Measuring Impacts of Supply Chain Initiatives for Conservation: Focus on Forest-Risk Food Commodities

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1. Executive summary

This report summarizes the main outcomes of forest conservation initiatives adopted by global agro-food companies. We focus on beef and leather, soybean, oil palm, coffee, and cacao, which have the highest risk of being cultivated on areas that have been deforested.

Four categories of supply chain initiatives can be discerned, according to their level of specificity and stringency: collective aspirations, company pledges, codes of conduct, and standards. Standards can be further divided into: i) standards that provide positive incentives for conservation to commodity producers (e.g., the Round Table on Responsible Soy and Roundtable on Sustainable Palm Oil certifications), ii) standards that provide sanctions (negative incentives) for conservation to commodity producers (e.g., the Soy Moratorium and G4 Cattle Agreement deforestation bans), and iii) standards that provide designations about where firms can clear land or not clear land for commodity production (e.g., High Conservation Value area designations).

Across all categories, this report found a dearth of evidence regarding conservation impacts of supply chain initiatives: Out of 2,682 papers, only 30 present robust evidence of the impacts of corporate policies on deforestation or other conservation outcomes. There are 5 papers evaluating company pledges and 25 evaluating standards. There are no studies assessing the conservation outcomes of collective aspirations or codes of conduct. Existing studies focus largely on soy and cattle in Brazil and in oil palm in Indonesia, Malaysia, and Papua New Guinea.

Company pledges: Modeling exercises for Indonesia show that company pledges to achieve zero-deforestation in their supply chains could be an effective mechanism to reduce CO_2 emissions (compared to a business as usual scenario) without sacrificing profits, as there is room for intensification and expansion in already deforested lands. However, in reality, encroachment by smallholders into concessions and drainage of nearby peatlands (inducing indirect deforestation) limits their effectiveness in reducing deforestation in the regions where they are implemented. Zero-deforestation pledges by cattle companies in the Amazon show positive results at reducing deforestation among direct suppliers, larger farms, and early adopters of the environmental property registration process, but those results are offset by deforestation by late adopters, indirect suppliers, and non-suppliers.

Sanction-based standards: Existing studies indicate that the Soy Moratorium in the Brazilian Amazon has helped to eliminate deforestation caused by soy production on large farms in the region. However, the moratorium does not monitor land conversion in protected areas or smallholders' plots. Two studies find that the G4 Cattle Agreement has been successful at reducing deforestation rates among direct suppliers to companies that signed the agreement. But several studies identify weaknesses in the agreement, indicating that it had only moderate effectiveness in reducing deforestation because indirect suppliers are able to launder cattle from non-compliant properties to compliant properties and illegal deforestation is still able to occur.

Few studies control for simultaneous changes in public deforestation governance, which may be responsible for much of the deforestation reductions achieved in the region.

Incentive-based standards*:* One analysis finds that the Roundtable on Sustainable Palm Oil (RSPO) has helped reduce deforestation and fire occurrence on certified oil palm plantations. However, this result may be largely due to selection bias – that is, most certified plantations had already deforested much of their land before becoming certified. Implementation of RSPO standards among third party suppliers is particularly challenging due to land tenure issues and conflicts between public and corporate policies.

Designation-based standards*:* Existing studies indicate that the use of "high-conservation value" and "high-carbon stock" designations can have positive biodiversity and carbon impacts if implemented at a large scale with a coherent regional strategy. However, the use of these standards is undertaken by individual companies and results in forest fragments that are too small and scattered to protect biodiversity.

Surprisingly, no independent research has been conducted evaluating the impacts of in-house codes of conduct. As these instruments become more widely adopted, especially by branded companies, measuring their effectiveness is of paramount importance.

Policy recommendations:

- Companies should adopt pledges to reduce deforestation and their associated implementation mechanisms in regions where larger amounts of forests and peatlands suitable for forest-risk commodity production exist.
- Companies should disclose information about the implementation of their codes of conduct and conservation outcomes achieved.
- For certifications to have an impact globally their adoption must be increased, particularly among smallholders, and they must enforce early deforestation cutoff dates.
- Assessments of high conservation value areas should be completed within a larger licensed concession before land is divided into smaller concessions and criteria for forest protection should include patches as small as 1000 ha.
- Agroforestry buffer zones should be established around high conservation value areas to reduce edge and matrix effects from forest patches.
- Given the limited scale of certification adoption, sectoral market exclusion mechanisms currently in use in the Brazilian Amazon should be adopted in other biomes with a high risk of land-use conversion - the Chaco and Cerrado in South America, Congo in East Africa, Guinea in West Africa, and Borneo in Indonesia.
- Guaranteeing deforestation-free soy and cattle purchases will require that buyers monitor all properties associated with their direct suppliers as well as indirect suppliers and enforce illegal deforestation on small properties and protected areas.
- Corporate standards are not a panacea and cannot be effective where existing public governance is lacking. Companies should work with national governments to adopt and enforce conservation policies in deforestation-risk areas.
- Clear property rights are needed to control leakage and laundering.

- Inclusion of smallholders in all initiatives is key for ensuring success. Although smallholders face greater costs of compliance, their exclusion reduces policy effectiveness, as they are large participants in the production of most agricultural commodities.
- Forest conservation efforts should adopt a landscape-level perspective. By focusing on specific farms, key ecosystem services for smallholders (such as watersheds) might not be covered by the instruments, putting farmers' livelihoods at risk.
- Access to detailed information on suppliers and their practices would help researchers understand and assess the actual impact of individual corporate actions in promoting sustainability to help companies in their strategic decisions.

2. Introduction

The production of food commodities is one of the largest drivers of forest loss and degradation in the tropics (Gibbs et al., 2010). As understanding of the negative outcomes of deforestation for these "forest-risk" commodities has increased (e.g., climate and hydrological change, social conflict, and biodiversity loss), civil society has undertaken a wide range of activities, including naming and shaming campaigns and company scorecards, to pressure companies that participate in forest-risk supply chains to address this issue. Since the international supply chains for edible oils, pulp and paper, and beef tend to be highly concentrated at the stage of processing, trading, and distribution (Hoffman, 2013), working with these large multinational entities often represents a promising leverage point to influence the behavior of a much larger number of producers further upstream. Since the early 2000s, companies have responded to increased information and pressure about the negative outcomes of their sourcing activities by adopting a wide range of deforestation-related conservation policies, ranging from prescriptive voluntary sustainability standards and codes of conduct to less prescriptive, aspirational goals and pledges (Lambin et al., 2018). Yet, there remains substantial concern over whether these supply chain initiatives are resulting in reduced deforestation and additional conservation benefits beyond business as usual (Thorlakson et al., 2018).

The Measuring Impacts project aims to develop theories of change and associated causal linkages that connect specific market-based approaches, including supply chain initiatives, with desired conservation outcomes, and to conduct pilot research efforts that characterize these linkages based on available evidence. This report contributes to the Measuring Impacts project by providing a typology of supply chain initiatives for conservation, as well as an initial review and synthesis of the impacts of these supply chain initiatives on conservation outcomes. Our work focuses on: beef and leather; soybean; oil palm; coffee; and cacao, which have the highest risk of being cultivated on areas that have been deforested.

Questions addressed by this study:

1. What are the reported effects of agricultural supply chain initiatives on terrestrial conservation outcomes?
2. Which agricultural supply chain initiatives (at what scale, in what regions, and by which types of actors) have been most effective at improving terrestrial conservation outcomes?

3. Typology of supply chain initiatives for conservation

Supply chain initiatives for conservation can be broken into six broad categories: collective aspirations, company pledges, codes of conduct, incentive-based standards, sanction-based standards, and designation-based standards (Table 1). A key feature of all supply chain initiatives is that they are voluntary at the stage of adoption (though they may not be voluntary for suppliers further upstream who seek to avoid losing market access). Thus, initiatives that are mandatory and led by governments, such as the Indonesian Sustainable Palm Oil System (ISPO) and the Brazilian Sustainable Palm Oil Production Program (SPOPP), do not qualify as supply chain initiatives.

Companies have used a variety of mechanisms to signal their intent to improve forest conservation outcomes (including establishing aspirations, pledges, and codes of conduct, and participating in the creation of standards). Yet, all of these initiatives need an implementation mechanism to become part of a corporate strategy (Table 2). Collective aspirations, which are a broad, collective objective established by a group of stakeholders (i.e., the New York Declaration on Forests), merely encourage companies to adopt pledges or codes of conduct that have more specific operational attributes, such as specific conservation targets and sourcing policies. Company pledges, which establish and communicate an individual company's conservation goals, help define these targets and policies, but still require more specific mechanisms for implementation, such as property registration or independent verification and associated monitoring and/or audits.

In contrast, codes of conduct and standards delineate policies and behaviors to enable compliance with a company's stated conservation targets. Codes of conduct are internal company policies for production and sourcing practices. They ask suppliers to conform to specific practices. Some of them are internally audited while others rely on external auditors to verify compliance, or at least progress towards compliance. Incentive-based standards are industry-wide protocols, such as certification programs, which aim to provide a benefit to individual producers for reducing deforestation (e.g. price premium, enhanced market access). Sanction-based standards (e.g. bans or moratoria) target individual properties or entire jurisdictions and establish a penalty for deforestation, typically by way of market exclusion. Designation-based standards develop plans that allow agricultural expansion outside "high conservation value" and "high carbon stock" areas (if production infringes on those areas, it would be excluded from the supply chain).

Key takeaway: There are six types of supply chain initiatives, which range in their specificity and stringency regarding intended conservation outcomes and implementation mechanisms. The broadest types of initiatives (collective aspirations and company pledges) set *targets* for conservation outcomes, while other initiatives (codes of conduct and standards) define *specific policies and behaviors* to reach a given target.

