

The role of supply-chain initiatives in reducing deforestation

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A major reduction in global deforestation is needed to mitigate climate change and biodiversity loss. Recent private sector commitments aim to eliminate deforestation from a company's operations or supply chain, but they fall short on several fronts. Company pledges vary in the degree to which they include time-bound interventions with clear definitions and criteria to achieve verifiable outcomes. Zero-deforestation policies by companies may be insufficient to achieve broader impact on their own due to leakage, lack of transparency and traceability, selective adoption and smallholder marginalization. Public-private policy mixes are needed to increase the effectiveness of supply-chain initiatives that aim to reduce deforestation. We review current supply-chain initiatives, their effectiveness, and the challenges they face, and go on to identify knowledge gaps for complementary public-private policies.

Growing public concern about the contribution of forest loss to climate change and biodiversity decline has spurred new initiatives by private sector actors to eliminate deforestation from their operations and supply chains. These efforts include the adoption of aspirational goals by single companies or coalitions of actors, corporate codes of conduct and sustainability standards that, in some cases, are implemented through certification schemes and moratoria. Convergence with public-sector goals to reduce emissions from deforestation and forest degradation, and increased pressure from civil society, have created a window of opportunity for increasing the scope and impact of private sector zero-deforestation commitments.

The number of private commitments to reduce deforestation from supply chains has greatly increased in recent years, with at least 760 public commitments by 447 producers, processors, traders, manufacturers and retailers as of March 2017¹. These sustainability pledges are part of corporate social responsibility strategies that have been embraced by companies to meet society's expectations^{2,3} and of growth strategies to improve branding and consumer loyalty, reduce reputational risk, increase market shares and profits^{4,5}, mitigate potential losses of critical environmental services⁶ and ensure long-term supply⁷. However, whether a commitment leads to measurable reductions in deforestation depends, in part, on corporate motivation. If the primary motivation is image building or decreasing reputational risk, companies are likely to emphasize communication of vague or easy-to-achieve goals, with little

on-the-ground impact. If instead companies are truly motivated to make their business more sustainable, then transformations of their supply chains are more likely, with impacts on land use. Some companies also participate in collective commitments. For example, 60 public, 59 private and 73 civil society actors have pledged, as part of the 2014 New York Declaration on Forests (NYDF), to at least halve the rate of natural forest loss by 2020 and strive to end natural forest loss by 2030. Under the same declaration, corporate actors pledged to end deforestation driven by major commodities by 2020 or sooner⁸. Similar actors also participate in the Tropical Forest Alliance 2020 (<https://www.tfa2020.org>), a public-private effort to reduce deforestation-related emissions from major global supply chains.

Understanding the implementation and effectiveness of these zero-deforestation commitments is challenging because: (1) they involve a wide range of companies, commodities, supply chains and geographies⁷, (2) they are diverse in their wording, scope, timelines for implementation and level of transparency, (3) many are recent, which limits the availability of evidence on their outcomes, and (4) they interact in synergistic or antagonistic ways with public and multi-stakeholder efforts⁹, which makes it difficult to assign responsibility for changes.

Guidance is needed to inform the design, implementation and monitoring of these supply-chain initiatives to reduce deforestation. Here we ask: what are these initiatives? Are they effective? And are they sufficient to reach their goals? What challenges do they face

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to reach meaningful reductions in deforestation globally? Can public and private policies reinforce each other to achieve this goal? Our findings suggest that outcomes from zero-deforestation initiatives could be improved by an integrated approach whereby public policies complement private actions, the resulting policy mixes are equitable and tailored to local context, and policies are structured to allow ongoing monitoring and verification.

Supply-chain initiatives

We propose a typology of strategies pursued by private sector actors to reduce deforestation based on two questions:

- (1) Was the strategy adopted independently by a single company or as part of a multi-stakeholder process? Single company initiatives can be tailored more precisely to the specific conditions a company faces, and they clearly assign responsibility to that company. In contrast, multi-stakeholder initiatives benefit from peer pressure and diverse perspectives, which potentially leads to greater legitimacy and transparency, but also dilutes responsibility¹⁰.
- (2) Does the initiative only define and communicate goals, or does it also implement actionable changes? Goal setting is an important step in coalescing, defining and communicating a vision of change. However, for goals to be reached, specific actions must be implemented.

