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LETTER

Using supply chain data to monitor zero deforestation commitments: an assessment of progress in the Brazilian soy sector

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Abstract

Zero deforestation commitments (ZDCs) are voluntary initiatives where companies or countries pledge to eliminate deforestation from their supply chains. These commitments offer much promise for sustainable commodity production, but are undermined by a lack of transparency about their coverage and impacts. Here, using state-of-the-art supply chain data, we introduce an approach to evaluate the impact of ZDCs, linking traders and international markets to commodity-associated deforestation in the sub-national jurisdictions from which they source. We focus on the Brazilian soy sector, where we find that ZDC coverage is increasing, but under-represents the Cerrado biome where most soy-associated deforestation currently takes place. Though soy-associated deforestation declined in the Amazon after the introduction of the Soy Moratorium, we observe no change in the exposure of companies or countries adopting ZDCs to soy-associated deforestation in the Cerrado. We further assess the formulation and implementation of these ZDCs and identify several systematic weaknesses that must be addressed to increase the likelihood that they achieve meaningful reductions in deforestation in future. As the 2020 deadline for several of these commitments approaches, our approach can provide independent monitoring of progress toward the goal of ending commodity-associated deforestation.

Introduction

More than 150 countries and multinational companies have made public zero deforestation commitments (ZDCs)—commitments to eliminate deforestation from the production of commodities (Donofrio *et al* 2017). These include multilateral commitments such as the New York Declaration on Forests (NYDF), signed in 2014 by a collection of companies, NGOs, indigenous peoples, and national and sub-national governments; the Amsterdam declarations, signed by six European countries in 2015 (with a seventh, Italy, joining in 2017); and a host of unilateral commitments made by individual companies.

If successfully implemented, these commitments offer a powerful lever for reducing deforestation and associated biodiversity loss and greenhouse gas emissions. In practice, however, the potential impact of ZDCs is undermined by weaknesses in their definition and implementation—not least a lack of transparency (Climate Focus 2016, Jopke and Schoneveld 2018, Lambin *et al* 2018, Garrett *et al* 2019). Transparency is a prerequisite for understanding the coverage and impact of ZDCs and crucial for their accountability

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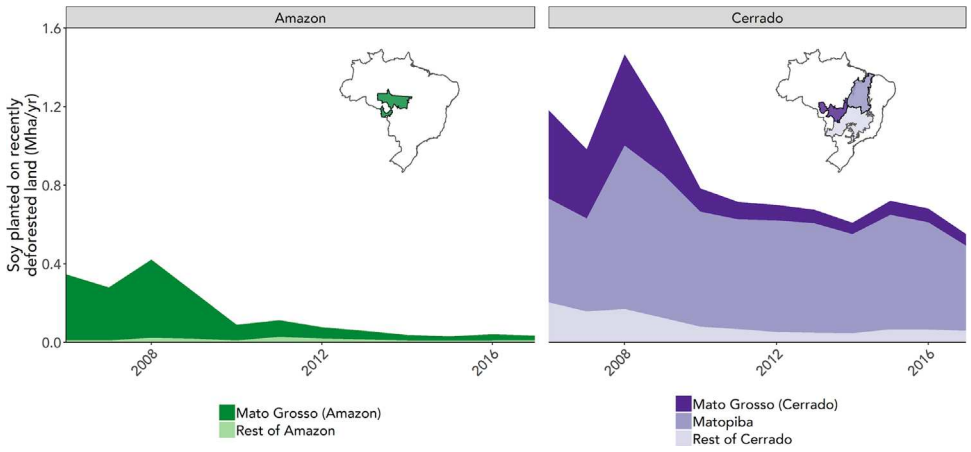

Figure 1. The area of soy planted on land deforested less than five-years previously. Source: authors' own calculations, based on Agrosatélite and PRODES data.

(Gardner *et al* 2018). Unless implementation is verifiable, it is not possible to determine whether ZDCs are actually translating into on-the-ground reductions in deforestation. Unfortunately, most ZDCs lack a clear blueprint for their implementation, monitoring, or progress reporting (Donofrio *et al* 2017, Rogerson 2019).

This lack of transparency arises in part because of the limited traceability in many commodity supply chains. Deforestation-risk products such as palm oil, beef, timber, and soy are all traded in bulk along global supply chains with multiple intermediaries between producers and consumers. They may be sourced via spot markets, and processed and incorporated into secondary products. At various stages in the supply chain—at storage facilities, processing plants, and maritime vessels—products from multiple sources are mixed and the identity of the original source lost. Even when companies have information about the location of production, as for some certified supply chains, they are often reluctant to publish such high-resolution information.

Here, we use a state-of-the-art wall-to-wall mapping of the Brazilian soy supply chain from the Transparency for Sustainable Economies (Trase) platform (www.trase.earth) to address this transparency gap. By combining official per-shipment trade records with comprehensive asset ownership registries, sanitary inspection records, sub-national commodity production statistics and remote sensing data on agricultural activities and land use change, we quantify the commodity-associated deforestation occurring in the sub-national jurisdictions from which different actors sourced soy between 2006 and 2017 (Godar *et al* 2016). We thereby estimate their 'deforestation risk'—the amount of deforestation associated with their sourcing, year-on-year, and how this has changed since individual actors have made ZDCs. We demonstrate this approach for ZDCs made by soy traders operating in Brazil and by countries sourcing soy from Brazil.

Soy is a heavily-traded oilseed and a major driver of global deforestation (Pendrill *et al* 2019). Soy is traded in bulk, both as a raw bean and as a processed product—soybean meal, used for animal feed, and soy oil, which is primarily used for biofuel production and other industrial processes (Brack *et al* 2016). From 2000 to 2016, the international trade in soy more than doubled (FAO 2018a), driven by growing demand for animal products in China and other emerging economies. Already the world's largest soy exporter, Brazil recently also overtook the US as the world's largest producer (Reuters 2018). In 2017, 73% of Brazil's soy harvest was exported, with major markets in China (65% of exports) and the European Union (15%).

