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How Trase assesses 'commodity deforestation' and 'commodity deforestation risk'

Contents

Introduction

Trase (www.trase.earth) maps supply chains of forest-risk commodities — such as beef and soy — to link sub-national jurisdictions of production, trading companies and countries of import. Trase then assesses deforestation associated with the production of each commodity in these jurisdictions and links it to the supply chains. It uses two indicators to do this:

1. **Commodity deforestation** (in hectares) estimates how much land is deforested each year due to the expansion of production of a given commodity. It is a *forward*-looking measure, meaning that the starting point is a deforestation event. From such an event, Trase determines how much of the deforested land has been put into commodity production. In the Trase platform, this measure appears on the map and in the jurisdictional profiles.

2. **Commodity deforestation risk** (in hectares) estimates the exposure of an actor (company or country) to the risk that the commodity it is sourcing is directly associated with recent deforestation in the region where it was produced. It is a *backward*-looking measure, meaning that the starting point is the production of the commodity. From this production, Trase determines how much recent deforestation was associated with a given area of production. Trase then shares this deforestation among actors according to the relative amounts of the commodity that they source from each jurisdiction. In the Trase platform, this indicator appears on the trade flows and the actor profiles, and in the data download.

While both indicators are related to deforestation associated with the expansion of commodity production, **commodity deforestation** assesses the extent to which commodity expansion is driving deforestation in new areas, while **commodity deforestation risk** assesses the extent to which the production of a given commodity is associated with recent deforestation.

In presenting these indicators, Trase aggregates all deforestation data across each commodity-producing jurisdiction, for example municipalities in Brazil or departments in Argentina. We derive both indicators using a predetermined 'allocation period' that varies among countries and commodities. This is a period of time during which commodity production can be linked to deforestation, considering the time needed to prepare the land following forest clearance. Figure 1 illustrates the two indicators, and we explain allocation and lag periods in more detail below.

This document describes in detail the methods Trase uses to assess commodity deforestation and commodity deforestation risk. First, it explains the general approach Trase uses to link deforestation to commodity expansion over time and for each commodity. It then describes how Trase calculates each indicator. Finally, its Appendix presents the datasets and methods Trase uses for each country and commodity.

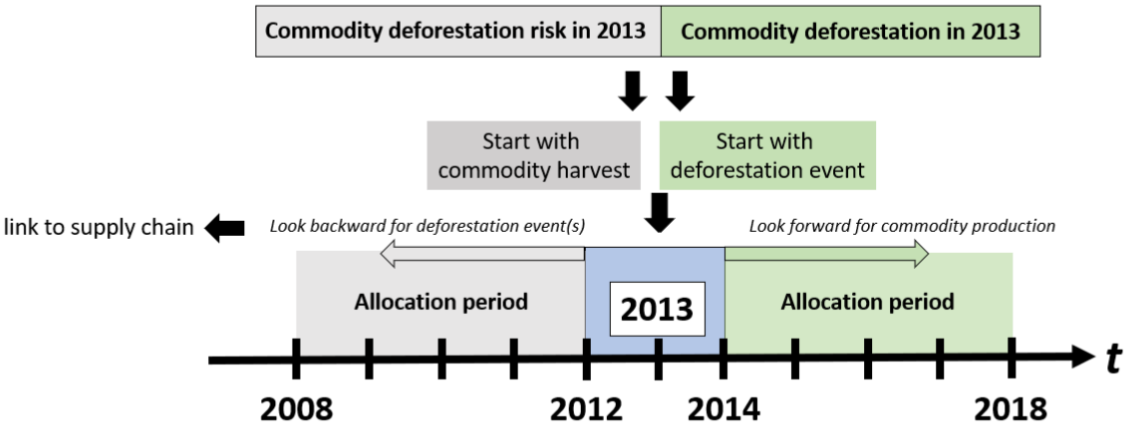

Figure 1: Illustration of how Trase assesses commodity deforestation or commodity deforestation risk in 2013 using the methods presented in this document. Commodity deforestation (green) links deforestation in 2013 to the production of a commodity during the following five-year allocation period, assuming that harvest of the commodity begins no sooner than the year after the deforestation event. Commodity deforestation risk (grey) links commodity production in 2013 to deforestation that took place during the preceding five-year period, again assuming that the harvest of the commodity began no sooner than the year after the deforestation event. The area in blue represents a lag period (one year in this example) between a deforestation event and the first possible year of commodity harvest (for commodity deforestation), or between the last possible year of deforestation and commodity harvest (for commodity deforestation risk). In Trase, we typically use a one-year lag period for crop commodities and no lag period for animal products.