We identify four categories of initiatives aiming to reduce deforestation (Table 1): (1) collective aspirations by stakeholder groups that go beyond the direct control of individual actors; (2) company pledges that express a company's commitment in their operations or supply chains; (3) company codes of conduct that define specific production or sourcing practices; and (4) sectoral standards including principles, criteria and forms of verification agreed on by several stakeholders within a sector that seek to foster alignment among actors. Sectoral standards may include either positive incentives (such as price premiums for certified products) or sanctions (moratoria on purchases from deforested lands, for example) on suppliers.

These initiatives vary significantly in scope, ambition and stage of implementation (Table 2), depending in part on the competitive environment faced by companies¹¹. Companies have variously pledged to meet targets of zero deforestation, zero net deforestation (that is, allowing for some deforestation provided it is compensated by reforestation elsewhere) or zero illegal deforestation (to abide by forestry laws in producing countries)¹². These can be achieved across an entire company; for a specific commodity such as palm oil, soy, beef, cocoa or pulp and paper; for a specific region; or they may be limited in scope to a combination of sector and region. Definitions of what is meant by forest, cut-off dates and target dates for implementation and deforestation reduction are rarely specified. Some commitments do not explicitly target deforestation but rather aim at increasing sustainable practices, which may indirectly benefit forest conservation.

Collective aspirations define broad, common objectives for multiple stakeholders, such as the NYDF. In striving to achieve transformation across broad swaths of the economy or planet, these goals fall outside of the direct control of any individual participant. Collective aspirations are often accompanied by recommended best

practices for meeting the aspirations, but infrequently specify who is accountable or how they will be implemented¹³.

Company pledges are publicly stated goals by single companies to eliminate deforestation from their operations, either associated with specific commodities and/or regions, or across entire supply chains. These pledges often involve a commitment to exclusively produce or source commodities associated with no deforestation, along with other social or environmental criteria (for example, child labour, environmental management). Most of these pledges are vaguely formulated¹⁴. Commitments vary greatly by sector. Far more companies sourcing and producing timber and pulp and palm oil have made commitments on deforestation than is the case for companies in the soy and cattle industries, despite the cattle sector being the largest driver of deforestation^{1,14}.

Company codes of conduct describe specific actions that are designed and managed by a company to reduce deforestation from its operations and supply chains. For example, they may require sourcing from approved suppliers who meet pre-defined sustainability principles (such as no deforestation); give preference to suppliers who offer third-party certified products; exclude sourcing from deforestation hot spots (for example, leather from the Amazon); or audit suppliers' operations against social and environmental requirements.

Sectoral standards are specific norms and criteria adopted by groups of companies to define their practices with respect to sustainability. The creation and availability of sectoral standards have helped to precipitate many of the company pledges. They help to operationalize and standardize codes of conduct across multiple actors within a supply chain. Standards may be defined by actors within the supply chain or through multi-stakeholder processes with external actors. They can be used by downstream manufacturers, retailers or consumers to allocate either positive incentives or market sanctions to upstream actors, such as producers or traders.

Sectoral standards that are used to incentivize positive behaviour include a variety of commonly agreed-on practices such as the protection of high conservation-value areas or eco-certification schemes. Certification requires producers to comply with specific production criteria. Compliance often involves significant costs to upgrade management practices, segregate supply chains and verify conformity¹⁵. Despite most commodity certification schemes not being designed to guarantee zero deforestation, certification has been widely adopted to help meet targets linked to deforestation-free supply chains¹⁶. For example, the Consumer Goods Forum, a group of over 400 companies whose board adopted a resolution to achieve zero net deforestation by 2020, suggests that members who adopt this voluntary commitment may achieve this goal by applying certification standards — for example, the Forest Stewardship Council (FSC), the Programme for the Endorsement of Forest Certification (PEFC), the Roundtable for Sustainable Palm Oil (RSPO) and the Round Table for Responsible Soy (RTRS)¹³. In 2015, more than 85% of companies with commitments to reduce deforestation in the palm, timber and pulp, soy and cattle supply chains relied on third-party certification to identify commitment-compliant commodity supply¹⁷. Certification systems can be used as a mechanism for preferential market access, such as the national commitments for sustainable palm oil alliances of ten European countries, whose members (constituting major industry associa-

Table 1 | Typology of the main private policy initiatives used to promote zero deforestation

		Purpose of initiative	
		Goal setting	Implementation
Actors involved in adopting initiative	Company	Company pledges	Codes of conduct
	Multiple stakeholders	Collective aspirations	Sectoral standards