The boom in soy production has changed the Brazilian landscape. Since 2000, the area of soy planted in Brazil has doubled, to cover an area of 34 Mha (IBGE 2017). This expansion has been an important direct and indirect driver of the loss of forests and other natural vegetation—with notable regional variation (figure 1). Since a peak in the late 2000s, clearance of native vegetation for soy has decreased in the Amazon biome and in older soy frontiers in the Cerrado—notably the state of Mato Grosso (figure 1). Soy, however, continues to be a major driver of habitat loss in the Cerrado's Matopiba region (made up of the states of Maranhão, Tocantins, Piauí, and Bahia), where over the last decade 0.5–0.8 Mha of soy each year has been planted on recently converted land (figure 1). The high rates of conversion in the Cerrado are especially concerning because it is a global biodiversity hotspot with little legal protection. The Cerrado is a wooded savannah biome, home to more than 4800 endemic plant and vertebrate species (Strassburg *et al* 2017). Though almost half of the Cerrado has already been converted to agriculture, only 7.5% lies in protected areas, and on private lands landowners may clear 65%–80% of each property (Strassburg *et al* 2017). In contrast, half of the Brazilian Amazon lies within protected areas

and landowners may only clear 20% of their land (Soares-Filho *et al* 2014).

Our study demonstrates how newly available supply chain data from Trase makes it possible, for the first time, to monitor progress against ZDCs for an entire sector, providing a quantitative and consistent assessment of the deforestation risk of committed and non-committed actors in the Brazilian soy supply chain. We find that ZDC coverage is increasing, but remains higher in the Amazon than the Cerrado, where most soy conversion is taking place. Soy deforestation declined in the Amazon after the implementation of the Soy Moratorium, a commitment by traders to avoid the purchase of soy planted on recently deforested land in the Amazon. We find no reduction, however, in the soy deforestation risk of actors in the Cerrado since any of these ZDCs were made. Recognising that several of the commitments analysed in this study are recent (post-2014), or were made after our time-series of soy deforestation risk and trade (i.e. post-2017), we also reviewed information on the formulation and implementation of these commitments to assess their potential effectiveness moving forward. Current ZDCs have several systematic weaknesses that must be addressed to deliver on the vision of deforestation-free commodity production.

Methods

Monitoring ZDCs at the sub-national scale requires mapping the sourcing patterns of supply chain actors through time, and quantifying the commodity-associated deforestation occurring in the jurisdictions from which they source, as well as information about the ZDCs themselves. We focus on ZDCs by soy traders and consumer countries. Supply chains are often hourglass-shaped (Lyons-White and Knight 2018), with a small number of traders acting as intermediaries between myriad producers and consumers. The ZDCs of traders, in particular, could have a disproportionate impact in reducing the deforestation risk of both upstream farmers and downstream consumer-facing brands.

Mapping soy supply chains

We used data from Trase to trace the origin of and deforestation associated with Brazilian soy exports from 2006 to 2017. Trase uses the Spatially Explicit Information on Production to Consumption Systems (SEI-PCS) approach to link exports of soybean products back to the municipality of production (Godar *et al* 2016). The SEI-PCS method is summarised below; more detail is available in the Trase manual (Trase 2018a). All analyses are based on SEI-PCS v2.4 (Trase 2019).

SEI-PCS uses customs declarations and/or per-shipment bills of lading to establish the dates of departure, volumes, ownership, exporting facility, port of export, and the country of import for specific shipments of soy. A logic-based decision tree is then used to map soy export flows back to a 'logistic hub'. Logistic hubs are supply chain nodes in a specific municipality where soy is produced, stored, handled, or transformed before export. The decision tree crosses the consolidated customs information with other independent data sets, including on the logistics and taxation of trading companies, as well as production and country-specific export permissions per facility, so that multiple lines of evidence are used to confirm a given subnational location as the origin of production of a given shipment. Where it is not possible to confidently trace flows back to a specific logistic hub, the origin is labelled as unknown (SI is available online at stacks.iop.org/ERL/15/035003/mmedia).

Where the decision tree traces soy back to a storage or processing facility but not a municipality of soy production, linear programming techniques are used to allocate soy from municipalities of production to logistic hubs. This constrained optimisation distributes available supply (total soy production per municipality) to known demand—both overseas and domestic—taking into account the location of company assets such as storage facilities and farms and minimising transport distances. When matching exports of soybean products (i.e. tons of soybean meal or oil) to soy production (tons of soybeans), SEI-PCS converts soy products into 'soybean equivalents' using conversion factors which respect meal versus oil crushing ratios and account for waste losses during crushing (FAO 2018b). To test the sensitivity of our results to the linear programming step, we also ran an alternative analysis, where instead of transport distance minimisation, the soy deforestation occurring within 200 km of each logistic hub was assigned proportionally to all traders operating there (SI figure S8).

Quantifying soy deforestation risk

For each municipality and year, we intersected maps of soy planted in the Cerrado and Amazon biomes with deforestation maps to calculate the area of soy planted on land deforested within the previous five years. Soy crop maps were available from 2006–2007, 2009–2010, 2014–2015, and 2016–2017 in the Amazon and 2006–2007, 2013–2014, and 2016–2017 in the Cerrado (Agrosatélite 2018). In each year, we used the subsequent available crop map and a five-year allocation period to link deforestation to soy (i.e. for the 2013 soy harvest in the Amazon, we intersected the 2014–2015 soy map with annual deforestation maps from 2009–2013; SI figure S1). We used a five-year allocation period to reflect that deforested land is typically not immediately suitable for soy production —the soil is prepared by planting with an intermediate crop (e.g. rice or pasture) before soy is planted for the first time (Osorio 2018). While previous studies have also used one-year or three-year time lags

Table 1. Summary of ZDCs in the soy sector. More details of these commitments are listed in SI Tables S2 and S3.