Table 1: Supply chain initiatives for conservation

Mechanism type		Description	Existing initiatives
Collective aspirations		A broad, collective objective established by a group of stakeholders	Consumer Goods Forum, TFA2020, 2014 New York Declaration on Forests, The Sustainability consortium, and the Sustainable Agriculture Initiative (SAI)
Company pledges		Establish and communicate a company's goal of reducing deforestation	Wilmar, GAR, APP, Unilever's, Cargill's or McDonald's zero deforestation commitments
Codes of conduct	Internal verification	Set internal policies for production and sourcing practices	Walmart´s Standards for Suppliers Code of Conduct, Nestlé´s Responsible Sourcing Guidelines
	Built-in external verification programs		Approved supplier lists, Unilever's Responsible Sourcing Policy, Starbuck´s CAFÉ practices, Nespresso´s AAA program
Incentive-based standards	NGO or 3rd party-led certification	Provide a benefit for reducing deforestation (e.g. price premiums, enhanced market access)	Sustainable Agriculture Network
	Roundtable-led certification		Round Table on Responsible Soy, Roundtable on Sustainable Palm Oil
	Government-led certification		Indonesian Sustainable Palm Oil (ISPO)
Sanction-based standards	Bans or moratoria	Establish a penalty for deforestation at the level of individuals (e.g. market exclusion)	Brazil's soy and cattle moratoria
	Jurisdictional approach	Establish a penalty for deforestation at the level of jurisdictions (e.g. market exclusion)	None currently in existence. Proposed by EDF: Zero-deforestation zones
Designation-based standards	Land use plans/zoning	Specify regions where different development and sourcing are appropriate - "go and no-go" areas	High Conservation Value Areas, High Carbon Stock Areas

Notes: Builds on Table 2 from Lambin et al. "The Role of Supply-Chain Initiatives in Reducing Deforestation." ***Nature Climate Change*** **8 (2018): 109–116.**

Table 2: Actions initiated by supply chain initiatives for conservation

<table>
<tr><th colspan="2">Initiative</th><th>Action initiated</th><th>Supplementary government programs</th></tr>
<tr><td colspan="2">Collective aspirations</td><td><u>Normative only:</u> encourages companies to adopt pledges or codes of conduct that have more specific operational attributes, but has no implementation component.</td><td>National governments at the country level set specific targets and definitions of scope (i.e., a definition of “deforestation”).</td></tr>
<tr><td colspan="2">Company pledges</td><td><u>Operational only:</u> Specifies individual corporate targets, but requires some form of standard and/or supplier audit for implementation.</td><td></td></tr>
<tr><td rowspan="2">Codes of conduct</td><td>Internal verification</td><td><u>Operational only:</u> Specifies policies, but requires some form of standard and/or supplier audit for implementation.</td><td></td></tr>
<tr><td>Built-in external verification programs</td><td><u>Implementable:</u> Requires suppliers to maintain compliance with targets and undergo external audits.</td><td></td></tr>
<tr><td rowspan="3">Incentive-based standards</td><td>NGO or 3rd party-led certification</td><td rowspan="3"><u>Implementable:</u> Requires suppliers to verify and maintain compliance with targets and undergo audits.</td><td rowspan="2">Requires national legislation to be aligned with the standard, especially for the most rigorous 3rd-party led certification that exclude non-compliant suppliers.</td></tr>
<tr><td>Roundtable-led certification</td></tr>
<tr><td>Government-led certification</td><td></td></tr>
<tr><td rowspan="2">Sanction-based standards</td><td>Bans or moratoria</td><td><u>Implementable:</u> Requires suppliers to register their property and maintain compliance with targets, which is verified through remote sensing.</td><td>Requires support via property registration systems, regional monitoring, and alignment of other positive and negative incentives such as access to credit or effective punishment for breaking the law.</td></tr>
<tr><td>Jurisdictional approach</td><td><u>Implementable:</u> Requires whole regions to maintain compliance with targets and establish monitoring practices to assess and enforce compliance.</td><td>Requires regional monitoring and alignment of other positive and negative incentives such as access to credit or effective punishment for breaking the law.</td></tr>
<tr><td>Designation-based standards</td><td>Land use plans/zoning</td><td><u>Likely only operational:</u> May require suppliers to register their property and verify that they are outside HCV or HCS, but generally only implemented through certification programs.</td><td>Improved via systematic national mapping efforts.</td></tr>
</table>

4. Conceptual framework for linking supply chain initiatives to conservation outcomes

Our conceptual framework assumes that corporations adopt certain supply chain initiatives because such actions are expected to produce desirable outcomes, either by dis-incentivizing deforestation or by incentivizing conservation, while also protecting their bottom line. However, supply chain initiatives may differ in the degree to which they aim to improve conservation outcomes within: i) a single supply chain, ii) a single target region, or iii) throughout all their supply chains (globally).

Numerous factors influence the conservation outcomes of supply chain initiatives at these three scales. First, there are the attributes of the market mechanism itself, which determine the types of behavior changes required of producers, including deforestation cutoff dates and the definition of forests utilized. Second, there are the implementation and compliance mechanisms and deadlines specified by the approach, which influence the degree to which behavior changes are enforced. Contextual factors mediate the impacts of these commitments on conservation outcomes (Figure 1), including attributes of the commodity and company's supply chain and contextual conditions in the region of implementation, including deforestation threats, the presence of forest maps, the regulatory, political, and financing environment, and the political context (Garrett et al., 2016).

The degree to which an initiative is effective in achieving a conservation goal at any scale beyond an individual supply chain is influenced by issues of selection bias (adoption by producers that already had already achieved desired changes in practices), leakage between regions (land expansion into non-target areas), the company's market share (the local or global significance of their purchases), and the extent to which primary inputs into their supply chain can be replaced (by production of the same input in other regions or substitutable commodities in the same or other regions) (Lambin et al., 2018; Rueda et al., 2017). As the number of supply chain initiatives for conservation increases it becomes less and less likely that an initiative adopted within a single supply chain or region would have no outcomes on conservation outside of the implementation region.

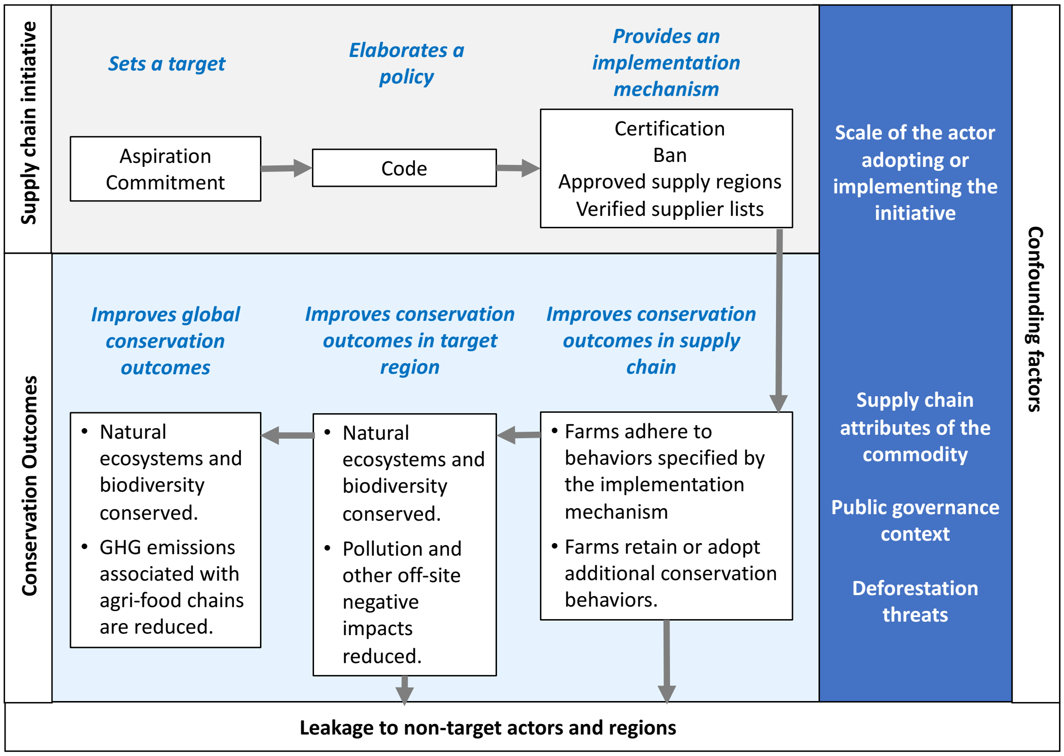

Figure 1: Conceptual diagram linking supply chain initiatives to conservation outcomes

5. Methodology for systematically analyzing supply chain initiatives for conservation

To review and synthesize the impacts of supply chain initiatives on conservation outcomes we conducted a systematic literature review of the existing white and grey literature on the subject. Systematic reviews provide a transparent and replicable process for collecting literature based on predefined search and paper inclusion criteria (Tranfield et al., 2003).

We followed the best practices laid out by (Haddaway et al., 2015) to avoid bias, increase transparency, and ensure consistency and objectivity. First, we established a protocol for identifying relevant and rigorous literature and sent this methodology to our peers for comments. We then searched multiple databases to maximize the number of papers included in the search and verify the stability of the search strings, including peer and non-peer reviewed literature: Web of Science (WoS) and SCOPUS to identify relevant white literature and Proquest to identify gray literature that met predefined standards of methodological rigor. Google Scholar (GS) was then used as a final stage to identify any white or grey literature not captured by the first three databases. Only the first 200 returns from GS were included. Although it is noted to provide less systematic returns than other databases, its inclusion of large amounts of grey literature and unique searching algorithms meant that it could, as a final check, provide some additional perspective to the papers identified through the other search engines. We screened all of the search results with the pre-defined inclusion criteria identified in the methodology: (i) the paper pertained to a supply chain initiative and (ii) the paper included rigorous quantitative or qualitative causal analysis of the impact of the initiative on conservation outcomes. Screening was undertaken by a minimum of two reviewers. We then synthesized the evidence according to the pre-established conceptual model. To ensure replicability and transparency we have provided our methodology and results as appendices.

Search terms were organized into six substrings (“Agriculture”, “Forest”, “Environment”, “Assessment”, “Corporate”, and “Supply Chain Initiative”), each capturing a specific area of inquiry (see Tables SI-3). To assess the impacts of each supply chain initiative separately we included each approach as an additional and separate secondary string to the primary string (Table S1, bottom panel). We limited our time frame for the search to 2000 to the present since most of these supply chain initiatives are very recent. Assessing incentive-based standards (e.g. certifications) was outside of the scope of our report, but if assessments of collective aspirations and company pledges analyzed RSPO or RTRS as an implementation mechanism, we included those analyses in our report.