Table 2 | Characteristics of the main supply chain initiatives used to promote zero deforestation

Initiative		Examples	Approach	Opportunities	Challenges*
Collective aspirations		Consumer Goods Forum, TFA2020, and 2014 New York Declaration on Forests	Broad, collective objective by a group of stakeholders	Potential to affect multiple commodities and regions	On their own, may lack accountability and fail to provide a clear path for implementation
Company pledges		Zero deforestation commitments by Wilmar, GAR, APP, Unilever, Cargill and McDonald	Establish and communicate a company's commitment to reducing deforestation	Combine a vision of change with clear accountability	Uncertain implementation, sometimes vague criteria and timeline
Codes of conduct		Approved supplier lists, and Unilever's Responsible Sourcing Policy	Set internal policies for production and sourcing practices	Provide actionable steps to reduce deforestation, tailored to a specific company's needs	May overlook perspectives of other stakeholders; often low transparency; difficult to monitor or verify. Potential for misaligned incentives to pass suppliers
Sectoral standards	Incentives	Certification programmes for sustainable production of palm oil, soy and sugarcane (developed by Roundtables or by certification bodies — for example, the Sustainable Agriculture Network)	Standardize sustainable production practices across participants; enable the assignment of market access or price premiums	If sufficiently stringent, changes behaviour at the property level; may address sustainability broadly	May reward those who comply easily (little additionality); unlikely to influence large regions
	Sanctions	Brazil's soy and cattle moratoria	Identify practices to be discouraged through market penalties by other actors within the supply chain	May reduce deforestation in a large region or biome for specific commodities; easy to monitor and communicate	Risk of leakage to other geographies and commodities: may shift patterns of clearing without stopping deforestation overall

*In general, and unless efforts are made to mitigate harm to local communities, these initiatives risk having disproportionately negative impacts on small-scale producers due to their dependence on local resources and unclear land rights in forest frontiers.

tions and brands) agreed to import only RSPO-certified palm oil by 2015¹⁸. In 2015, the Belgian and Dutch Alliances for Sustainable Palm Oil achieved 100% and 84% certified palm oil imports respectively¹⁹. In certification schemes, price premiums for producers are often low, if not absent. Global brands emphasize benefits such as preferential market access and improved farm management practices rather than premiums.

Sectoral standards used as supply-chain sanctions are market-exclusion mechanisms, such as moratoria on sourcing from deforested lands. They are associated with producers' compliance with land-use regulations or standards. Non-compliant producers face restricted market access, but neither traders nor producers receive price premiums. Moratoria tend to be an immediate response to strong external pressures and are focused on deforestation. This narrow scope facilitates adoption, monitoring and communication with producers. So far, implemented private-sector moratoria have been limited to single commodities and regions, such as the Soy Moratorium and Zero Deforestation Cattle Agreements in the Brazilian Amazon^{20,21} or the Joint Solutions Project governing timber production in Chile²². Companies implement market exclusions immediately, in contrast to certifications standards, which tend to be implemented gradually. Market exclusion considers all suppliers to be in compliance until they are demonstrated to breach a rule, whereas certification requires each producing property to adhere to a standard.

Many initiatives are running simultaneously and have the potential to reinforce each other to achieve forest conservation. For example, Cargill's *Forest Protection Action Plans* outline the

implementation steps to meet the internal targets of its *Policy on Forests*^{23,24}. These codes of conduct commit Cargill to existing standards, including supporting incentives for reduced forest clearing (for example, RSPO certification of palm oil) and excluding products associated with deforestation (such as Brazil's Soy Moratorium). Other multinational companies such as Unilever, Nestlé or Wilmar pursue a similar approach. More broadly, most of the 59 multinational companies who signed the collective aspirations of the NYDF have adopted consistent internal targets and specific codes of conduct governing production and sourcing, sometimes relying on pre-existing sectoral standards for their implementation⁷. These standards often apply only to select commodities or geographies.

Evidence on effectiveness

We examined recent studies for evidence on whether the following private zero-deforestation initiatives have reduced deforestation or — as a proxy — led to behavioural changes that are expected to ultimately reduce deforestation (see Method in Supplementary Information).