Commitment	Geographical scope	Year introduced	Cut-off for deforestation	Wording
Multi-stakeholder commitments				
Soy Moratorium	Brazilian Amazon biome	2006	July 2008	The Brazilian Association of the Vegetable Oil Industry (ABIOVE), the Brazilian Association of Cereal Exporters (ANEC) and their respective members commit to not purchase soy which is planted after October 2006 and which comes from areas deforested in the Amazon biome after July 2006. *Note: the cut-off date was subsequently moved to July 2008.*
New York Declaration on Forests	Global	2014	2020/2030	With our varying mandates, capabilities, and circumstances, collectively we commit to doing our part to achieve the following outcomes in partnership: • At least halve the rate of loss of natural forests globally by 2020 and strive to end natural forest loss by 2030. • Support and help meet the private-sector goal of eliminating deforestation from the production of agricultural commodities such as palm oil, soy, paper and beef products by no later than 2020. *Signed by 35 national governments, the European Union, 19 subnational governments, more than 50 companies (including Cargill), 26 indigenous peoples, and more than more than 50 NGOs. A full list of signatory countries is included in Table S1.*
Amsterdam Declaration	Global	2015	2020	We reiterate our objectives to support and help meet the private sector goal of eliminating deforestation from the production of agricultural commodities such as beef and leather, palm oil, paper and pulp, soy and other commodities such as cocoa and rubber by no later than 2020. *Signed by the governments of Norway, the United Kingdom, France, Germany, Denmark, the Netherlands, and Italy.*
Soft Commodities Forum	Global, with an initial focus on the Brazilian Cerrado	2019	None	SCF member companies each have pledged to eliminate deforestation from their agricultural supply chains worldwide, deploying credible, tested science-based methodologies for defining forests and biodiversity… The SCF first aims to tackle land use challenges in the Brazil Cerrado *Note: monitoring is initially focused on 25 'priority municipalities' in the Cerrado, selected based on having more than 5,000 hectares of planted soy, high rates of soy-associated deforestation, and being municipalities where SCF companies purchase soy.*
Company commitments				
Cargill	Global	2014	2030	In 2014, Cargill endorsed The New York Declaration on Forests, announcing at the United Nations Climate Summit our goal to eliminate deforestation across our entire agricultural supply chain, halving it by 2020 and ending it completely by 2030. *Note: Cargill updated this commitment in February and June 2019:* Cargill commits to a transparent and sustainable South American soy supply chain that: • Transforms our supply chain to be deforestation free while protecting native vegetation beyond forests.
Bunge	Global	2015	2020-2025	Bunge commits to: • achieve deforestation-free supply worldwide, considering both direct and indirect sourcing • employ science-based definitions and cutoff dates for deforestation determined by credible multi-stakeholder processes
Archer Daniels Midland (ADM)	Global	2015	None	We commit to build a transparent, traceable soy supply chain that does not contribute to deforestation or exploitation.
Amaggi	Global	2017	None	With this commitment, we reaffirm our desire to reach a supply chain that is entirely deforestation free, therefore we declare that we will work in conjunction with suppliers, customers, the civil society,

Table 1. (Continued.)

Commitment	Geographical scope	Year introduced	Cut-off for deforestation	Wording
				and governments in order to achieve this result in the shortest time possible. *Note: Amaggi updated this commitment in June 2019, clarifying that:* [The commitment] applies to all locations where we operate, in and outside Brazil, including the Cerrado and Amazon biomes
Louis Dreyfus	Global	2018	None	LDC commits to influence and collaborate with stakeholders across the soy supply chain in order to: Eliminate engagement in, or financing of deforestation throughout our supply chain, and conserve biomes proven to be of high ecological value, such as the Cerrado, Brazil, with the intent to discourage and eliminate conversion of native vegetation.
Glencore Agriculture	Global	2019	None	We are working collaboratively with producers and suppliers along our supply chains to eradicate deforestation, increase sustainability and protect high carbon stock forest, valuable conservation areas and peatlands from uncontrolled expansion.

(Gibbs *et al* 2015, Trase 2018b), a five-year time lag captures the vast majority of crop-associated deforestation in Latin America (Graesser *et al* 2018).

We then attributed deforestation-associated soy to the actors sourcing soy from each municipality. In the absence of data on the individual contracts between farmers and traders, we allocated soy deforestation to each trader in proportion to the volume of soy that they export from a given jurisdiction relative to its total production of soy. We report these figures as the 'soy deforestation risk' (in hectares/thousand tons soy/year) of each actor. When presenting these results per biome, municipalities were classified according which biome made up the majority of their area. Since deforestation varies year-on-year due to many factors not related to soy sourcing policies, we also calculated the soy deforestation risk ratio relative to the market average for each year—the 'scaled deforestation risk'. This metric identifies actors who consistently source from low- or high-risk regions, even as deforestation rates fluctuate in the short-term. Finally, we report the total deforestation risk associated with each trader (in hectares/year), though this metric reflects to a large extent their overall market share (SI figure S7), and so we focus on the relative and scaled deforestation metrics.