To capture a wider range of evidence on terrestrial conservation outcomes beyond deforestation, we also included the extent or change in extent of native vegetation cover, measures of habitat configuration (e.g., patch size, fragmentation, connectivity), level or change in vegetation cover quality (e.g., plant species diversity or assemblage), assemblages of terrestrial wildlife (e.g., species richness, abundance, or assemblage metrics of wildlife taxa), conservation of focal species (e.g., rare, endangered, or keystone species), reduction in fire occurrence, and ecosystem services provision from terrestrial ecosystems (e.g. carbon storage).

The first round of our WoS search identified 123 papers total across the different supply chain initiatives, which yielded 8 papers that met criteria for relevance and rigor. After completing this analysis across all of the categories we determined that our search was excluding many important papers due to the inclusion of too many "AND" search terms, so we removed the search strings pertaining to "Environment" (sustainability outcomes beyond forest conservation), "Assessment" (containing words related to evaluation), and "Corporate" (specifically having language about a company). We then added in specific commodity types (soy, palm, cattle, beef, coffee, and cacao) as "OR" qualifiers to the "Agriculture" search to make sure we obtained results for studies that did not reference agriculture broadly in the abstract, but did mention the specific commodity. The amended search resulted in a total of 441 papers, of which 16 papers met our criteria for relevance and rigor (Table S2).

Between the WoS, SCOPUS, GS, and Proquest searches we identified a total of 5 papers on company pledges, 5 papers on incentive-based standards, 15 papers on sanction-based standards, and 6 papers on designation-based standards that met our criteria for inclusion (Table 3). There were no papers evaluating the conservation outcomes associated with codes of conduct, and all of the papers on collective aspirations that focused on company outcomes pertained to company pledges.

The synthesis of these papers followed the conceptual framework laid out above and was organized by i) market based approach, ii) scale of the actor making and/or implementing the approach, iii) commodity or commodities, iv) region or regions, and v) governance context in the implementing region.

Table 3: Number of papers that met the inclusion criteria

Supply chain initiative	# of papers identified
Aspirations	0
Pledges	5
Codes of conduct	0
Incentive-based standards	5
Individual sanction-based standards	14
Jurisdictional sanction-based standards	0
Designation-based standards	6
TOTAL	**30**

Note: One study overlapped between pledges and individual sanction based standards. The five papers on incentive based standards were identified when conducting the searches for other initiatives.

6. Impacts of supply chain initiatives for conservation

6.1 Company pledges

Key takeaway: Company pledges for zero deforestation in Indonesia show no effectiveness, as fires are being detected inside concessions given to companies who signed the zero-deforestation agreement. For the Brazilian Amazon, the cattle supply chains show positive results at the farm level for early adopters of the agreement, but those results are overshadowed by larger deforestation by late adopters and by land-use changes occurring in other places.

Company pledges to achieve a specific conservation target (e.g., zero-deforestation) are a relatively new phenomenon and are largely implemented through certification programs and bans, which may explain the paucity of existing studies on this topic (only 5)[1]. These papers refer to company pledges to stop deforestation in Indonesia (linked to oil palm expansion) and the Brazilian Amazon (linked to pasture expansion) (Table 4). Most papers that have analyzed the impacts of certifications and moratoria in recent years have not framed their papers as analyses of company pledges and most papers specifically analyzing pledges were published in the last year and a half (2017 and 2018). There were no studies analyzing the effects of company pledges on biodiversity, but some studies have analyzed CO_2 emissions and fire occurrence in addition to deforestation outcomes.

Company pledges to reduce deforestation induced by oil palm expansion: Austin et al. (2015) is the first study to analyze company pledges to achieve zero-deforestation. This study is a modelling exercise on the potential impacts of policy instruments on deforestation in Kalimantan, Indonesia. Austin et al. (2015) use a logistic model to estimate the probability of forest conversion to agriculture under different policy scenarios, one of which excludes peatlands, primary and secondary forests. According to authors, this is the policy scenario that most closely resembles a situation in which all palm oil companies commit to zero-deforestation. Results show that CO_2 emissions could be reduced by 35% (45.3 – 74.3 Mt CO_2 yr-1), with relatively low leakage, as most expansion would occur in cultivated land (47-54%). This policy scenario has the lowest impact on yields, suggesting that industry representatives would be most supportive of this scenario versus other policy restrictions, such as an outright moratorium. The

[1] This total includes a recent review paper by Lambin et al (2018) shows that company pledges lack time-bound actions that would help companies implement commitments. As of 2016, only 20-25% of those in the Consumer Goods Forum, for instance, had such plans and implementation was below 50% for any given commodity. However, these data come from non-peer review reports and authors do not present any evidence of impact assessment.

study is hopeful about the financial feasibility of companies' willingness to commit to a zero-deforestation agreement, but the effectiveness of its actual implementation is still uncertain.

Austin et al. (2017b) analyze patterns of recent palm oil expansion in Sumatra, Kalimantan, and Papua to show that palm oil has expanded mainly in non-forest areas. Based on this analysis they conclude that zero-deforestation commitments would be more effective in Kalimantan and Papua than in Sumatra, because the latter has less forest available for conversion.

Gaveau et al., (2017) identify fire occurrence between 2013 and 2014 in Sumatra, for both forests and peatlands, inside concession land given to companies who have signed the zero-deforestation agreements. According to the study, encroachments from smallholders explain these deforestation occurrences. This is an empirical study in which authors also find that plantations expand beyond their limits, encroaching mainly on public lands, causing fires, either directly or by draining peatlands. They conclude that overlapping land claims need to be resolved for effective monitoring of company commitments.

Company pledges to reduce cattle-ranching induced deforestation in Brazil: Alix-García and Gibbs (2018) assess the avoided deforestation derived from the zero-deforestation agreement for cattle in Mato Grosso and Pará, Brazil. Using land cover data for the 2010-2014 period and different counterfactuals, they show that properties in areas exposed earlier to the zero-deforestation policies (G4 and MPF-TAC[2])—that is, companies that registered their property earlier in the national environmental property registration system (CAR) to sell to committed companies—, showed less deforestation than companies that were exposed later (by registering later). This avoided deforestation was offset by greater deforestation on properties in areas that became exposed to the agreements later on. Thus, at the regional scale, the zero-deforestation agreement had no net impact on deforestation. Authors do not analyze the causal mechanisms for this behavior. However, they hypothesize that forest conservation only occurred on farms that were registered earlier because their land use behavior is more transparent. Exposure to monitoring due to greater transparency might have triggered behavioral change. Displacement of deforestation may have occurred because of the complex life cycle and associated value chain of cattle may enable laundering to occur (calves produced on non-compliant properties can be laundered for finishing on compliant properties). Solutions to this problem include full traceability of cattle to their place of birth via ear tags, which is expensive, or animal vaccination records, which currently exists but are not publicly available.

In sum, there are only two papers presenting evidence of the impacts of existing company commitments: one for cattle in Brazil, one for oil palm in Indonesia. The other study examines potential effectiveness. In the Brazilian case, positive results at the farm level are overshadowed by larger deforestation elsewhere. In Indonesia, fire events exist inside and outside concession areas driven by smallholders encroachment and by plantations' actions, both directly (i.e., by setting fires inside their plantations, or indirectly (i.e., by draining adjacent peatlands, thus leaving those prone to fires by external actors). The results of Alix-García and Gibbs (2018) are also included below as a result of the search on sanction-based standards.

[2] "Terms of Adjustment of Conduct"

Table 4: Company pledge results

Paper:	Time period analyzed	Spatial area	Scale	Methods	Results
Austin et al. 2015	Estimation for 2010-2020 based on data from 2000-2010 and sub-decadal data 2000-2005 and 2005-2010.	Kalimantan (Indonesia)	Entire region. Random sample of 250*250 m pixels at elevations less than 1000 m. both inside and outside concessions (over 5,000 samples).	Regression model with a binomial link function to explain deforestation based on biophysical and socio-economic variables	Positive
Austin et al. 2017b	2010-2015	Kalimantan, Sumatra, Papua (Indonesia)	Maps of all large oil palm plantations at a resolution of 250*250 m, interpreting Landsat imagery for the years 1995, 2000, 2005, 2010, 2015 and Land-cover data form the Ministry of Environment for similar years.	Based on these two inputs, builds a suitability map for forecasting land-use change.	Positive for Sumatra; negative for Kalimantan and Papua
Gaveau et al. 2017	2013-2014	Sumatra (Indonesia)	Burned area extent in and around 163 government registered concessions (1.8 Mha) in a 4.1 Mha region in Riau province, Sumatra, using using fire hotspots (MODIS), medium (30 m; LANDSAT), high (<1 m; Digital Globe satellites) and very high resolution (0.1 m; UAV) imagery.	Examines whether fires occurred inside or outside plantations committed to zero deforestation.	Negative in both forests and peatlands caused by smallholders in concessions or large companies (directly or indirectly) in peatlands (via peat drainage)

Table 4, ctd: Company pledge results

Paper:	Time period analyzed	Spatial area	Scale	Methods	Results
Alix-Garcia and Gibbs 2017	2007-2015	Brazil: Pará and Mato Grosso (Amazon biome portion)	Pixels within supply sheds (235, 145 and 75 km) of i) federally inspected (SIF) slaughterhouses, ii) all companies that had signed G4 or MPF-TAC and iii) all companies that had signed G4	Examined how deforestation behavior differed on pixels with varying degrees of exposure to G4 or MPF-TAC signatory companies or exposure to any G4 or MPF-TAC signatory. Also compared CAR and non-CAR properties.	Neutral – no net changes in deforestation in supply sheds of companies that are signatories to the agreement
Notes:* Also reviewed in bans and moratoria as bans depend on company pledges for their implementation.					

6.2 Codes of conduct

Large, branded companies have established codes of conduct for their suppliers. These protocols usually include provisions that suppliers comply with local legislation and international laws pertaining to social and environmental issues. Our search string produced no independent evaluation of the effectiveness of these mechanisms for conservation. To further increase the scope of the search, we purposefully looked for individual programs introduced by large agri-business companies (Freidberg, 2017) including: manufacturing companies: Unilever's Responsible Sourcing Program, Nespresso's Triple A program, Nestlé's Responsible Sourcing Program, Mars' Supplier Code of Conduct, Starbucks' CAFE practices; and retailers: Walmart's Sustainability Index and Carrefour's Sourcing Policy. These companies have specific commitments on forest conservation. Nevertheless, we did not find a single paper that met our criteria of rigorous independent assessment.

