia in Asia represents equal emissions from livestock (red) and crops (blue). Dark areas are areas of low emissions. Adapted from Roman-Cuesta *et al.* 2016 [68].

regions have the highest uncertainties. These are up to 30% of the mean AFOLU emissions, so research needs to focus on reducing uncertainties for emissions estimates [68]. This is because uncertainty in these estimates leads to uncertain potential benefits from interventions. Forests have the highest uncertainties associated with their emissions, with their uncertainties accounting for 98% of the AFOLU emission uncertainty. This is due to the combined effect of uncertain areas and uncertain carbon densities, so future research could focus on quantifying these variables [68]. The contribution of forests as a carbon sink therefore requires further research, as the impact of the recovery of carbon stocks after wood harvesting and fire could be better understood [68].

Once locations for mitigation initiatives have been identified, the impact of the initiatives must be monitored. Measuring and evaluating mitigation options for smallholder farmers (who occupy most land holdings in developing countries) is difficult due to the lack of available emissions factors and the diversity of smallholder farming systems [e.g. 58]. The needs of the organization doing the measuring also differ in terms of accuracy required, budget and scale of measurements, so one monitoring, reporting and verification system will not suit all scenarios. However, protocols have been developed that offer options for measuring performance according not only to mitigation and adaptation goals, but also to food security and local livelihoods, and which can be adjusted to suit the needs of the project developer [69]. Research could focus on testing and improving such approaches, as well as incorporating monitoring of forests and agricultural interventions using the same system.

Policy coherence

At the international level, agriculture and forests are often addressed through their own international platforms such as the Committee on Food Security for agriculture and the United Nations Forum on Forests (UNFF) for forests, and even through different UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) negotiation tracks. There has been a call for an SBSTA negotiation track on agriculture [70,71], but a better option might be to establish an SBSTA negotiation track that could accommodate landscape issues (including forests and agriculture) in one body. In addition to the UNFCCC, other international interventions and their targets are relevant for both forests and agriculture, including the Sustainable Development Goals, the Soils for Food Security and Climate 4‰ Initiative, the Aichi targets under the UN convention on Biological Diversity, and the land degradation neutrality target under the UN Convention to Combat Desertification. As well as conflicting goals and trade-offs relating to forest and agriculture objectives within these, conflicts among them should be investigated.

At the national level, strong policy coherence is also important [23], and conflicting incentives (e.g. subsidies and tax breaks) should be removed and trade-offs addressed to create a supportive environment for both adaptation and mitigation in the land-use sector. Utilizing the institutional structures of REDD+ (specifically in its national policies, which have been relatively rapidly developed [72]) and integrating CSA should be explored as priorities, particularly where there are clear links between the two (e.g. high-yield palm oil in Peru [73]). Inspiration might be found in India's agroforestry policy adopted in 2014, which opted for an 'agriculture plus forestry' concept in a level playing field: any policy applied to one should be applied to the other, relative to measurable performance. In this case, specific funds were allocated for the harmonization of the approaches [74].

The Nationally Determined Contributions (NDCs) implemented under the UNFCCC relate to different components of the land sector, and could be a starting point for an integrated national approach. In fact, agriculture and forestry are already prominent components of many NDCs, with most parties using forest management and reforestation in their mitigation measures [16], so including agricultural NDCs or linking them to forest mitigation and adaptation could be further developed in future. Indeed, forest-based mitigation could provide a quarter of the emission reductions planned in several NDCs [75].

As the demand for agricultural products is responsible for much deforestation [76], the role of the private sector (including international markets) is important in connecting REDD+ and CSA. Private-sector commitments include green public procurement policies, for example the Roundtable for Sustainable Palm Oil and Round Table on Responsible Soy. One promising example from the private sector is the zero-deforestation commitments that many companies are adopting, even though the choice of net or gross zero deforestation creates space for a disparity of outcomes [77]. Despite these policies being adopted by some companies, a report from Forest 500 reveals that there are still many companies with weak or no policies on deforestation [64].