Our data on soy deforestation risks come with three qualifications. First, we used the Brazilian government's official PRODES datasets when monitoring soy deforestation risk in the Amazon and Cerrado (INPE 2018a, 2018b). These data in the Cerrado include both the loss of forest, and also some areas of natural vegetation that are not strictly forest, but which also are important for biodiversity conservation, carbon storage, and the provisioning of other ecosystem services (Strassburg *et al* 2017), and are explicitly included in some ZDCs (SI table S3). Second, these data do not monitor deforestation beyond the Amazon and Cerrado. Though soy is planted in all regions, only 1% of cropland expansion outside of the Amazon and Cerrado in Brazil between 2000 and 2014 occurred over native vegetation (Zalles *et al* 2019). Our results therefore capture the majority of native vegetation cleared for the expansion of soy in Brazil. Finally, though we use the term 'deforestation risk' to reflect each actor's exposure to deforestation-associated soy, soy traders and other supply chain actors (producers, financiers, investors, and retailers) are of course not passive risk-receivers. Traders, for example, can actively create conditions favouring the expansion of soy production through local infrastructure and financial investments in new frontiers, or reduce direct deforestation in the jurisdictions from which they source by implementing ZDCs.

Reviewing ZDCs in the soy sector

We identified a list of the 30 traders that purchased more than 1% of Brazil's soy harvest in any given year over the last decade (2008–2017). In total they handled 87% of soy exports over that period. We assessed their soy sustainability policies, drawing on the Forest 500 assessments (Global Canopy 2018) and analysis of company websites and corporate sustainability reporting materials. We defined 'zero-deforestation commitments' as written commitments to avoid, for a specific region or globally, commodities produced on recently converted land, to remove from their soy supply chain all deforestation (a zero *gross* target), or to balance deforestation with reforestation (a zero *net* target). For consumer countries, these commitments included the NYDF and Amsterdam declarations. We then assessed each of these commitments against eleven criteria of their potential effectiveness (Garrett *et al* 2019) and linked them to our data on deforestation risk. One prominent commitment, the Soy Moratorium, has been the subject of several previous assessments (Rudorff *et al* 2011, Azevedo *et al* 2015, Gibbs *et al* 2015, Kastens *et al* 2017, Silva and Lima 2018); we therefore focus our analyses on the remaining commitments, for which there are no quantitative estimates of their impact.

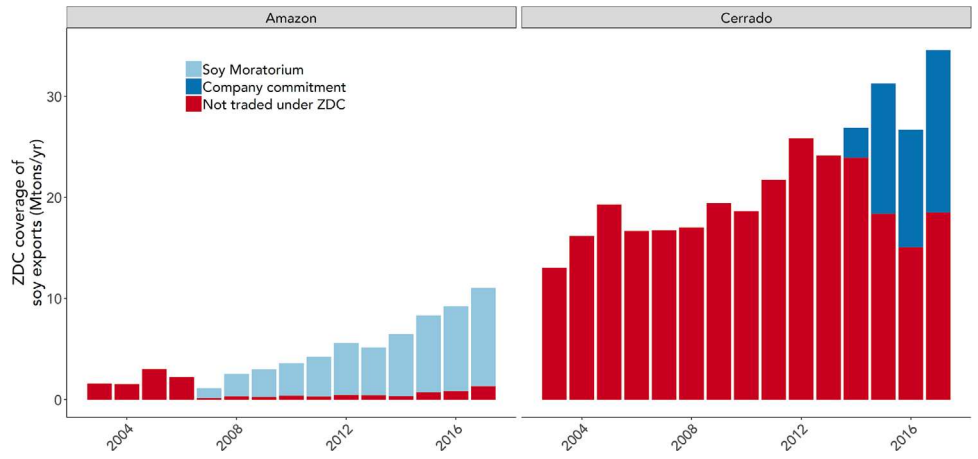

Figure 2. The coverage of ZDCs is higher in the Amazon, where the Soy Moratorium applies, than in the Cerrado, where it does not.

Results and discussion

We identified ten ZDCs applying to the Brazilian soy sector (table 1, SI table S3). Four of these are multi-stakeholder commitments: the Amazon Soy Moratorium, NYDF, Amsterdam Declaration, and Soft Commodities Forum. The remaining six are unilateral commitments by the five largest soy traders (Bunge, Cargill, Amaggi, Louis Dreyfus, and Archer Daniels Midland, henceforth 'ADM'), and the 13th largest trader, Glencore, together responsible for 56.6% of Brazilian soy exports and 66.3% of export-associated soy deforestation risk over the last decade (SI figure S2). Amongst these ZDCs there appears, however, to be a trade-off between their ambition and accountability. The Soy Moratorium applies only to the Amazon biome, but is independently audited for direct soy deforestation using satellite imagery (ABIOVE 2019). The other pledges are global in scope but lack independent auditing and transparent monitoring mechanisms.

ZDC coverage has increased but is uneven

Signatories of the Soy Moratorium handle approximately 90% of the soy exported from the Amazon (figure 2). In contrast, only 46.5% of soy exported from the Cerrado in 2017 was traded by companies who have made commitments, though this figure was zero only four years earlier (figure 2). The growth in ZDC coverage stems from an increase in the number of commitments over time rather than an increase in the market share of committed traders (table 1, SI figure S10), and ZDC coverage is expected to increase further. The members of the Soft Commodities Forum (launched in 2019), purchased 56.2% of soy exported from the Cerrado between 2006 and 2017, though in practice the ZDC coverage will be lower than this, because the monitoring of this commitment is initially focused on 25 'priority municipalities' which supply 25.3% of member companies' soy from the Cerrado (Glencore Agriculture 2019).

No evidence of reductions in soy deforestation risk outside the Amazon

Together with public policies to reduce deforestation, the Soy Moratorium helped curtail direct clearance for soy in the Amazon (Nepstad *et al* 2014, Gibbs *et al* 2015). The soy deforestation risk of traders operating in the region declined in particular from 2008 onwards (figure 3), the year that satellite monitoring of the Soy Moratorium was introduced (Gibbs *et al* 2015) . The individual corporate commitments, the NYDF, the Amsterdam Declaration, and the Soft Commodities Forum are all more recent (post-2014) and we have limited years of post-commitment data with which to judge their progress. Our data—the first quantitative monitoring of their impacts—show no evidence of additional reductions in the deforestation risk of committed actors since making these pledges.