6.3 Incentive-based standards

Key takeaway: Company zero-deforestation pledges in palm oil supply chains are often implemented through the Roundtable on Sustainable Palm Oil (RSPO). RSPO appears to have helped reduce deforestation and fire occurrence on certified plantations. However, this result may be largely due to selection bias – that is, most certified plantations had already deforested much of their land before becoming certified. Implementation of RSPO standards among third party suppliers is particularly challenging due to land tenure issues and conflicts between public and corporate policies.

Many companies rely on multi-stakeholder ("roundtable") or NGO led certification programs to implement their supply chain sustainability initiatives. The leading multi-stakeholder certification program for oil palm is the Roundtable on Sustainable Palm Oil (RPSO), which comprises 19% of the global oil palm market (*www.rspo.org*). RSPO bans the conversion of 'primary forests' and high conservation value (HCV) areas. The multi-stakeholder certification program most commonly used as an implementation strategy in zero-deforestation commitments for soybeans is the Round Table on Responsible Soy (RTRS) (Garrett et al., In prep), though certified properties account for only 2% of global production (Garrett et al., 2016). RTRS bans the conversion of 'native forests' and HCV areas. Both RSPO and RTRS oblige producers to comply with existing environmental and social regulations in producing countries. The existing leading certification for beef cattle is through the Sustainable Amazon Network (SAN), but adoption is extremely limited.

There were three studies examining the impacts of incentive-based standards on conservation outcomes as an implementation strategy for zero-deforestation commitments. These studies all focused on the impacts of RSPO certification on deforestation and fire occurrence outcomes.

Carlson et al. (2017) examined differences in deforestation rates and fire occurrence on Roundtable on Sustainable Palm Oil (RSPO) certified and noncertified oil palm plantations in Indonesia. This analysis utilizes a dataset of RSPO certified and noncertified oil palm plantations and annual remotely sensed metrics of tree cover loss (LANDSAT) and fire occurrence (MODIS) to evaluate the impact of certification on deforestation and fire. They constructed a counterfactual of what would have occurred in the absence of certification by matching non-certified farms to certified farms with similar conditions. They found that certified plantations had 33% lower deforestation rates than comparable non-certified farms, but were older with more planted oil palm and less forest remaining at the time of certification. Mean deforestation rates for annual cohorts of certified plantations peaked about 5 years before publishing their letter of intent to obtain certification. They also found high fire occurrence rates on both certified and non-certified plantations, with most fires on certified plantations occurring from 2002 to 2006.

Noojipady et al. (2017) had a similar dataset to Carlson et al (2017), but their spatial scope included Indonesia, Malaysia, and Papua New Guinea. They did not construct a counterfactual for certified farms using the matching techniques employed by Carlson et al (2017). They found that fire activity during the 2002, 2004, and 2006 El Niño events was similar among oil palm plantations in Indonesia that would later become certified, non-certified plantations, and surrounding areas. However, total fire activity was 75% and 66% lower on certified plantations than non-certified plantations during the 2009 and 2015 El Niño events, respectively.

Larson et al. (2018) conducted interviews with key informants across the oil palm industry in 2015 and 2016 to assess: 1) How commodity chain actors view the limitations of their own private regulation and 2) The implications of such perspectives for efforts to improve the governance of commodity chains through hybrid governance. They focused on companies linked to European markets as identified using the TRASE database (*trase.earth*), a project of the Stockholm Environmental Institute to provide transparent data on global supply chains. A notable contribution of this work is to highlight the degree to which confusion around issues of land tenure and conflicts between public regulations and corporate sustainability policies influence ability of companies to implement their commitments. Land tenure problems include illegally distributed forest concessions and "opaque and dynamic ownership structures in different types of 'shadow holdings'". Conflicts between public regulations and corporate sustainability policies include a requirement that plantations use their forests or risk losing them. Implementation is particularly challenging with respect to sourcing from smallholders and other third party suppliers (which may comprise 40-80% of supply) whom may be difficult to trace and enforce. Additionally, these smallholders are vulnerable to land grabbing, encroachment on protected forest areas, and burning of forests and might not even be in control of deforestation their properties.

Garrett et al. (2016) examine the *potential additionality* of RTRS and RSPO in mitigating conversion of native vegetation to cropland in regions where soy and oil palm are produced by examining business as usual land cover change dynamics and existing public regulations in these countries. They find that both RSPO and RTRS are being adopted in regions with high potential additionality. That is, RTRS and RSPO are being adopted in regions where these standards require greater conservation levels than existing national policies (except in Brazil and Uruguay) and are being adopted in regions with high levels of forest conversion for agriculture. Like most certification programs, neither roundtable is effectively targeting smallholder producers.

Table 5 Certification results

Paper:	Time period analyzed	Spatial area	Scale	Method	Conservation outcomes assessed	Results
Carlson et al. 2017	2001-2015	Sumatra and Kalimantan (Indonesia)	Plantation	Dataset of RSPO certified and noncertified oil palm plantations and annual remotely sensed metrics of tree cover loss (LANDSAT) and fire occurrence (MODIS) to evaluate the impact of certification on deforestation and fire.	Deforestation and fire	Mixed: Certification lowered deforestation by 33% per year. But most plantations contained little residual forest when they received certification and certification had no impact on forest loss in peatlands or fire rates.
Meijaard et al 2017	2000-2015	Kalimanton, Sabeh, and Sarawak	Plantation	Dataset of RSPO certified and noncertified oil palm plantations and annual remotely sensed metrics of tree cover loss (LANDSAT) to evaluate differences in deforestation on certified vs. non-certified properties. Orangutan population numbers and population trends are from a data set prepared by Santika et al. (in review).	Deforestation and overlap with Orangutan habitat	Mainly positive: Absolute levels and rates of deforestation, and the proportion of the concession area deforested are lower in concessions and estates that were certified by RSPO vs. non-RSPO-certified by 2016. The paper also identifies a great deal of overlap between oil-palm concessions and estates and orangutan habitats, especially in West and Central Kalimantan Indonesia.

Table 5, ctd. Certification results

Paper:	Time period analyzed	Spatial area	Scale	Method	Conservation outcomes assessed	Results
Noojipady et al. 2017	2002-2014	Indonesia, Malaysia, and Papua New Guinea	Plantation	Dataset of RSPO certified and noncertified oil palm plantations and annual remotely sensed metrics of tree cover loss (LANDSAT) and fire occurrence (MODIS). Their assessment excluded forested areas identified as oil palm. Forest definition is >30% canopy cover.	Deforestation and fire	Positive: Fire activity during the 2002, 2004, and 2006 El Niño events was similar among oil palm plantations in Indonesia that would later become certified, noncertified plantations, and surrounding areas. Yet, total fire activity was lower on certified plantations than noncertified plantations during the 2009 and 2015 El Niño events.
Larson et al 2018	2015-2016	Indonesia	National	Interviews with key informants across the oil palm industry. They focus on companies linked to European markets as identified using the TRASE database.	Compliance with No Deforestation No Peatland Expansion (NDPE) commitments, RSPO standards, and public regulations	Negative: Highlight numerous implementation challenges, particularly on the farms of third-party suppliers.
Garrett et al. 2016		Global	Country	Dataset of RSPO and RTRS certified area, deforestation for cropland expansion, and existing forest regulations in each region to assess the potential impacts of RSPO and RTRS on deforestation across regions	Deforestation for cropland expansion	Mixed: Uptake of RSPO and RTRS is higher in places with higher potential additionality for reduced deforestation, but overall adoption is very limited, especially among small farmers.

6.4 Sanction-based standards

Key takeaway: The Soy Moratorium in the Brazilian Amazon has proven to be an effective mechanism for halting deforestation in large parcels in the region. The moratorium may have fostered leakage to other regions and does not monitor land conversion in natural reserves or smallholders' plots. The G4 Cattle Agreement has been successful at reducing deforestation rates among direct suppliers, but shows only moderate effectiveness in reducing deforestation in regions where it is implemented because laundering cattle from non-compliant farms to compliant farms is occurring.

There are two existing private bans or moratoria that companies employ to reduce deforestation in food supply chains. The first is the Soy Moratorium, whereby the group of companies known collectively as the Brazilian Soy Industry (ABIOVE), agreed not to purchase soy grown on Brazilian Amazon lands deforested after July 2006. After the new Brazilian Forest code was passed the deforestation cut-off was adjusted to July 2008 (Junior and Lima, 2018). The second ban, generally referred to as the "G4 Cattle Agreement", pertains to the Brazilian cattle industry, but references two related mechanisms. In 2009, individual meatpacking companies in several Brazilian Amazon states began signing legally binding Terms of Adjustment of Conduct ("MPF-TAC") agreements to stop purchasing cattle from properties that undertook illegal deforestation after July 2009. In 2009, Brazil's four largest meatpacking companies (Marfrig, Minerva, JBS, and Bertin) also agreed not to purchase beef grown on lands deforested after October 2009 by signing the "G4" agreement. The Indonesian Moratorium on New Concessions, while sharing a similar name as the soy moratorium, is excluded from this analysis because it is led by the Indonesian government to reduce transnational air pollution and achieve their nationally determined contributions to climate mitigation.