Linking commodity expansion and deforestation

Direct deforestation

The expansion of commodity production can be linked both directly and indirectly to deforestation. This document and the two indicators — commodity deforestation and commodity deforestation risk — focus on 'direct deforestation'. This is deforestation that occurred with the intent to produce a given commodity on the newly-cleared land. Indirect effects, often known as indirect land-use change, occur when the expansion of one commodity displaces another, which in turn drives new deforestation. While this 'indirect deforestation' is also important, it is currently beyond the scope of what Trase provides.

Allocation and lag periods

Trase's estimates of direct deforestation are based on typical 'allocation periods' that represent the time between the initial deforestation of an area of land and the production of the commodity for which the land was cleared. We allocate new deforestation to commodity crops or cattle pasture that expand onto the newly converted land at *any time within* this period of time.

The allocation period relates to the time needed to prepare deforested land for planting, which may include preparation of the soil and licensing. Trase uses remote sensing data and independent research to derive these lag periods, which vary among commodities. In South America, for example, we use a period of five years for soy or pasture expansion (for cattle ranching).

Once we have set the allocation period between deforestation and planting, we then use it to determine which deforestation is associated with the harvest of a particular commodity or slaughter of livestock in a particular year.

In addition to the allocation period, we also consider a 'lag period' representing the minimum time needed between a deforestation event and the harvest of a crop commodity or animal slaughter (Figure 1). In Trase, we typically use a lag period of one year for crop commodities and no lag period for animal slaughter.

Considering the above definitions, Figure 1 shows that:

- In the case of deforestation in 2013, we could look forward in time and link soy production to that deforestation if the soy was harvested anytime in 2014, 2015, 2016, 2017 or 2018 (a five-year allocation period). This allocation time period considers a lag period of one year between the deforestation event and the first possible soy harvest.
- In the case of soy produced in 2013, we could look backward in time and link it to deforestation that occurred anytime in 2008, 2009, 2010, 2011 or 2012 (the years for which 2013 falls within the five-year allocation period). The one year lag period still holds, this time between the last possible deforestation event and the soy harvested in 2013.

Historical deforestation and recent deforestation

Across much of the tropics, within the last few decades natural vegetation covered most land now producing soy, cattle, palm oil and other commodities. It is important to assess and understand these longer-term dynamics especially because land is often cleared and temporarily placed into a relatively unproductive use, such as low productivity cattle pasture, with the long-term (speculative) intent that it will be later converted to a more profitable land-use, such as soy. In such cases it can be hard, if not impossible, to separate the expansion of the final land-use (such as soy) from the initial drivers of deforestation.

Historical deforestation can be linked to current land uses using an accounting approach called 'amortization', which distributes the responsibility for deforestation in a given area to all subsequent land-uses (within a given time period, such as 10 years), with more deforestation being allocated to the land uses that occurred earlier in the time period.

By contrast, in defining 'direct deforestation', Trase looks only at recent deforestation. It does not allocate all historical deforestation in a given area of land to a commodity being produced on that land today. The indicators on the Trase platform are focused on direct deforestation in order to assess the new deforestation and commodity expansion that contributes towards a given harvest and export. We reason that this deforestation is a direct responsibility of the commodity's buyers, who directly benefit from the land clearing that enabled the supply of the product of interest.

When an area of land produces multiple commodities

In some areas, an area of recently-deforested land can produce more than one commodity. This may be in sequence, as in the case of beef and soy in many parts of South America, or as a rotation of two crops in the same year, as in the case of soy and maize, as also happens in many parts of South America.

How Trase treats these situations depends on the situation and the objective — either a forward-looking assessment of 'commodity deforestation', or a backward-looking assessment of 'commodity deforestation risk'.