How to link commitments from the private sector to REDD+ is a key question. Research shows that there is a potential for agricultural value chains to be further integrated into REDD+ and CSA strategies [78]. Examples include 'jurisdictional approaches to zero-deforestation commitments' (JA-ZDCs) that allow policies such as REDD+ to be linked with private-sector interventions that also seek to reduce deforestation. Zero-deforestation policies and REDD+ already exist in parallel, so this option allows their numerous synergies (in terms of social and environmental goals) to be brought

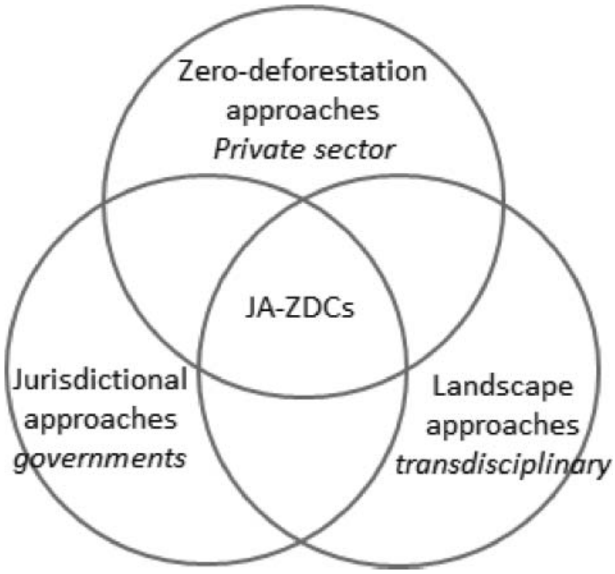

Figure 3. Intersection of three strategies to reduce deforestation which centre around jurisdictional approaches to zero-deforestation commitments (JA-ZDCs). Adapted from [80].

together [79]. These approaches encompass a number of stakeholders and spheres in which they operate, including jurisdictions of governments (national or subnational), private-sector actors, and also a landscape perspective [80] (Figure 3). Notable examples include the Forest, Farms and Finance initiative, whose goal is to link interventions that aim to increase agricultural productivity and improve smallholder livelihoods with interventions that reduce deforestation [81]. Monitoring of these integrated approaches may also be more efficient. The Earth Innovation Institute has proposed a Territorial Performance System, which includes integrated incentives, an online monitoring system and multi-stakeholder governance. Other jurisdictional approaches to zero-deforestation commitments have been led by the private sector, including Marks and Spencer, and Unilever who pledged to preferentially source production from jurisdictions that adhere to a number of criteria including that the jurisdiction has a strategy for reducing emissions from deforestation [82]. Success of integrated approaches has been seen in the Brazilian Amazon, for example, where deforestation has been halted due to a combination of efforts from both the private sector and jurisdictional government, and voluntary efforts in the landscapes [83].

In addition to supply-side policies, policies or efforts to address demand for different types of food are needed. Demand-side measures have been suggested to have a greater mitigation potential (1.5–15.6 Gt CO_2-eq. yr^{-1}) than supply-side measures (1.5–4.3 Gt CO2-eq. yr^{-1}) [84]. They are, however, difficult to achieve and require great societal change and commitment. One example requiring social commitment is diet change. Since there is a strong relationship between income and meat intake, future increases in meat consumption are expected. Limiting animal protein intake can save land [85,86]. Examples of mechanisms that can achieve societal change are Voluntary Sustainability Standards (VSS) that inform consumers about the sustainability of goods [87]. Examples are Forest Stewardship Council (timber), Marine Stewardship Council (fish) and UTZ (coffee). Although they originate from private and civic sectors that cooperate to 'green' global value chains, governments can – and do in various cases – actively endorse these through their own policies (the Netherlands being an example). An integrated framework for analyzing where and how standards and certification emerge and evolve in the case of tropical timber, coffee, cacao, palm oil and rubber is provided by Mithöfer *et al.* [88]. VSS with very high social and environmental requirements provide information to consumers. However, they represent a small segment of the market, so product-wide commitments even with lower requirements could also lead to a larger impact. The Carbon Disclosure Project is a platform where companies can voluntarily report their environmental impacts, and most of the largest companies in the world participate [89]. Like voluntary standards, this information allows investors and consumers to make informed choices; however, the system remains voluntary. Mandatory reporting could provide more comprehensive information on emissions and carbon management practices, although reporting of practices to reduce emissions does not necessarily lead to a reduction in emissions [90]. The authors recommend that any future reporting should indicate the emissions reductions made by the company as well as reporting on forest impacts, both direct and indirect, from the supply chain. This would be part of monitoring the three components of CSA.