The impacts of these two bans have been very difficult to assess because they focus on the Brazilian Amazon, a region that experience several simultaneous changes in public governance before and after the two bans were established. Brazil regulates deforestation on private properties through the federal Forest Code (Law 12.651/65), passed in 1965, which requires 80% of each property in forest areas of the Legal Amazon[2] to be set aside in a Legal [conservation] Reserve. This proportion is 35% in Cerrado areas of the Legal Amazon, 20% in non-forest areas of the Legal Amazon, and 20% for all vegetation types outside the Legal Amazon. Riparian areas and steep slopes within properties must also be conserved in Permanent Preservation Areas. Historically, compliance with the Forest Code was low, with more than 80% of producers failing to meet Legal Reserve requirements in some regions (Stickler et al., 2013). However, enforcement in the Amazon biome was vastly improved in the 2000s, linked to the 1st and 2nd Federal Action Plans to Prevent and Control Deforestation in the Amazon, through several mechanisms, including fines, increased field visits and field-based enforcement (Börner et al., 2015), and confiscation of illegally acquired goods or assets. In 2008, the federal government also initiated a 'black list' program that eliminated agricultural credit for properties in municipalities in the Amazon that had the highest deforestation rates (Picketty et al. 2015). In 2013, the Federal Government also launched a program requiring all farmers in the country to become registered in a Rural Environmental Registry (CAR) by 2016 to identify compliance gaps with existing environmental regulations and develop plans to achieve compliance (Daniel Nepstad et al., 2014). The government also dramatically increased the number of protected areas and indigenous lands (100% between 2002 and 2008 for the Amazon), which helped significantly slow down deforestation in the region (Nolte et al., 2013). Finally, in 2010, the major Brazilian federal bank (Banco do Brasil) also signed onto this agreement, effectively limiting public credit to farmers who deforested after July 2006 (ABIOVE, 2010).

While most of the below studies focus on an individual ban, Nepstad et al. (2014) assess the combined impact of private and public instruments to halt deforestation in the Brazilian Amazon. Using mainly descriptive methods and process tracing, they conclude that the decline in deforestation after 2006 was the result of mutually reinforcing factors between both public and private conservation policies, as well as changing market dynamics. They conclude that the Soy Moratorium and G4 Cattle Agreement helped slow deforestation by providing market incentives for non-deforestation commodities and increasing the risk of deforestation via fines and embargoes. The contribution of each individual ban, however, is difficult to assess.

Soy Moratorium results: There were 9 papers that assessed the impacts of the Soy Moratorium on deforestation, which varied widely in their time period, spatial area, and scale (Table 6). There were no papers analyzing reforestation, conservation of focal species, reduction of fire occurrence, or provisioning of ecosystem services.

Six of the Soy Moratorium papers analyzed of rates of forest to soy cropland transitions using remotely sensed data, while only one paper interviewed farmers directly to understand how the soy moratorium was enforced and influenced conservation behavior. Despite using similar methods to detect forest loss and soy occurrence, the six remotely sensing analyses varied in the way that they analyzed transitions from forest to soy (what time period they considered after deforestation), their scale (pixels versus properties), and their interpretations of moratorium effectiveness. Notably, the implicit counterfactual used to assess Soy Moratorium effectiveness varied widely. Some studies assessed rates of forest to soy cropland transitions before and after the introduction of the Soy Moratorium within Mato Grosso state (Kastens et al., 2017), between the Amazon and Cerrado (Gibbs et al., 2015), and between properties registered with CAR versus non-CAR properties (Gibbs et al., 2015). Azevedo et al., (2015), Junior and Lima (2018), and Rudorff et al. (2012) do not assess before and after effects of the Soy Moratorium, only the occurrence of soy cropland in deforested polygons. None of these papers controlled for simultaneous changes in public governance to assess the *additional* effect of the moratorium, which confound the selection of the periods that classify as “before” and “after” the intervention (le Polain de Waroux et al., 2017).

Collectively these papers suggest that the Soy Moratorium contributed to a reduction in deforestation for soy cropland expansion relative to the period before the advent of the moratorium and relative to rates occurring the neighboring Cerrado. The magnitude of the effect of the Soy Moratorium remains uncertain, particularly considering the lack of counterfactual, but it is almost certainly positive. Gibbs et al (2015) estimated that the amount of new soy cropland that occurred into deforested areas dropped from 30% of new plantings to <1% in the Amazon after the adoption of the Soy Moratorium, while it remained between 11% - 23% in the Cerrado (Gibbs et al., 2015). Within Mato Grosso, Kastens et al (2017) note that the pre Soy Moratorium average annual deforestation rate drops from ~1 million hectares per year to just ~180,000 hectares per year and the amount of deforested area that ends up in soy cropland within five years drops from 14.2% - 5.6%.

The analysis by Rudorff et al (2011) only accounts for three years since the implementation of the Soy Moratorium. They find that 0.25% of total deforestation in the Amazon (6,300 ha) between 2006-2010 was planted with soybeans as of 2009/2010. Rudorff et al (2012), which spanned 2006-2011, found similar numbers. Their analysis indicated that the conversion of forest to soy in the Amazon biome after the Soy Moratorium was 11,698 hectares, which corresponded to: 0.3% of total deforestation in the Amazon biome; 0.39% of the deforestation in the states of Mato Grosso, Rondônia and Paraá; 2.4% of the deforestation observed in the monitored municipalities. These low percentages of soy cropland occurring in deforested areas after five years of the Soy Moratorium are taken to indicate the success of the initiative.

A weakness of both Rudorff et al (2011) and Rudorff et al (2012), as well as the broader Soy Moratorium monitoring program is that 22.7% of the deforested areas, including deforestation events less than 25 ha in size, deforestation in protected areas, and deforestation in public settlements, are not monitored for soy expansion so as not to penalize smaller farmers (Rudorff et al., 2012). Within Mato Grosso and using six additional years of data (2006-2017) and a broader spatial area (their analysis includes all deforested areas, including small <25 ha deforestation events, protected areas, and settlements), Junior and Lima (2017) found that the conversion of forest to soy in the Amazon biome portion of Mato Grosso after the Soy Moratorium was 59,972 ha, accounting for 12.5% of the deforestation that occurred in this region over the same period. For Rondônia, da Costa et al (2017) found that soy cropland area more than doubled in the state from 61,742 ha to 147,812 ha between 2005 and 2014, but only 5% of soy cropland present in 2014 was deforested after 2005.

Azevedo et al (2015) do not provide estimates for the area of soy in deforested areas, instead focusing on the number of properties that were found to be non-compliant with the soy moratorium (18.4% of properties). A strength of this work is that it also looks at how much soy would be compliant with both the Soy Moratorium and existing public regulations (i.e., fully "legal"). They find that only 35% of properties would meet both regulations, highlighting the fact that there is a higher rate of compliance with the deforestation cut-off dates associated with the moratorium than with existing public regulations. This study also underscores the degree to which the Soy Moratorium fails to control illegal behavior.

Nepstad (2017) shows that Soy Moratorium-compliant land for expansion is not evenly distributed among micro-regions. Central Mato Grosso has less than 25% of its land available for moratorium-compliant expansion, while other regions have more. The dissertation shows that the Soy Moratorium has spared land from deforestation. More importantly, Nepstad suggests that had the moratorium been applied to the Cerrado as well, about 34,000 ha of pre-2006 forest in

Pauí could have been spared. They conclude that a Soy Moratorium in Cerrado would shift production from current centers to less cultivated states such as Mato Grosso da Sul, eastern Mato Grosso and Goiás. Effective monitoring and enforcement, however, might be more difficult.

Table 6: Soy Moratorium Results

Paper:	Time period analyzed	Spatial area	Scale	Method	Conservation outcomes assessed	Results
Gibbs et al. 2015	2001-2014 (Amazon biome) and 2001-2013 (Cerrado biome)	Brazil: Mato Grosso, Pará, and Rondonia, municipalities with at least 1000 ha of soy in Mato Grosso, Para, and Rondonia; Cerrado biome, all areas with 2 successive years of large-scale crop production	Deforested polygons >6.25 ha (Amazon) and >25 ha (Cerrado) and properties using CAR boundaries	Detecting forest-soy transitions using PRODES (Amazon deforestation), LAPIG (Cerrado deforestation), and MODIS (soy identification); comparing rates of transitions before/after SoyM rates in Amazon to the Cerrado. Transition recorded if soy occurs w/in three years after forest cleared.	Deforestation	Positive – rates of deforestation for soy cropland slowed
Kastens et al 2017	2001-2014	Brazil: Mato Grosso, Amazon	Deforested polygons >6.25 ha	Detecting forest-soy transitions using PRODES (deforestation) and MODIS (soy identification); comparing rates of transitions before/after the Soy Moratorium	Deforestation	Positive – rates of deforestation for soy cropland slowed
Rudorff et al 2012	2006-2012	Brazil: Mato Grosso, Pará, and Rondonia, municipalities with at least 5,000 ha of soy, Amazon	Deforested polygons >6.25 ha	Detecting forest-soy transitions using PRODES (deforestation) and MODIS (soy identification); only only after SoyM	Deforestation	Positive – rates of deforestation for soy cropland were very small
Rudorff et al 2011	2007-2009	Brazil: Mato Grosso, Pará, and Rondonia, municipalities with at least 5,000 ha of soy, Amazon	Deforested polygons >6.25 ha	Detecting forest-soy transitions using PRODES (deforestation) and MODIS (soy identification); only after SoyM	Deforestation	Positive – rates of deforestation for soy cropland were very small

Table 6, ctd: Soy Moratorium Results

Paper:	Time period analyzed	Spatial area	Scale	Method	Conservation outcomes assessed	Results
Junior and Lima 2017	2006-2017	Brazil: Mato Grosso	Deforested polygons >6.25 ha	Detected soy cropland on areas that were forested as of 2006 using PRODES (deforestation) and SojaSat (ref)	Deforestation	Positive – rates of deforestation for soy cropland were very small
da Costa et al 2017	Soy areas: 2000, 2005, 2010, 2014; Deforestation: 1997-2014	Brazil: Rondônia, Amazon	Deforested	Assessed the time period when deforestation occurred for the land that contained soy cropland that was present in years 2000, 2005, 2010, and 2014	Deforestation	Positive – new soy cropland largely not occurring on land deforested after 2005
Azevedo et al 2015	2008-2010	Brazil: Mato Grosso, Amazon	Deforested polygons >6.25 ha (Amazon) and >25 ha (Cerrado) and properties	Detected soy cropland on areas that were forested as of 2008 using PRODES (deforestation) and soy estimates from Macedo et al (2012). Linked these estimates to CAR.	Deforestation	Mixed – most farms are compliant with deforestation cut-off dates, but not broader legality requirements
Nepstad, Lucy 2017 (Master's Dissertation)	Soy areas estimates before 2008 and in 2014	Brazil. Amazon and Cerrado	Soy-producing micro region (52 in Amazons, 173 in Cerrado)	Estimated amount of hypothetical soy-moratorium compliant land that could be converted to soy as well as the Soy-M violating land that could have been spared, had moratorium been applied to Cerrado.	Deforestation	Positive – the soy moratorium spared forest land from development
Rausch and Gibbs 2016	2013 and 2014	Brazil: Three counties in Mato Grosso.	Properties	Producer and key-informant interviews as well as personal observations. Interviewed 43 producers and 17 expert informants.	Deforestation	Mixed – pathways to evading the moratorium still exist

Notes: While the scope of the Soy Moratorium includes the entire Brazilian Amazon, the monitoring system is limited to municipalities in the states of Mato Grosso, Pará, and Rondônia with at least 5000 ha of soy planted in the current or previous year, or to be grown in the coming year. Protected areas, indigenous territories, and public settlements are excluded. This area is thought to comprise 97% of the soy area in the Amazon (Rudorff et al., 2011).