The soy deforestation risk of Bunge fell over the past decade (figure 2(a)), following the broader market trend (figure 1), though their risk in the Cerrado, where the Soy Moratorium does not apply, remained consistently above or equal to the market average for each year (figure 2(b)). There has been no marked improvement in their soy deforestation risk since making their commitment in 2015; Bunge's deforestation risk in Matopiba rose in 2016, and fell in 2017, with their deforestation risk in the Cerrado as a whole remaining close to the market average in 2017. Similarly, Cargill's soy deforestation risk in the Cerrado and Matopiba fluctuated around the market average with no clear improvement since their 2014 commitment to halve deforestation in their supply chains by 2020. ADM's deforestation risk fluctuated around or below the market average, with no change after making their commitment. The commitments by Amaggi (in 2017), Louis Dreyfus (in 2018), and Glencore (in 2019) are too recent to be assessed, though Amaggi's and Louis Dreyfus' deforestation risk in the Cerrado has been consistently below the market average since the late 2000s, and they have only intermittently sourced soy from within Matopiba. Glencore's

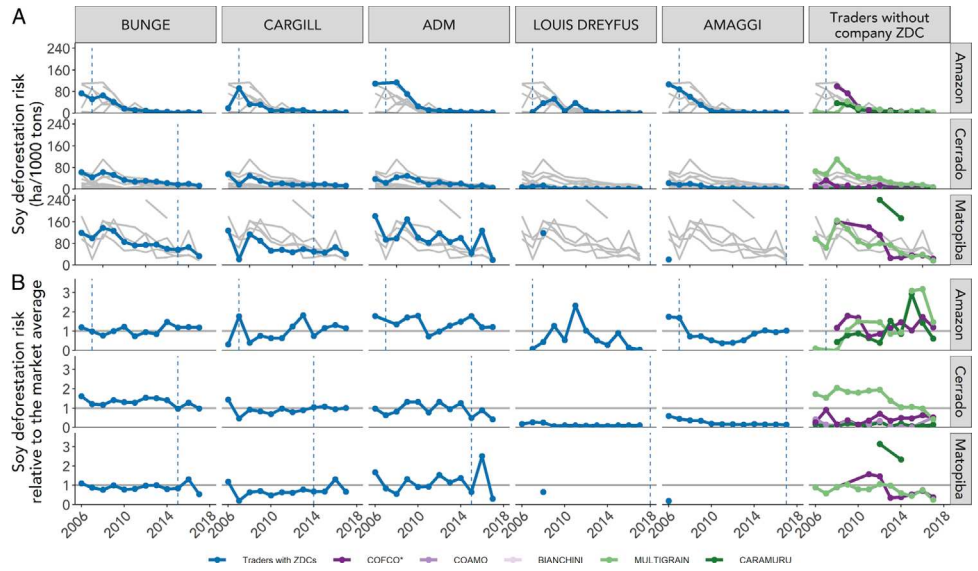

Figure 3. (A) The soy deforestation risk (ha/thousand tons soy) of the top ten soy exporters, in the Amazon, Cerrado, and Matopiba. (B) Soy deforestation risk, scaled to the market average for each region and year (shown as a horizontal grey line). Points above (below) one, shown as a grey line, have above (below) average market risk in each region in each year. Dashed blue lines demark the year that ZDCs were implemented, 2008 for the Soy Moratorium, and 2014–2018 for other commitments. Note: COFCO entered the Brazilian soy market through the acquisition of the traders Nidera and Noble Agri between 2014 and 2017; the trend-line for COFCO pre-2014 refers to the deforestation risk of these two companies. These trends are plotted for all assessed traders in SI figures S3–5.

deforestation risk has also been low, though it has increased since 2010, when their sourcing expanded out from states in the south of Brazil, such as Paraná into states such as Mato Grosso and Matopiba, where soy deforestation rates are higher (figure S11).

Though these companies' soy deforestation risk declined in the Amazon after the implementation of the Soy Moratorium, companies' soy deforestation risk in the Cerrado appears to be more strongly determined by the geographies in which they have historically made infrastructure investments than their specific procurement policies. Bunge, for example, is the largest exporter of soy to Europe (handling 20% of EU imports from 2006 to 2017) and has invested heavily in the Amazon and Matopiba, which are logistically closer to European markets. Bunge operate two ports in Pará in the Amazon, and two soy crushing facilities and one refining facility in Matopiba, where most soy deforestation is taking place (figure 1). Cargill and ADM also operate in Matopiba and have higher soy deforestation risk in the Cerrado than Amaggi and Louis Dreyfus, who operate mainly in older soy frontiers in Mato Grosso and the south-west Cerrado, respectively, where soy already occupies much of the landscape (SI figure S3). Amaggi's soy deforestation risk, for example, was high in the mid-2000s before decreasing, reflecting the pattern of soy expansion in Mato Grosso (figure 1). Since 2011, Glencore have operated three storage facilities in Mato Grosso, where they have since sourced 15%–36% of their soy, though they are otherwise and an asset-light trader, with the origin of their sourcing shifting year-on-year (SI figure S4).

A similar picture emerges for commitments by countries. After the implementation of the Soy Moratorium, deforestation risks in the Amazon declined to low levels for all consumer markets. NYDF and Amsterdam declaration countries have oscillated around the market average in all regions, and this has remained essentially unchanged since their commitments, with their deforestation risk increasing in 2016, but falling in 2017 (figure 4).

Using supply chain data to monitor ZDCs

We apply a state-of-the-art data set on the Brazilian soy supply chain to attribute deforestation to supply chain actors and provide much needed transparency on the coverage and impacts of ZDCs in the soy sector. As with all analyses, some limitations apply.