Transparency

Transparency should be understood as a catalyst for action by providing open and consistent data, definitions, assumptions and methodologies for an assessment of the credibility and reliability of land-use-sector mitigation and adaptation activities in both developing and developed countries. Transparency and open data allow the sharing of information between the forest and agriculture sectors, thus allowing the goals to be evaluated together. Enhancing transparency is now a fundamental step to make the bottom-up nature of the PA work in practice, and increases accountability for the various stakeholders involved [91]. This development is supported by an increasing set of free and open data and methods, for example through Global Forest Watch [92], OpenForis [93] and Global Open Data for Agriculture and Nutrition (GODAN) [94]. On the national level, enhancing transparency for emissions accounting, including estimates for mitigation action impacts (for example NDCs) [75], is already one of the reporting criteria for the IPCC GHG inventories (transparency, accuracy, completeness, comparability, consistency) [95]. Such national reporting will be increasingly compared to independent data sources as part of the technical reviews and UNFCCC global stock-takes. National and other independent data sources should become available for local stakeholders to underpin their mitigation and adaptation activities. This should target non-state actors in particular, such as land owners, farmers, local communities and the private sector, to stimulate them to participate in and achieve more climate-smart land-use decisions and actions. Transparency for the private-sector initiatives (e.g. zero-deforestation commitments) is key to ensure that consumers trust in results, and independent assessments or third-party verification is a requirement for the voluntary sustainability standards mentioned earlier. Transparency should be multi-dimensional and interactive, and cover all stakeholders, thus being a pathway to engagement. Open and transparent sharing of information is essential for collaborative design and interactive processes to involve communities, for example using the participatory methods described by Salvini *et al*. [62]. This has been shown to reduce the risk of failure in mitigation activities, for example in the case of the voluntary carbon market that led to a decrease in credit prices [96]. Thus, transparency should become a key element in planning, implementation and reporting of activities related to reducing the impact of agriculture on forests, with a particular need to address the following issues:

- Provide data, case studies and guidance, which can be used to identify emissions reductions related to CSA activities that reduce agriculture expansion into forests, and can therefore assist in decision-making priorities and reporting at the national level, as well as contributing to UNFCCC-coordinated technical assessment processes and upcoming global stock-take(s);
- Underpin multi-stakeholder processes, involving both the agriculture and forest sectors, for streamlining pathways to achieve land use sector mitigation and adaptation on the national (i.e. NDCs) and landscape scales, as well as increasing food production;
- Facilitate participatory monitoring for tracking and impact assessment of land-use mitigation activities involving the private sector engaged in zero-deforestation, civil society and government agencies.

Conclusions

New local integrated solutions, transdisciplinary research approaches and priorities, policy coherence and transparency can all be independently sought and achieved, but transformational change will only happen when they are pursued simultaneously. We recommend that this transformational change include several components. First, that landscape-level accounting is used to assess the mitigation potential for interventions in the agricultural sector, which not only deliver increased production within a changing climate (food security), but also avoid land-use change (particularly from forests or other high carbon landscapes) where possible. Second, interventions in 'hotspot' regions, where the most emissions are occurring are given priority. In order to limit global average temperature increase to 1.5°C, attention should first be given to those emissions hotspots, and all aspects of the land sector – particularly the potential of the agriculture and forest sectors – should be utilized. Research should focus on decreasing uncertainties in emissions estimates in the land sector, so that more accurate mitigation potentials can be calculated. Third, policies at all levels must be coherent, and must support both mitigation and adaptation. At the international level, landscape issues should be discussed together. At the national level, institutional structures from REDD+ can be used to support CSA interventions, and these can also integrate private-sector actors, such as through JA-ZDC. Demand-side measures are also achieved and can be furthered through voluntary private-sector standards, for example. Fourth, transparency can be used to build trust, and to encourage the engagement of stakeholders. Support from the international community, including scientists, through the development of open data and tools can ensure that these initiatives are successfully implemented. This transformational change will also support other platforms, for example Sustainable Development Goals 2, 13 and 15 in particular, which focus on hunger, climate change and sustainable management of natural resources.

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