Rausch and Gibbs (2016) do not assess overall results of the Soy Moratorium, but highlight the pathways of non-compliance. They find that the compliance mechanisms of the soy moratorium (checking embargo lists and non-compliance areas from the moratorium monitoring systems) are largely being followed by soy buyers, but there are still at least minor possibilities for non-compliance (via laundering) by obscuring the origin of the property where the soy originates.

Cattle agreement results: There were only three papers that assessed the impacts of the G4 Cattle Agreement and MF-TAC on deforestation. These studies mainly focused on the state of Pará, the largest cattle producing state that lies fully within the Amazon biome, with one study spanning the Amazonian portion of Mato Grosso, as well as Pará. The studies all relied on remote sensing methods combined and utilized property level data from the environmental registry (CAR), though Alix-Garcia and Gibbs (2017) focused on pixel level outcomes, not property level compliance (Table 7). There were no papers analyzing the impact of the cattle agreements on reforestation, conservation of focal species, reduction of fire occurrence, or provisioning of ecosystem services.

Gibbs et al. (2016) provide evidence that the cattle agreements changed the sourcing behaviors of the four JBS slaughterhouses they assessed. JBS slaughterhouses reduced their purchases of cattle from recently deforested properties after adopting the commitment. In this sense, JBS appeared to be abiding by their commitment not to source directly from suppliers that deforested their land after October 2009. Gibbs et al. (2016) also found that post-agreement properties that were supplying to JBS had lower deforestation rates and higher reductions in deforestation than non-supplying properties. Yet these same suppliers had a higher rate of deforestation beforehand and lower forest cover at the onset of the agreement (<1% of the forest on their property remaining), which might explain why rates of deforestation were lower. Overall, all groups had lower deforestation rates after the agreements (2010–2012) than beforehand (2006–2008).

Despite the earlier results of Gibbs et al. (2016), most studies conclude that the G4 Agreement was not effective in reducing rates of deforestation in areas where signatories are operating or eliminating deforestation within committed supply chains. Alix-Garcia and Gibbs (2017), whose study includes both Mato Grosso and Pará, find that there was no statistically significant impact of the cattle agreements on forest cover in the regions surrounding signatory slaughterhouses by the end of 2014. Results show avoided deforestation of about 6% from the agreements on properties that enrolled early in CAR. But forest loss increased on properties that registered later which diminishes the positive effects of the early registrants. Also, slaughterhouses bought plants in regions with higher deforestation both before and after the agreement, suggesting that companies were not deterred in avoiding important deforestation hotspots.

Klingler et al. (2018) provide compelling circumstantial evidence that the cattle agreement is allowing for wide scale laundering of cattle grazed in areas that violate criteria of the TAC and G4 in Southwester Para. They find that 3% of all cattle in the region are grazing in areas that were deforested after August 2009, while 15% of the cattle were in legally restricted areas (protected and indigenous areas), and 10% of the cattle were in areas that were embargoed by the environmental crimes agency (IBAMA). Klingler et al. (2018) also find that 40% of the non-TAC/G4 compliant cattle were located on properties less than 300 ha.

Table 7: Cattle agreement results

Paper:	Time period analyzed	Spatial area	Scale	Methods	Conservation outcomes assessed	Results
Gibbs et al. 2016	2008-2013	Brazil: Southeastern Pará, Amazon	All CAR registered properties within 10 km of 4 JBS slaughterhouses	Examined how forest cover, deforestation, and property size differed among three groups: a) those selling to JBS in 2013 after they signed the agreement, 2) those selling to JBS in 2009 before they signed the agreement, and iii) those selling to JBS in both 2009 and 2013. Examined how JBS' sourcing behavior changed from 2009-2013.	Deforestation	Positive – suppliers to JBS had lower deforestation rates after the agreement
Alix-Garcia and Gibbs 2017	2007-2015	Brazil: Pará and Mato Grosso (Amazon biome portion)	Pixels within supply sheds (235, 145 and 75 km) of i) federally inspected (SIF) slaughterhouses, ii) all companies that had signed G4 or MPF-TAC and iii) all companies that had signed G4	Examined how deforestation behavior differed on pixels with varying degrees of exposure to G4 or MPF-TAC signatory companies or exposure to any G4 or MPF-TAC signatory. Also compared CAR and non-CAR properties.	Deforestation	Neutral – no net changes in deforestation in supply sheds of companies that are signatories to the agreement
Klinger et al. 2018	Locations of cattle in 2014; land use and land cover change and infractions from 2000-2014	Brazil: Sothwestern Pará, Amazon	CAR registered properties in Novo Progresso	Examine the presence of pasture area and cattle head in areas which should have been "off limits to the cattle supply chain": a) located in restricted areas, b) deforested since July 2009, c) under an environmental property embargo by IBAMA, d) not included in eligible CAR area, or e) linked to slave labor. Conducted 132 interviews in the region to assess compliance of the cattle agreements.	Deforestation	Negative – cattle continue to graze in recently deforested and legally off-limits areas and companies continue to purchase these products.
Notes: Studies focus on Pará and Mato Grosso because of the large size of the of the cattle herd in these two states and their contributions to deforestation (>50%) in the Amazon biome.						

6.4 Designation-based standards

Key takeaway: High Conservation Value and High Carbon Stock approaches to conservation contribute to improved protection of biodiversity and high carbon ecosystems, not just forests. However, if they are applied only at the scale of small forest fragments they may fail to protect areas with high levels of biodiversity.

The two primary designation--based standards used to implement supply chain initiatives for conservation are High Conservation Value (HCV) areas and High Carbon Stock (HCS) areas. HCVs are areas that are designated as containing biological, ecological, social, or cultural values that are outstandingly significant or critically important (www.hcvnetwork.org). In practice, this translates to protecting very rare species and habitats, high concentrations of wildlife, and/or large landscape-level areas of forest (Edwards and Laurance, 2012). HCS is a methodology for distinguishing forests with high carbon and biodiversity value from degraded lands based on vegetation class, validated by above ground biomass measurements and field observations (www.highcarbonstock.org). Both tools provide systematic guidance on how to assess and map vegetation classes at the property level, but do not cover all native ecosystems. HCV and HCS maps have not yet been developed for key regions and since not all HCV and HCS are detectable using remote sensing, a lack of adequate mapping inhibits monitoring of changes in these areas (Carlson et al., 2018).

The HCV designation is particularly key to the implementation of global commodity roundtable certifications related to forest-risk commodities, including Roundtable on Sustainable Palm Oil (RSPO) and Round Table on Responsible Soybeans (RTRS) (Englund and Berndes, 2015). As mentioned above, RPSO bans the conversion of 'primary forests' and HCV areas, while RTRS bans the conversion of 'native forests' and HCV areas. There are intentions to include the HCS approach within the RPSO standard (RSPO, 2017), but currently only a handful of individual companies use it.

We found four papers that empirically analyzed the impacts of designation-based standards and two additional papers that discussed *potential* impacts of the standards. Unlike the company pledges and sanction-based standards, which focused on land cover outcomes, most designation-based standards focused on biodiversity and carbon impacts.

Tawatao et al. (2014) examine differences in habitat quality, species richness, and species composition of ant assemblages in HCVs publically-managed virgin jungle reserves – VJRs extensive tracts of primary forest. They found that HCVs had much poorer habitat quality than VJRs, including lower sizes and densities of trees, less canopy cover, fewer dipterocarp trees and shallower leaf litter. HCVs supported only half the species richness of ants in VJRs, which in turn supported 70% of the species richness of control sites, explaining 77% of the variation among forest fragments in ant species richness.

Austin et al., (2017a) quantify the forest area, carbon stock, and biodiversity resources that would be protected in the country of Gabon under HCV and HCS criteria using newly developed maps of priority species distributions and forest biomass. They find that less than half of rare species distributions and rare habitats that meet HCV criteria 1.c and 3 would overlap with HCS at the carbon threshold of 75 tC per hectare. This demonstrates the potential shortcomings of an oil palm expansion strategy that focuses only on preventing deforestation by using an HCS approach.

In contrast, Deere et al., (2018), who conducted their analysis in Indonesia, found that the use of an HCS approach could have significant co-benefits for biodiversity. At the community level, HCS forests supported comparable mammal diversity to continuous forest control sites in continuous forest, while lower carbon stock areas supported fewer species. They also found that carbon stocks were positively correlated with the number of threatened and disturbance-sensitive species. Pirker et al., (2016) also provide a somewhat favorable view of HCS, finding that the use of HCS criteria at a threshold of 100 tons of above ground biomass per hectare, would prohibit conversion of the greatest amount of land globally – roughly 1 billion hectares of land that is suitable for oil palm cultivation, while protecting regions with high biodiversity would protect 507 million hectares. However, this is likely highly dependent on their definition of high biodiversity (containing more than 4 overlapping global terrestrial biodiversity priority areas or more than 20,000 ha of continuous forest), which is not the same as HCV and ignores many culturally important landscapes as well as smaller forest tracts with rare species and habitats.