First, we present a novel approach for monitoring ZDCs, though the conclusions we can draw from the presented data (covering 2006–2017) are limited by the time series analysed. Additional data from pre-2006 would capture the pattern of deforestation risk prior to the establishment of the Soy Moratorium; unfortunately, deforestation data are only available from 2000 in the Amazon and 2001 in the Cerrado, which prevents earlier analysis (accounting for the five-year lag between deforestation and the establishment of soy). Similarly, the impact of the commitments by Amaggi, Louis Dreyfus, Glencore, and the Soft Commodities Forum on deforestation risk cannot be analysed with our trade data, as they were made after our time-series. We do, however, present additional assessments of the formulation of these commitments (table S3), and note that our proposed method allows for future monitoring

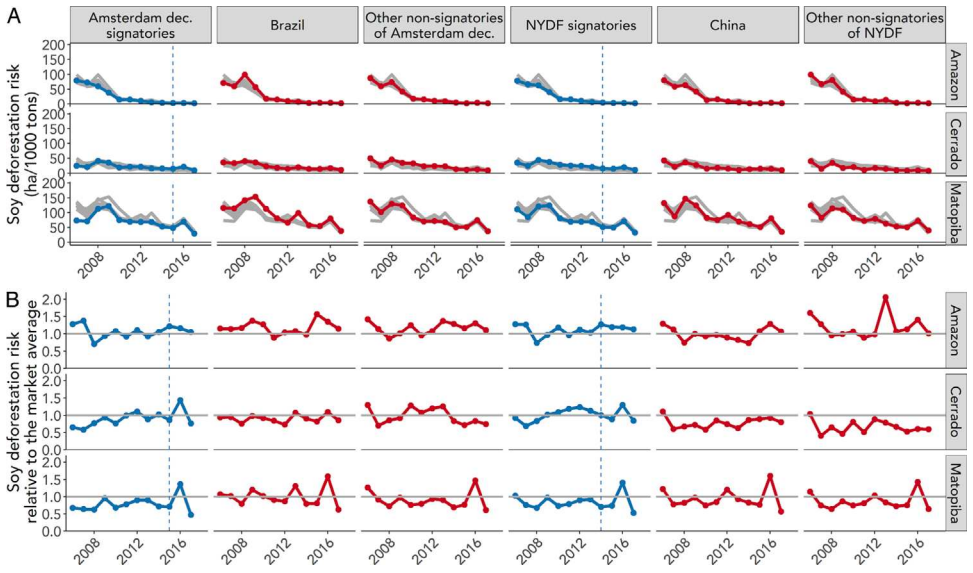

Figure 4. (A) The soy deforestation risk (ha/Mton) of different consumer markets. (B) The soy deforestation risk, relative to the market average in each year (the grey line).

of the changes in their deforestation risk as time goes on.

Second, though we use rich data on soy infrastructure and trade, we are unable to triangulate the origin of all soy flows. The proportion of unknown flows varies between traders (SI figure S8), but was 6.7%–9.9% of the total exported volume in the post-2014 period.

Third, our soy deforestation risk does not include indirect land use change where the expansion of soy drives deforestation through the displacement of cattle ranching or effects on expected agricultural rents (Richards *et al* 2015; Arana *et al* 2019).

Fourth, several of these commitments include multiple commodities and regions (SI table S3). The NYDF, for example, applies to all sources of deforestation and the Amsterdam Declarations apply to both soy and oil palm production, and a complete picture of their impacts must analyse deforestation trends across multiple commodities and regions. The Trase initiative is seeking to address these gaps and cover 70% of forest-risk agricultural commodities by 2020 (Trase 2018b).

Fifth, since there are no public data on individual contracts between farmers and traders, soy deforestation risk is measured at the municipal, rather than the farm level. While it is in theory possible for actors to have deforestation-free supply chains even while sourcing from jurisdictions where there is soy-associated deforestation, we contend that municipal-level 'soy deforestation risk' is a meaningful measure of each actor's deforestation footprint. In many regions, soy-sourcing is locally consolidated: 30%–51% of soy (and 31%–63% of soy deforestation risk) each year was traded through logistic hubs where three or fewer companies operated, and at the municipal-level, we estimate that 48%–67% of soy (and 38%–74% of soy deforestation risk) comes from municipalities where three or fewer companies were actively sourcing soy. This consolidation suggests that we can have some confidence when allocating municipal-level deforestation risk to each actor. Our results are also robust to a sensitivity analysis allocating soy deforestation risk from municipalities of production to logistic hubs not using linear programming, but assuming a 200 km sourcing distance around the logistic hubs from which they source (SI figure S8). Alternative methods of allocating risk (for example based on changes in traders' sourcing from jurisdictions, rather than their market share), would be a valuable area of future work. Even so, any local mis-matches in the allocation of deforestation risk are further mitigated when analysing deforestation risk across the entirety of each actor's sourcing areas. Municipal-level assessments also bring some advantages. ZDCs should arguably be judged on their net impact on deforestation (Garrett *et al* 2019), as they can be undermined by leakage. If a committed actor's non-compliant producers continue to clear land and switch to sell to non-committed traders, the ZDC's net effect on deforestation will have been zero. Farm-level analyses of individual supply chains will, however, fail to assess these net effects, which may be detected at larger scales.

Sixth, supply chain data alone cannot address some of the definitional issues with ZDCs—notably ambiguity around what constitutes deforestation. The Cerrado, the hotspot of soy expansion in Brazil, is a savannah biome, which consists of a mosaic of natural vegetation types, from tall forest to shrub- and grassland. While Cargill's, Amaggi's and Louis Dreyfus's commitments explicitly mention the protection of the Cerrado, others do not, and there is ambiguity over what vegetation types are covered (SI table S3). When monitoring soy deforestation risk in the Amazon and

Cerrado, we used Brazilian government data on the loss of native vegetation. Our results are therefore aligned with official efforts to monitor and enforce the Brazilian Forest Code, the Amazon Soy Moratorium, and the Soft Commodities Forum's ZDC, and reflect the ongoing impact that committed actors have on Brazil's natural resources. Narrower definitions of what natural vegetation types are protected under ZDCs risk leakage, where biodiversity and carbon benefits are undermined by the displacement of soy expansion into other natural vegetation types (Popp *et al* 2014, Garrett *et al* 2019).