Collective aspirations and company pledges. As visionary statements of broad goals, collective aspirations and company pledges can primarily be evaluated based on: (1) their ambition and attainability (for example, zero net deforestation is less ambitious but might be easier to attain than zero gross deforestation), (2) whether they include specific company actions (such as a pledge to purchase certified products) and (3) whether they triggered and legitimized

an implementation process. In response to recently announced collective aspirations, a rapidly growing number of companies have adopted and reported on company-specific supply-chain pledges¹. Nevertheless, the translation of these pledges into time-bound actions such as codes of conduct is lagging⁷. As of 2016, only 20–25% of the member companies of the Consumer Goods Forum with sustainability commitments had developed their own quantified and time-bound action plan to reduce deforestation and had put in place measures to ensure compliance in their business processes or suppliers^{25,26}. These are some of the conditions for both on-the-ground outcomes and verification of attained targets by external actors. The Sustainability Consortium, whose 43 corporate members include General Mills, Mars and Walmart, has developed toolkits to help companies implement actions for a range of sustainability concerns. The Consortium provides metrics to track performance and assesses the percentage of members avoiding high conservation-value or high carbon-stock areas in commodity supply chains. In 2016, the status of implementation was below 50% in any commodity²⁷.

Company codes of conduct. Empirical research on the effectiveness of company codes of conduct is scarce, due to the often proprietary nature of such information²⁸ and to limited disclosure about implementation progress. One example, Starbucks' Coffee and Farmer Equity standard, was shown to help coffee farmers increase yields and uptake of good agricultural practices²⁹, which may have decreased the expansion pressure on forests. Research on voluntary corporate approaches to pollution reduction in the United States suggests that, without third-party oversight, firms with environmental commitments do not perform better than companies with no such commitments^{30,31}. Other research, however, shows that audit-based approaches encounter difficulty in changing supplier practices because they can conceal violations during audit visits^{32–34}. Wider adoption of satellite monitoring for verification might help to address this concern for deforestation. Overall, there is a lack of evidence on the effectiveness of approaches such as approved supplier lists in changing suppliers' practices.

Sectoral standards used to assign incentives. A growing literature provides somewhat mixed evidence regarding the potential for certification to reduce environmental and social impacts^{35,36}. Tree cover in certified coffee farms in the eastern Andes of Colombia increased significantly more than tree cover on non-certified farms³⁷. FSC certification had no or minimal effect on deforestation in Mexico³⁸, Cameroon and Peru³⁹, but reduced deforestation in certified forests in Chile²² and Indonesia⁴⁰. In Indonesian oil palm plantations, RSPO certification led to reduced deforestation, although certified plantations were also those with the least remaining forest area⁴¹. Fire activity in Sumatra and Kalimantan was significantly lower on RSPO-certified concessions than non-RSPO-certified concessions, but only for years and locations with a low likelihood of fire⁴².

Sectoral standards used to assign sanctions. Immediate, sector-wide sanctions, often combined with improvements in public sector governance, have been shown to change suppliers' land-use decisions and practices. For example, soy expansion at the expense of forest in the Brazilian Amazon declined dramatically after 2004 due to a combination of factors that included public enforcement efforts and the Soy Moratorium^{20,43}. In 2009, major meatpacking companies in the Brazilian Amazon signed zero-deforestation cattle agreements. As a result, these companies now monitor the land use of their direct suppliers, which fatten more than half of the cattle slaughtered in the Brazilian Amazon²¹. Major slaughterhouses that control a third of the slaughter in the state of Pará stopped buying from direct suppliers with post-2009 deforestation. They also incentivized ranchers to enrol their properties in a rural environ-

mental land registry, which stores georeferenced property boundaries for monitoring purposes²⁰. However, by 2014, the agreements had no average impact on forest cover in the regions surrounding signatory slaughterhouses in Mato Grosso and Pará due to leakage to nearby properties⁴⁴. In 2017, scandals in Brazil's meatpacking industry highlighted the low reliability of the data used to track the origins of beef from indirect suppliers. In Chile's timber sector, public campaigns by environmental non-governmental organizations led retailers to demand an end to deforestation. In response, the three largest forestry companies agreed to stop clearing native forests for plantation expansion. After adoption of this zero native deforestation standard, properties controlled by these companies experienced a significant reduction in deforestation in comparison to other forestry properties in Chile²².