Two of the papers on designation-based standards do not contain impact assessments (Koh et al. 2009, Edwards and Laurence 2012). Nevertheless, they raise important considerations about standard limitations from practical experience of its implementation. Koh et al. (2009) indicate that RSPO provides no clear guidelines on the identification of HCV areas or how their conservation should be integrated into management and coordinated with the plans of other growers. Consequently, many HCV area fragments are very small (several hundred hectares) and disconnected from other forest fragments. Given the small size of HCV fragments they then synthesize existing knowledge about forest fragments to conclude that HCV areas are not very promising for biodiversity conservation due to edge effects and a lack of connectivity between protected areas. Edwards and Laurance (2012) argue that the HCV criteria focus too heavily on protecting large patches, which can overlook smaller areas of biological importance if the regions do not contain rare species or habitat. Like Koh et al. (2009) they argue that there needs to be greater attention to matrix level biodiversity and connectivity.

Table 8: HCV and HCS results

Paper:	Time period analyzed	Spatial area	Scale	Methods	Conservation outcomes assessed	Results
Koh et al 2009	NA	NA	NA	Synthesis of existing knowledge about forest fragments and one financial report. Not an impact evaluation.	Biodiversity	Negative – HCV fragments are often very small and do not retain biodiversity.
Edwards and Laurance 2012	NA	NA	NA	Synthesis of existing knowledge about HCV criteria applications. Not an impact evaluation.	Biodiversity	Negative – HCV applications ignore important biodiversity outcomes because they focus too heavily on just protecting large areas.
Tawato et al 2014	2006-2010	Malaysia: Sabah, Borneo	Forest fragments (HCVs and publically-managed virgin jungle reserves - VJRs)	Compare the species richness and composition of ant assemblages in HCVs and VJRs, versus control sites in extensive tracts of primary forest	Habitat quality and biodiversity – species richness and composition of ant communities	Negative – Found that HCVs had poorer habitat quality and <half the species richness of ants in VJRs and extensive forest tracts
Austin et al 2017a	2013	Gabon	National	Quantify the forest area, carbon stock, and biodiversity resources protected under HCV and HCS criteria using maps of priority species distributions and forest biomass for Gabon.	Biodiversity and carbon stocks	Neutral - HCV and HCS would both protect vast amount of areas, but less than half of rare species distributions and rare habitats overlap with HCS areas at a carbon threshold of 75 tC per ha

Table 8, ctd: HCV and HCS results

Paper:	Time period analyzed	Spatial area	Scale	Methods	Conservation outcomes assessed	Results
Deere et al 2018	2012-2014	Malaysia: Sabah, Borneo	13,153 ha development area comprising the Stability of Altered Forest Ecosystems project	Examined the biodiversity value of land meeting REDD+ vs. HCS across various types of land cover to continuous forest control sites	Biodiversity and carbon stocks	Positive - found that the use of an HCS approach could have significant co-benefits for biodiversity
Pirker et al 2016	Data are from various years	Global	Minimum scale of 300 m	Combined suitability estimates with protected area, HCS, and high biodiversity maps to assess how much land that is suitable for oil palm would be restricted under various criteria	Biodiversity and carbon stocks	Positive - found that the use of an HCS approach would protect 1 billion ha of oil palm suitable land globally, while high biodiversity classifications would protect 507 million ha

7. Summary of current impacts of supply chain initiatives for conservation

7.1 What we know

The effectiveness of company pledges for zero deforestation varies substantially across regions. Pledges in the Amazon designed within cattle value chains show positive results at the farm level for early adopters of the agreement; but those results are overshadowed by larger deforestation by late adopters and in other places. Pledges within palm oil value chains have not been effective in Indonesia.

The Roundtable on Sustainable Palm Oil (RSPO) has had mixed results in reducing deforestation and fire use. RSPO appears to have helped reduce deforestation and fire occurrence on certified plantations. However, this result may be largely due to selection bias – that is, most certified plantations had already deforested much of their land before becoming certified. Implementation of RSPO standards among second-tier suppliers is particularly challenging due to land tenure issues and conflicts between public and corporate policies.

The Soy Moratorium and G4 Cattle Agreement sanction-based standards have had some success within individual supply chains, but supply chain attributes limit broader effectiveness. Both the Soy Moratorium and G4 Cattle Agreement have had helped reduce deforestation within the supply chains of committed actors, but broader effectiveness is impeded by continued deforestation among smaller farms and indirect suppliers and within properties operating in unmonitored areas or properties that are not yet registered publically. The G4 Cattle Agreement tends to be less effective than the Soy Moratorium due to greater amount of implementation challenges related to differences in the supply chain structure for these two commodities (Lambin et al., 2018). First, Cattle Agreement signatories control only 40% of the local market, while the Soy Moratorium signatories controlled 90% of the market (Sousa 2015). The Cattle Agreement is undermined by: i) the covert sale of cattle from non-compliant to compliant producers (laundering), ii) a redirection of non-compliant cattle sales to slaughterhouses not covered by agreements (leakage), and iii) a displacement of cattle production by the expansion of soy onto cleared pasturelands.

The High Conservation Value and High Carbon Stock approaches contribute to improved conservation outcomes because they enable protection of biodiversity and high carbon ecosystems, not just forests. However, used in isolation they may fail to protect areas with high levels of biodiversity. While HCS has been found to have some co-benefits for biodiversity it does not protect biodiversity as well as an HCV approach. Since HCS or HCV are typically implemented at the farm scale (rather than through a national or regional strategy), they may fail to protect forest tracts of sufficient size and continuity to protect threatened biodiversity.

The success of all approaches depends greatly on interactions with existing public policies, other standards, and the macroeconomic context: Public policies for conservation, including effective law enforcement through fines, embargoes, credit restrictions, and confiscation of means of production and produce linked to deforestation often improve the effectiveness of existing private approaches in conserving forests and biodiversity locally by increasing the penalties associated with non-compliance (Piketty et al., 2015; Sousa, 2016). Certifications have limited uptake so biome-wide market exclusion mechanisms allow companies to reach larger areas. HCS is most likely to be effective when it includes HCV safeguards. Worsening economic conditions for export production can help improve the effectiveness of both public and private mechanisms by reducing farmers' incentives to expand agricultural production (Sousa, 2016). In the case of Brazil, large deforestation reductions were achieved through synergies between public and private approaches, as well as unfavorable economic conditions (i.e., revaluation) (Nepstad et al., 2014).

Neither sanction based or incentive based standards are effectively tackling deforestation among smallholders. The Soybean Moratorium excludes monitoring of deforestation events smaller that 25 ha in size. Deforestation in protected areas or public settlements are not monitored for soy expansion so as not to penalize smaller farmers (these comprise 22.7% of the deforested areas in the Brazilian Amazon). The G4 Cattle Agreement fails to reach many smallholders due to its focus on direct suppliers. In Brazil small farms often focus on calf production and then sell calves to larger properties for stocking and finishing. Klinger et al (2018) found that much of the non-TAC/G4 compliant cattle were located on properties smaller than 300 ha and on properties located in protected and indigenous areas. Similarly, RSPO certified areas substantially underrepresent smallholder farms (Garrett et al., 2016), who comprise 40% of oil palm production globally (www.rspo.org).

7.2 What we don't know

There is no information on the conservation outcomes associated with existing collective aspirations or codes of conduct. Additionally, jurisdictional sanction-based standards have not yet been implemented and there are no assessments of their potential impacts. Approaches that lack implementation mechanisms are difficult to assess. To date no study has pieced together the various implementation aspects of existing commitments to assess their spatial footprint, market coverage, or impact on deforestation, biodiversity, and carbon stocks.

There are large geographic areas that include major proportions of production as well as globally important eco-regions, with few supply chain initiatives for conservation. One such region is Matopiba, a large area of the Cerrado, outside of the Soy and Cattle Moratoria, where in the period 2007-2015 nearly 40% of soy expansion directly replaced native vegetation – far higher than in other regions (Gibbs et al., 2015). Additionally, emerging palm oil producers such as Colombia, Brazil and Thailand are not addressed in the current literature, nor is the Chaco region (in Argentina, Paraguay and Bolivia) where soy and cattle are resulting in large amounts of deforestation (le Polain de Waroux et al., 2016). Malaysia is highly underrepresented in comparison to Indonesia, despite being the second largest producer of palm oil globally.

Information on the conservation outcomes associated with company pledges is very limited. Several company pledges have been made by large multinational corporations that: i) sell directly to consumers, such as Unilever, McDonalds, ii) are involved in trade, such as Cargill, or iii) plant and process large amounts of agricultural commodities for manufacturing companies, such as Wilmar. In spite of the abundance of corporate pledges, there is very little evaluation of those efforts. We assume that value chain complexities and proprietary information have prevented researchers from tracing company purchases to specific locations. Though this may change with recent attempts to obtain local customs data to create international transparency databases (Gardner et al., 2018).

Research designs vary substantially across assessments of company approaches and greatly influence conclusions about the effectiveness. Issues of scale, position in the value chain, and methods of inquiry influence the nature of the evidence generated by different studies. Surprisingly, many of the studies using remote sensing to assess commitment effectiveness relied on different methods (e.g. time periods, areas, satellites) for calculating forest to soy transitions. Studies that covered a broader spatial scale and did not exclude small properties in settlements and protected areas were more likely to identify failures in achieving desired conservation outcomes.

8. Recommendations

Collective aspirations and company pledges to reduce deforestation are a critical step toward developing mores sustainable global agri-food sourcing practices. Promising tools for implementing aspirations and pledges include adoption of codes of conduct, targets to source 100% certified products, and market exclusion mechanisms. The goal of these initiatives is to incentivize farmers' adoption of practices that conserve forests and biodiversity, and reduce fires and greenhouse gas emissions.

Company pledges to reduce deforestation and their associated implementation mechanisms are likely to result in the greatest global conservation and climate mitigation benefits when they are adopted in regions where larger amounts of forests and peatlands suitable for forest-risk commodity production exist. They are likely to be more effective in regions where complementary government regulations and enforcement capacities exist, yet their additionality might be lower in these regions. For oil palm these regions include West Africa, Papua and Kalimantan, and the Western Amazon. For soy and cattle these regions include the Amazon, Chaco, and Cerrado forest of South America. All company pledges to conserve forests should include HCS with HCV safeguards to ensure that important non-forest ecosystems are also being protected (Austin et al., 2017a).