Finally, it is worth highlighting that improvement in transparency, whether through independent initiatives such as Trase, or through trader initiatives such as the Soft Commodities Forum, of course does not, in and of itself, reduce deforestation. While transparency is a critical precondition for accountability (Gardner *et al* 2018), concrete changes in company sourcing and producer land use decision-making are required to break the link between the expansion of soy and deforestation.

Prospects for deforestation-free soy

Brazil has large areas of forests and savannah that may legally—and illegally—be cleared for commodity production. We show, however, that a growing proportion of Brazil's soy exports are traded by companies who have made ZDCs. Apart from the Soy Moratorium, however, we find no noticeable reduction of soy deforestation risk of committed actors. Which begs the question—what are the prospects for zero deforestation soy?

On paper, deforestation-free soy production is achievable. In the Amazon, where the Soy Moratorium applies, direct clearance for soy occurs at low levels (~1% per year) (Gibbs *et al* 2015, ABIOVE 2019), and in the Cerrado, 70% of recent soy expansion (2000–2014) occurred over land that in 2000 was pasture, rather than native vegetation (Carneiro *et al* 2016). The Brazilian context is in many ways favourable to the implementation of ZDCs. Both the Amazon and Cerrado have abundant pasture land available for further soy expansion (Carneiro *et al*2016, Strassburg *et al* 2017, Rausch *et al* 2019), and Brazil also has unique public monitoring capacities, including high-quality remote sensing products and a rural property cadaster (SI table S3). As these ZDCs are currently defined and implemented, however, prospects for their future effectiveness in reducing deforestation remain very uncertain (SI table S3).

Other than the Soy Moratorium, these commitments either set future cut-off dates for deforestation or no cut-off dates at all. Without concrete cut-off dates for deforestation in the immediate future or the past, these commitments are very unlikely to discourage further clearance, as producers continue to receive the message that deforestation-associated soy can be marketed without repercussion.

Outside the Amazon, none of these commitments set out transparent mechanisms for their monitoring or enforcement, and implementation appears to lag behind promises. Signatories of the Soy Moratorium have implemented an independently-audited, standardised monitoring system (SI table S3), while monitoring efforts in the Cerrado are not standardised and less transparent. Bunge reports having 90% traceability to the farm level for their direct suppliers in Matopiba and Mato Grosso and state that in 2017/18, 98 of their monitored farms were flagged for deforestation, of which nine were subsequently suspended (SI table S3). Cargill has a pledge to eliminate deforestation from their supply chain by 2030, but their efforts to date have focused on illegal deforestation (SI table S3). Even so, as recently as October 2017 both Bunge and Cargill, along with ABC Industria (part of Algar Agro group), and a handful of other soy traders were fined BRL 24.6 million (USD 6.7 million) for illegal clearance in the Cerrado (Spring 2018). ADM releases a quarterly progress report on their soy sustainability initiatives, which states that they have collected farm boundary data for 100% of their supplier farms in 13 priority municipalities in Matopiba. Beyond improving traceability, their implementation appears to be at the engagement stage, however. ADM lists efforts to 'engage with suppliers' and 'explain the No Deforestation Policy', but does not report levels of non-compliance, nor the procedures they follow when infringements are identified (SI table S3). Amaggi reports that 19% of its soy is traded under zero deforestation certification, with a further 12% covered by the Soy Moratorium (SI table S3). In 2018, 1315 grain supplier registrations were flagged for socio-environmental non-compliance, though Amaggi does not report what actions were taken after identifying these possible breaches. Louis Dreyfus does not provide details of their traceability or mechanisms of enforcement (SI table S3). Glencore began monitoring its suppliers in September 2018, but does not provide any information on the origin of their sourcing. Glencore reports that it has since detected non-compliance in its supply chains but does not detail how many infringements occured, what these infringements were, or what actions were taken (SI table S3).

Regarding commitments by governments, evidence of implementation is also lacking (SI table S4). Government participation in the NYDF was arguably more a goal-setting exercise than a concrete move to reduce the deforestation risks of their consumers (Lambin *et al* 2018), and civil society efforts to follow up on it have focused on private sector signatories (Climate Focus 2016). The Amsterdam Declarations were meant to have a stronger focus on translating commitments into action, but still appear to be in the engagement rather than implementation stages. France, with arguably the most advanced efforts,

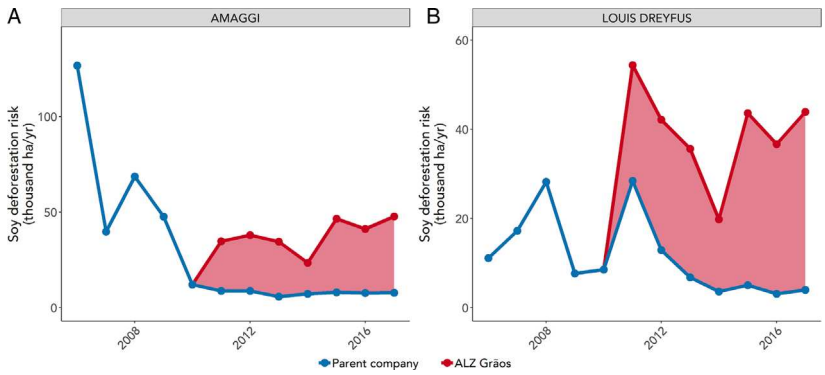

Figure 5. The soy deforestation risk (ha) of Amaggi (A), Louis Dreyfus (B), and their joint-venture ALZ Grãos.