Challenges

Although collective aspirations and pledges are important tools for communicating a vision of a deforestation-free world, direct actions are required to precipitate on-the-ground change. The vague nature of many company commitments may lead to greenwashing, defined as poor environmental performance accompanied by positive communication about environmental performance⁴⁵. Actionable interventions such as company codes of conduct and sectoral standards generally focus on individual supply chains. Achieving changes in land use within supply chains or regions is not sufficient to reduce global deforestation. Leakage, low and selective adoption, and unintended social consequences all undermine the potential of private interventions to aggregate towards meeting broader aspirational goals.

Leakage occurs when interventions with a limited geographic scope restrict the production of commodities in one place, therefore decreasing supply of those commodities and encouraging displacement of production to other locations. Local leakage occurs under Brazil's cattle agreements when ranchers move their cattle from a ranch with deforestation to one free of clearing to 'launder' cattle, or when they sell to slaughterhouses that are not part of the agreement^{21, 44,46}. Under the Soy Moratorium, on-property leakage may occur when soy farmers continue to deforest for non-soy land uses such as cattle ranching^{20,47}. Compliance with government anti-deforestation policies and country-specific supply-chain initiatives may also cause leakage across political boundaries. Large-scale soy and cattle producers in the Chaco region of Argentina, Paraguay and Bolivia tend to acquire land for deforestation in areas with laxer regulations, so that local increases in deforestation regulations displaced deforestation to neighbouring areas⁴⁸. This changing governance context may also reorient trade patterns, causing reductions in exports from regions with more stringent deforestation regulations that are redirected to domestic markets⁴⁹. Leakage is likely to occur whenever interventions limit production, unless demand is reduced or met by other means.

Low adoption rates for voluntary programs, due to unclear business cases and costs of compliance, are also a challenge for private sustainability schemes^{15,50}. Producers must typically bear most of the costs of shifting towards deforestation-free production systems and do not always perceive the benefits of such schemes, especially when there are no price premiums for doing so. In some cases, companies, donor organizations or governments cover these costs for small producers. For Brazil's soy and beef moratoria, producers, processors and traders are subject to restrictions beyond the cost of legal compliance, but are not compensated for the opportunity costs generated by these restrictions outside of potential preferential market access⁵¹.

As certification schemes are voluntary, they have a gradual uptake and only cover a fraction of producers in a region. Their impacts can thus be weakened by selection bias if producers who can easily comply due to previous deforestation, favourable location or

pre-intervention compliance, are more likely to participate⁵². RSPO member companies preferentially certified non-forested areas that were cleared long ago⁴¹. This selective adoption is expected to constrain or nullify the additional protection that voluntary sustainability schemes provide for forests, especially with low adoption rates.

Supply-chain initiatives can have unintended social consequences by entrenching positions of powerful actors and excluding smallholders and indigenous groups from market access^{53,54}, though in some cases they help small-scale producers retake control of price setting from large multinational companies⁵⁵. Zero-deforestation initiatives may disadvantage small-scale producers and companies, who can play an important role in both deforestation and conservation^{56,57}. The costs of complying with environmental and social standards may increase market consolidation and push small and less price-competitive companies to less demanding markets or even out of business. Farmers with good access to capital and technology are more likely to comply with zero-deforestation standards, further marginalizing poorer producers, which goes counter to broader sustainability goals. The certification of legality, which is increasingly adopted in the timber sector, risks criminalizing local small-scale producers unless accompanied by adequate tenure and legal reforms protecting local access to forest resources^{58,59}. Recently, some supply-chain initiatives have taken steps to encourage smallholder participation and avoid their exclusion, such as the RSPO's smallholders certification programme.

Supportive public policies

Supply-chain initiatives by private sector actors have the potential to contribute to reductions in deforestation if they are associated with effective on-the-ground actions. This requires greater action from the private sector, but also supportive public policies — an essential component to enhancing the success rate and scale of supply-chain initiatives. Research from other sectors suggests that government regulatory quality is a key predictor of the effectiveness of company-led sustainability approaches⁶⁰. Governments can encourage industry self-regulation through the threat of stronger public regulations, endorse and reinforce private standards, facilitate information sharing and supply-chain transparency, cover the costs of compliance of small producers and create mechanisms to avoid free-riding⁹. We identify major knowledge and implementation gaps that should be addressed to enhance the complementarity of private and public-sector efforts to reduce deforestation.