Codes of conduct are a common initiative adopted by companies to adjust their sourcing practices. Yet, there are no empirical studies assessing the impacts of codes of conduct on conservation outcomes, likely due to a lack of data. To improve understanding of the effectiveness of these codes it will be necessary for companies to disclose information about the spatial extent of their sustainability activities, which researchers can then anonymize and assess.

Incentive-based standards (i.e. certifications) and their associated designation-based standards (i.e. HCV and HCS designations) may be the only viable mechanism for implementing company pledges for zero-deforestation when broad sectoral coordination cannot be achieved to establish deforestation bans. They may also be necessary as a complement to market exclusion mechanisms when these initiatives can't be carried out effectively due to unclear property boundaries and registration, which limit property level deforestation monitoring capacity. For these programs to have an impact globally their scope must be increased. Additionally, they must enforce early cutoff dates for deforestation so that preemptive deforestation does not occur. Critically these certifications programs need to improve adoption among smallholders so that they are not excluded from certified or zero-deforestation supply chains.

Improving the biodiversity effectiveness of certification and associated HCV and HCS will require coordination in the way value assessments are done, certifications are adopted, and conservation areas are implemented. HCV assessments should be completed within a larger licensed concession before land is divided into smaller concessions. Then, only sustainable land outside the HCV areas should be allocated to land users (Edwards and Laurance, 2012). The HCV criterion should protect forest patches as small as 1000 ha to ensure the protection of agricultural matrix-level biodiversity and habitat connectivity, rather than just areas greater than

20,000 ha (Edwards and Laurance, 2012). Agroforestry buffer zones should be established around HCVs to reduce edge and matrix effects from forest patches (Koh et al., 2009) Finally, countries should develop a national strategy of how to protect HCV areas to prevent companies from opting out by not adopting the certification programs that require their protection (Edwards and Laurance, 2012).

Forest conservation efforts should adopt a landscape-level perspective. By focusing on specific farms, key ecosystem services for smallholders (such as watersheds) might not be covered by the instruments, putting farmers' livelihoods at risk.

Given the limited scale of certification adoption and selection bias among existing adopters, an expansion in the scope of sectoral market exclusion mechanisms beyond the Brazilian Amazon is needed to ensure global conservation outcomes. The Chaco and Cerrado forest biomes in South America, Congo forests in East Africa, and Borneo forests in Indonesia remain highly vulnerable to deforestation for forest-risk food commodities.

Existing market exclusion mechanisms must also be improved. Guaranteeing deforestation-free soy and cattle purchases will require that buyers monitor all properties associated with their direct suppliers as well as indirect suppliers (e.g. calf producers for cattle). Tracking indirect suppliers will only be possible with the establishment of information systems linked to individual cows, such as ear tags or vaccination records (Gibbs et al., 2016). Both mechanisms need better enforcement of illegal deforestation and deforestation on small properties and protected areas (Azevedo et al., 2015; Klingler et al., 2018).

Corporate standards are not a panacea and cannot be effective where existing public governance is lacking. NGOs and companies seeking to reduce deforestation must support deforestation risk countries in improving complementary public governance mechanisms and strengthening regulations. Where this is not possible and government policies are explicitly antagonistic to conservation efforts, companies should consider not sourcing from those regions.

Clear property rights are needed to control leakage and laundering. Encroachment and illegal clearing are occurring in federal lands, protected areas and regions with unclear property rights. As countries improve their property registration systems, monitoring and enforcing becomes more useful in supporting corporate efforts to excluded non-compliant suppliers.

Inclusion of smallholders in all initiatives is key for ensuring success. Although smallholders face greater costs of compliance, their exclusion reduces the effectiveness of conservation policies. Smallholders are key participants in several agricultural value chains, including coffee, cocoa, and palm oil. Complementary mechanisms should be devised to help them comply with forest conservation policies in their lands and neighboring forests.

More broadly, forest conservation efforts should adopt a landscape-level perspective. By focusing on specific farms, key ecosystem services, particularly for smallholders, such as watersheds, might not be covered by the instruments, putting farmers' livelihoods at risk.

Access to detailed information on suppliers and their practices would help researchers understand and assess the actual impact of individual corporate actions on promoting sustainability to help companies in their strategic decisions. To help prevent competitors from not complying with their existing initiatives and help achieve broader transformations in food system governance, all companies should support transparency of their supply chain activities (Gardner et al., 2018). A well-designed traceability system could improve the ability of industry actors to implement commitments, and for consumers to verify industry claims. A public registry of purchases by farm could support traders' current efforts of setting limits on sales by a single producer to reduce the probability of purchasing non-compliant products. Such a system would be challenging to implement due to concerns about sensitive business information and producer confidentiality, but could reduce risk in the long run.

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Supplementary information:

1. Search terms

Due to the different Boolean and wild card operators across different databases we were required to translate our search string into an appropriate form for each platform. We have made these changes explicit below. Each database used contains extensive information regarding the operators used, but we will briefly outline the differences below.

Boolean operators are phrases such as AND OR or NEAR used to perform Boolean logical queries upon databases. Near is executed by NEAR/n were n is equal to the number of characters away in the text that the query will recognize.

Wild card are characters used in place of letters to represent various characteristics e.g. an asterisk (*) in Proquest and Web of Science replaces one or more characters following the asterisk e.g. farm* returns farms, farmer, farmland etc. as well as farm. In Web of Science the dollar sign ($) replaces just one character i.e. farm$ returns just farms and farm. In Proquest this character is replaced by the question mark symbol (?). For the purposes of this report, this is the only difference between Web of Science and Proquest. The only other modification was to apply the filter "no full text" in Proquest as this avoided a large amount of irrelevant material.

Table S1: Initial search strings

Substring category	**Substring contents (as used in WoS)**	**Number of papers identified in WoS & Scopus**	
		Initial search	**After narrowing for relevance and rigor**
Primary search string			
Agriculture	agricultur* OR farm* OR agribusiness OR crop$ OR commodit* OR "supply chain$"	NA	NA
Forest	forest* OR deforest	NA	NA
Environment	sustainab* OR environment* OR conserv* OR degrad*		
Assessment	outcome$ OR impact$ OR assessment$ OR result$ OR effectiv*	NA	NA
Corporate	private OR company OR companies OR supply chain$ OR corpor* OR commodit*	NA	NA
Supply chain initiative (SC) secondary search string			
SC1	"collective aspiration*" OR "international agreement*"	3	0
SC2	commitment OR pledge OR declarati*	34	4
SC3	"sourcing standard$" OR code$ OR	57	0

	"code$ of conduct" OR policy		
SC4	ban NEAR/3 FOREST) OR moratori* OR market exclusion OR sanction* NOT pesticide$	19	4
SC5	(zone$ OR "market exclusion" OR penalt*) AND (jurisdictional)	0	0
SC6	("high conservation value" area$ OR "high carbon stock" area$)	8	2
TOTAL		131 (includes duplicates across approaches)	10

Table S2: Updated search strings to broaden the search

Substring category	Substring contents (as used in WoS)	Number of papers identified	
		Initial search	**After narrowing for relevance and rigor**
Primary string			
Sector (agriculture)	(agricultur* OR farm* OR agribusiness OR crop$ OR commodit* OR supply chain$ OR soy* OR cattle OR beef OR coffee OR cacao OR palm)	NA	NA
Deforestation	forest* OR deforest	NA	NA
Supply chain initiative (SC) secondary search string			
SC1	"collective aspiration*" OR "international agreement*"	17	0
SC2	commitment OR pledge OR declarati*	228	5
SC3	"sourcing standard$" OR code$ OR "code$ of conduct" OR "company policy"	102	0
SC4	(ban NEAR/3 FOREST) OR moratori* OR market exclusion OR sanction* NOT pesticide$)	93	11
SC5	(zone$ OR "market exclusion" OR penalt*) AND (jurisdictional)	1	0
SC6	("high conservation value" area$ OR "high carbon stock" area$)	66	6
TOTAL		507 (includes duplicates across approaches)	22

GS doesn't recognize any wild card operators therefore all words were modified to the simplest form of the word. In addition, GS assumes that all spaces without a pair of quotation marks implies a Boolean AND operation, thus all of these were removed. The other critical difference between GS and the other search tools is that GS includes an implicit ranking of words, assuming that earlier words are more important than latter. To address this, for GS only, we used the supply chain initiative secondary string first.

Because we found zero results for collective aspirations and codes of conduct we also attempted more targeted searches on the New York Declaration on Forests for collective aspirations and Unilever's Responsible Sourcing Program, Nespresso's Triple A program, Nestlé's Responsible Sourcing Program, Mars' Supplier Code of Conduct, Starbucs' CAFE practices; and retailers: Walmart's Sustainability Index and Carrefour's Sourcing Policy for codes of conduct.

Table S3: Results of grey literature search

Substring category	**Substring contents (as used in Proquest)**	**Substring contents (as used in GS)**	**Number of papers identified**	
			Initial search	**After narrowing for relevance and rigor**
Primary string				
Sector (agriculture)	(agricultur* OR farm* OR agribusiness OR crop? OR commodit* OR supply chain? OR soy* OR cattle OR beef OR coffee OR cacao OR palm)	agriculture OR farm OR agribusiness OR crop OR commodity OR "supply chain" OR soy OR cattle OR beef OR coffee OR cacao OR palm	NA	NA
Deforestation	(forest* OR deforest)	forest OR deforest	NA	NA
Supply chain initiative (SC) secondary search string				
SC1	("collective aspiration*" OR "international agreement*")	"collective aspiration" OR "international agreement"	200	0
SC2	(commitment OR pledge OR declarati*)	commitment OR pledge OR declaration	612	1
SC3	("sourcing standard?" OR code$ OR "code? of conduct" OR "company policy")	"sourcing standard?" OR code OR "code of conduct" OR "company policy"	458	0
SC4	(ban NEAR/3 FOREST) OR moratori* OR "market exclusion" OR sanction* NOT pesticide$)	Ban AROUND(3) forest OR moratorium OR "market exclusion" OR sanction	351	2

SC5	(zone? OR "market exclusion" OR penalt*) AND (jurisdictional)	Zone OR “market exclusion” OR penalty jurisdictional	202	0
SC6	(“high conservation value” area? OR “high carbon stock” area?)	“high conservation value” OR “high carbon stock”	221	0
TOTAL			2044	3