Looking forward from deforestation to commodity production

If the objective is to assess the relative importance of different commodities in driving the deforestation of a newly cleared area of land (what we call *'commodity deforestation'*) then it makes sense to allocate each pixel of deforestation only to one driver (commodity). In the case of land that is temporarily used for pasture but is converted to soy within five years then we assign soy as the main driver of deforestation of that pixel. In the case of land that is shared for commodity production, such as soy and maize, we treat them as a soy/maize complex.

For example, land that was deforested in 2010 and planted with soy only in 2013 can be considered to have been deforested for soy – even if the land was occupied by pasture for one or more years in between (Figure 2).

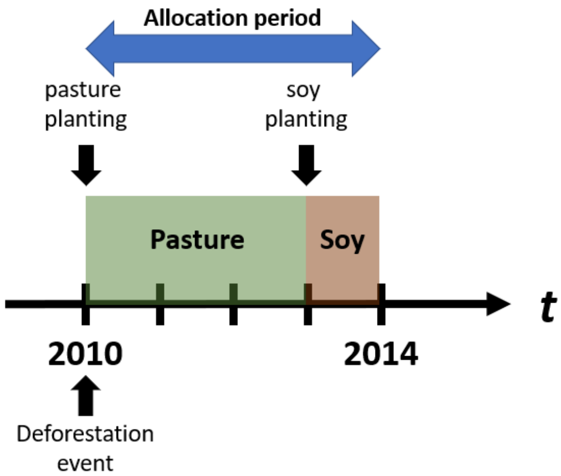

Figure 2: Example of a five-year allocation period following deforestation (in 2010), in which soy is planted (in 2013). The 2010 deforestation is allocated to soy, despite there being pastureland in 2010-2012.

Looking backward from commodity production to the deforestation event

If the objective is to assess the 'commodity deforestation risk' associated with buyers of two crops grown on the same land in the same year (such as soy and maize in Brazil), then we fully allocate any deforestation that occurred within the lag period to the exports of both crops, in terms of hectares of deforestation per tonne (= metric ton) of export.

For example, if 100 hectares of deforested land produced 300 tonnes of soy and 700 tonnes of maize exported worldwide, both the soy deforestation risk and the maize deforestation risk indicators would take account of these 100 hectares.

In the case of cattle and soy, if a newly-deforested area of land is occupied by pasture for three years and then soy for two years, the entire deforestation of that area of land is allocated both to the buyers of cattle (in the first three years), and to the buyers of soy (in the fourth and fifth years). This approach is needed to ensure that the responsibility for tackling deforestation is shared across all the buyers of any commodity produced on the land within the allocation period since clearance occurred.

The alternative approach would be to discount the deforestation for cattle on land that subsequently became soy within the allocation period (on the proviso that the initial intent was to

clear forest for soy, not cattle), but this would dilute the amount of deforestation associated with cattle production and export, which still benefited from the deforestation having taken place.

Summing deforestation across commodities (as with cattle and soy, or soy and maize) that are exported from the same area and in the same allocation period has implications. It can result in a number that is greater than the total amount of deforestation that occurred — because of the double counting of deforestation on land that was first used for cattle pasture and then soy production.

This needs to be accounted for when looking at the total deforestation associated with a buyer (a company or country) of multiple commodities to avoid attributing artificially high levels of deforestation to them. Trase can provide aggregated measures across commodities on request.

Trase indicators on deforestation linked to commodity production and trade

The two objectives described above (looking backward or looking forward) underpin the two main indicators provided by Trase: commodity deforestation and commodity deforestation risk.

Commodity deforestation

As mentioned in the Introduction, 'commodity deforestation' (in hectares) measures how much land is deforested each year to expand production of a given commodity. It is *forward*-looking, meaning that it starts by accounting for new deforestation in a given year and assessing how much of the newly-deforested land is used — within a defined future allocation period — for the production of the commodity of interest.

In the first example in Figure 3, we start with a deforestation event in 2014. We then assess use of the deforested land for soy production in the five-year allocation period that starts with the year after the deforestation event, so 2015-2019 inclusive.