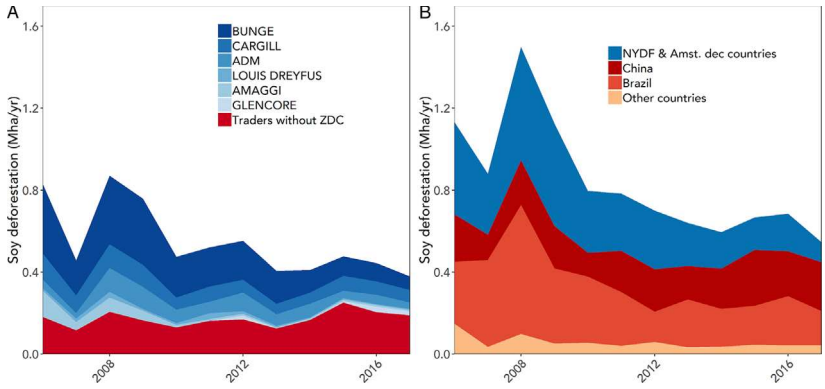

Figure 6. Traders and consumer markets not covered by ZDCs account for an increasing proportion of soy deforestation risk.

announced in December 2018 a 17-point plan for reducing the deforestation embedded in their imports. The plan includes a commitment to use development aid to incentivise producing regions to adopt zero deforestation practices, and promises a review of legislation about businesses' due diligence on deforestation risks (France 2019) (SI).

Importantly, several other systemic issues must be addressed to increase the potential effectiveness of ZDCs. First, ZDCs must not be selectively applied. While Amaggi and Louis Dreyfus have made ZDCs and have soy infrastructure in lower risk areas, in 2009 they set up a joint-venture, ALZ Grãos to establish a foothold in the soy frontier in Matopiba (Graner 2018). ALZ Grãos has invested in soy storage, wholesale facilities, and a port terminal in the region and export 0.4–1.2 Mtons each year. Including the deforestation risk of this joint-venture in the sourcing of Amaggi or Louis Dreyfus increases their deforestation risk in 2017 by 5-fold and 10-fold, respectively (figure 5).

Second, though committed traders made up 47.9% of the soy export market in 2017, the proportion of soy deforestation associated with other companies and markets is growing (figure 6). The relative importance of Amsterdam Declaration and NYDF signatory countries is also decreasing as their market share has been overtaken by the growth of exports to China, which purchased 64% of Brazil's soy exports in 2017 (SI figure S11). ZDCs will be most effective at reducing commodity-associated deforestation if they avoid creating a segmented marketplace, where deforestation-free soy is sold to a minority of committed markets and other soy flows elsewhere. Part of the success of the Soy Moratorium in reducing soy-associated deforestation likely comes down to its comprehensiveness, in including all ABIOVE and ANEC members (table 1), responsible for ca. 90% of soy exports from the Amazon, thereby sending a consistent message to producers and limiting inter-actor leakage. Multi-stakeholder initiatives, such as the Soft Commodities Forum (table 1) and the Cerrado Working Group could play a key role in trying to move the sector as a whole onto a more sustainable footing. The recent (December 2019) development of a compensation mechanism in the Cerrado also offers promise (Byrne 2019), especially if the original participants (Tesco, Nutreco, and Grieg Seafood) are joined by other signatories of the Cerrado Manifesto. Ultimately, the demands of the Chinese market are increasingly setting the agenda for soy sustainability. While Chinese firms are more focused on legality than zero deforestation, the Chinese meat industry, a major downstream consumer of Brazilian soybeans, has adopted a ZDC (WWF 2017), and the chairman of

COFCO, the largest Chinese soy trader operating in Brazil, has called for extending the Soy Moratorium to the Cerrado (Lyu 2019).

Finally, soy ZDCs will only be effective if committed actors seek solutions across the agricultural sector. Even where soy expands over pasture and is 'deforestation-free', it displaces beef production and creates incentives for further deforestation by driving up expected agricultural rents and injecting capital into agricultural markets (Richards 2015, Richards and Arima 2018, Miranda *et al* 2019). Rapidly expanding crops, such as soy, can therefore only be deforestation-free if deforestation is constrained in the agricultural sector into whose land it expands. Ultimately, cross-sectoral collaboration is required to pair efforts to guide soy expansion onto low productivity agricultural land (e.g. cattle pasture) with efforts to close the forest frontier and constrain the expansion of cattle ranching in frontier regions, and spare land through the intensification of cattle ranching and adoption of integrated crop-livestock systems (Garrett *et al* 2018, Koch *et al* 2019, Nepstad *et al* 2019).

Conclusion

Between 2006 and 2017, 0.6–1.9 Mha of soy were planted each year on recently deforested land in Brazil, driven by growing global demand and fluctuations in capital availability, political opportunity, and exogenous factors such as currency exchange rates (Richards *et al* 2012, Pailler 2018, Richards and Arima 2018). Deforestation-free commodity production is however possible, and a growing proportion of the market have made commitments to zero deforestation commodity production. Without transparency on their implementation and impacts, however, committed actors cannot be held accountable, and ZDCs risk becoming a missed opportunity for supply chain governance. Here we present a pragmatic approach for monitoring the deforestation risks of actors with and without ZDCs, finding mixed impacts of ZDCs so far in the Brazilian soy sector. Though the Soy Moratorium has helped reduce direct clearance for soy in the Amazon, we find no evidence for ZDCs reducing deforestation risk in the Cerrado. Looking forward, our approach can be used to provide independent monitoring of progress in delivering on promises for zero deforestation commodities.

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Data availability statement

The data and code that support the findings of this study are openly available at doi:10.5281/zenodo.3582934.

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