Supporting legal reforms and enforcement. Zero-deforestation supply-chain initiatives suffer from shortcomings in laws and in their enforcement in commodity-producing countries. Increasingly, laws in importing countries, company codes of conduct and sectoral standards require compliance with laws in the producing country. However, these laws may be weak and contradictory, and are often poorly enforced due to the limited capacity of public agencies and corruption. As a result, zero-deforestation supply-chain initiatives adopted by private actors often go beyond legal requirements. They may also challenge existing regulations such as Indonesia's 2014 Plantation Law, which requires clearing forests within permitted agricultural concessions⁶¹. Continued pressure and support from private actors and civil society to achieve the necessary legal reforms and consistent enforcement improve public governance and ensure a level-playing field for companies⁶². We need to better understand how supply-chain interventions can effectively support improvements in legal frameworks and their enforcement to produce systemic and jurisdiction-wide beneficial impacts.

Reforming land tenure without triggering more deforestation. Unclear and insecure property rights may weaken incentives for land users and financial institutions to invest in sustainable land-use practices that reduce deforestation. A lack of documented property

boundaries also constrains efforts by private-sector actors to limit deforestation in their supply chains due to difficulty in linking specific suppliers to land-use practices^{63,64}. Clarifying property rights, including through recognition of local and customary systems of land and resource tenure where appropriate⁵⁸, might facilitate implementation of zero-deforestation commitments. Tenure reform may also help prevent negative social impacts of supply-chain interventions by ensuring that poor and marginalized farmers are not criminalized or excluded⁵⁹. However, in a few countries, national policies still make tenure security conditional on developing the land, among other criteria, thus creating a disincentive for forest conservation⁶⁵. Land tenure reforms can also spur deforestation by sparking greater investments in agriculture, land competition and exclusion and displacement of the poor to forest areas⁶⁶. The impact of tenure security on forest conservation is thus ambiguous: it depends on local context and the form of tenure⁶⁷. Better understanding of this land tenure–deforestation nexus is needed to identify safeguards against potential perverse environmental effects of improved land tenure clarity in specific contexts.

Reaching marginal forest users. Moratoria and certification may not adequately reach actors who are producing for domestic or informal markets. In addition, stringent voluntary standards tend to be adopted by a subset of producers who are already in, or close to, compliance, thus causing a selection bias. Public policies can help private efforts by identifying actors that contribute most to deforestation, and improving the capacity of these actors to achieve and demonstrate sustainable land management. For example, Brazil designed payments for environmental services to compensate farmers for conservation actions, thus reducing income losses for those hit hardest by law enforcement and providing additional income to some land users⁶⁸. Government and private-sector programmes may also mitigate the marginalization of smallholders — for example, by offering better access to technologies, information and financial resources. We need to better understand how private and public land-use governance can complement each other in providing incentives and disincentives for all forest users, whether small- or large-holders.

Broadening the scope of interventions. Including more companies, regions, commodities and supply chains could decrease the leakage of deforestation to unregulated and unmonitored regions or segments of supply chains. Yet, companies have few means to extend impacts beyond their own supply chains. They are also likely to adopt non-comprehensive standards that give them some leeway. The scope of initiatives to reduce deforestation may increase if multiple initiatives with collective aspirations cooperate, through public–private partnerships, for example. Recent efforts aim to expand the reach of Brazil's cattle agreements to the entire supply chain by including indirect suppliers that are not currently monitored by slaughterhouses. Similar sectoral standards are being discussed for soy and cattle in the Cerrado and Chaco biomes. Certification across an entire jurisdiction, such as the 2015 commitments by the governments of Central Kalimantan (Indonesia) and Sabah (Malaysia) to certify palm oil production for the whole province or state, is a new approach to expand the scope of commitments. We need an improved understanding of how government action can help to integrate jurisdiction-wide and farm-level supply-chain interventions across multiple commodities.

Incentivizing producers to participate in supply-chain initiatives. To increase adoption, compliance with sustainability requirements must be economically and technically feasible for producers. This requires that all value chain actors, not just the producers or processors, share costs and risks. For example, providers of inputs (such as fertilizer companies) and transport (freight ship companies, for example) have, by and large, remained outside zero-defor-

estation initiatives. For producers to shift their practices, traders, retailers, research agencies and governments must develop business cases and incentives for deforestation-free products. In addition to price premiums, alternate mechanisms can facilitate adoption by covering compliance costs at the producer level, such as subsidies, favourable financing or contract terms, international climate financing and official development assistance. Once enrolled in programmes with sustainability requirements, producers generally value improved market access and non-monetary benefits, including greater efficiency, higher yields, technical aid and access to information^{29,69}. Once participants in zero-deforestation programmes demonstrate compliance, it becomes more efficient for their purchasers to buy from them over others that must be vetted²¹. To overcome barriers to adoption, certification bodies have increasingly adopted a stepwise approach, enabling producers to gradually move towards improved social and environmental performance⁷⁰. We need a better understanding of how both monetary and non-monetary benefits of sustainable production practices lead them to outcompete existing practices and motivate adoption by producers.

Improving traceability and transparency. Traceability along the supply chain and verification of compliance lend external credibility to zero-deforestation commitments. In the case of palm oil, despite progress in traceability between mills and refineries, global traders and producers are not always able to trace the origin of fresh fruits bunches sold by third-party suppliers to independent mills. This may allow fruits cultivated on illegal forest or park encroachments to enter global supply chains⁷¹. A transparent system requires substantial investments in data collection for monitoring and verification. Some governments have better institutional and financial resources to collect such data than private-sector actors, and may better guarantee long-term open access to data. For example, Brazil's satellite-based forest monitoring system and targeted public enforcement efforts that are based on this monitoring contributed to recent success in reducing deforestation^{72,73}. These monitoring data have also been essential to efforts by companies to avoid purchasing soy and beef from deforested areas^{20,21}. Brazil's rural environmental registry (Portuguese acronym CAR) is another centrepiece to ensure accountability of private-sector standards, but coverage is not yet complete and most CAR registries are self-declared and not validated⁷⁴. When governments are unable or unwilling to provide data, non-profit platforms (such as the Global Forest Watch and Trase), private monitoring companies and civil society–corporate partnerships are collecting some of the data needed to improve traceability and transparency⁷⁵. However, some dimensions of sustainability — such as forest cover change — lend themselves more readily to external surveillance than others (biodiversity and local welfare, for example). The multiplicity of actors and initiatives that are involved in uncoordinated data collection does raise questions about validation, confidentiality, interoperability and coverage, suggesting a need to better integrate disparate transparency efforts.

Stepping up demand-side measures. The global demand for sustainable products is still limited. Demand in importing countries can expand through public procurement policies, investor standards, labelling requirements and consumer information campaigns. In the 2015 Amsterdam Declaration, several European countries committed to eliminate deforestation from agricultural commodity chains. Similar pledges by governments and companies in emerging economies, particularly in Asia and South America, would greatly expand the market for deforestation-free products. We need to better understand how country- and company-level commitments reinforce each other by stimulating demand for deforestation-free goods. We must also examine how the single-issue focus of these initiatives on zero deforestation is impacting other dimensions of sustainability.

Conclusion

Influential private actors are making commitments to reduce deforestation in their commodity supply chains. Recent research demonstrates that: (1) collective aspirations by the private sector and company pledges to end deforestation, while laudable, require implementation through a combination of internal codes of conduct and sectoral standards; (2) fully implemented supply-chain interventions can have measurable impacts on producer behaviour and deforestation rates within target supply chains; (3) these impacts are largely insufficient to lead to an end to deforestation; (4) aggregate impacts of these interventions can be undermined by leakage, low and selective adoption and unintended consequences on smallholders and (5) effective supply-chain initiatives by private actors depend on public policies that can help overcome these challenges. Zero-deforestation initiatives by individual companies may fail to target the forms of deforestation that are most difficult to address, including those associated with illegal activities or poor forest governance more generally. Governments play an important role in generating incentives and threat of sanctions for adopting sustainable practices, creating and maintaining key infrastructure (for information sharing and law enforcement, for example), and implementing measures and safeguards to avoid perverse effects on small producers. However, much remains to be understood about the complex policy ecosystems in which zero-deforestation commitments are implemented and how multiple, often parallel, initiatives influence commitment effectiveness. Public and private environmental policies need to complement and reinforce each other rather than fragment efforts. In a remarkable development, many private-sector actors have made commitments to eliminate deforestation from their supply chains. The eventual success of this ambition requires mechanisms for effective on-the-ground implementation and policies from the public sector that create the foundation for effective environmental governance.

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E.F.L. and H.K.G. conceived and chaired the workshop that led to this paper. E.F.L., H.K.G. and R.H. led the paper writing. R.H., K.M.C., L.C.F., R.D.G., Y.I.P.d.W., C.L.McD.,

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Competing interests

The authors declare no competing financial interests.

Additional information

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