In the most recent years, where data is not yet available to confirm the use of newly-deforested land, we use a forward projection. This is shown in the second example in Figure 3, where we start with a deforestation event in 2018. To assess how much of that deforestation can be attributed to soy production requires an estimate of the amount of the land deforested in 2018 that is converted to soy in 2019-2023 (a five-year allocation period).

We use a forward projection in each jurisdiction based on the proportion of deforested land that is converted to soy for the last fully observed five-year period. So, in the case of deforestation in 2018, we use the proportion of total land deforested in 2014 that is converted to soy in the 2015-2019 period (considering the lag period of one year between deforestation and the first possible crop).

If we did not use a forward projection based on rates of conversion, or some other form of simulation, then we would underestimate commodity deforestation in the most recent years, as a diminishing time period would be available in which to observe conversion of deforested land to the commodity of interest. In other words, if 2019 were the present year, then deforestation in 2018 could only be associated with commodity production in 2019 in places where conversion occurred within one year.

As time passes and more observations of both deforestation and commodity production are available (past 2019 in this example), then we revise commodity deforestation accordingly using new observations and conversion rates.

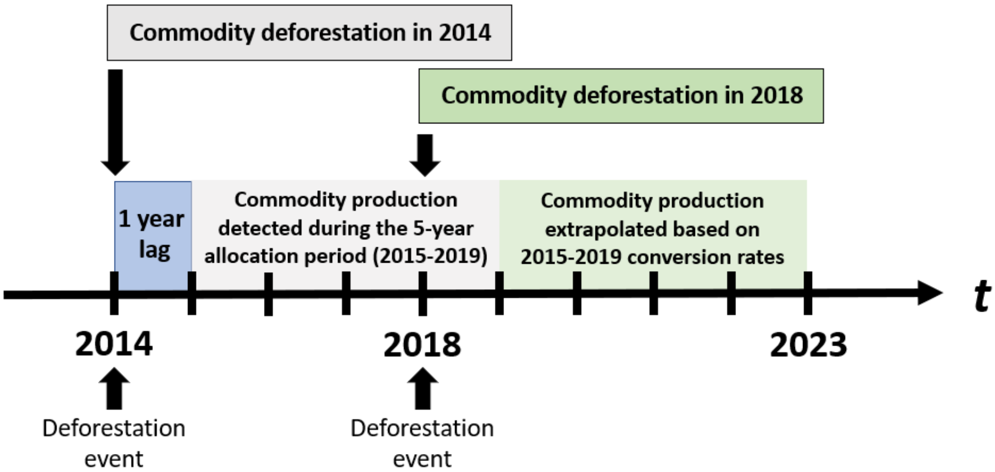

Figure 3: Representation of commodity deforestation in 2014 and 2018. The indicator is forward-looking. In this example, the indicator represents the allocation of deforestation in either 2014 or 2018 to the commodity of interest produced during a five-year allocation period that begins one year after the deforestation event (lag period). For deforestation in 2014, we determine commodity deforestation using observations over the 2015-2019 (five-year inclusive) allocation period. For deforestation in 2018 (the present year in this example), we determine commodity deforestation using a conversion factor $C_{c,j,y+t}$ (Equation 1) of direct deforestation since there are no observations past 2018.

We calculate commodity deforestation using Equation 1: Commodity deforestation for commodity *c*, sourced from jurisdiction *j* in year *y*, is obtained by multiplying deforestation $D_{j,y}$ (hectares) by the rate of the conversion of deforestation into commodity *c* over *y+t* years (where *t* is the allocation period in years), as $C_{c,j,y+t}$ (%).

$$\text{Commodity deforestation}_{c,j,y} = \sum_{y}^{y+t} D_{j,y} \times C_{c,j,y+t} \qquad \text{Equation 1}$$

In cases where year *y+t* is a year without an available observation (for example, 2019 onward), then $C_{c,j,y+t}$ is estimated using the conversion rate for the most recent fully-observed allocation period for each jurisdiction.

We derive the deforestation area ($D_{j,y}$) and conversion rate ($C_{c,j,y+t}$) using remote-sensing information on both forest cover loss and agricultural expansion, with values aggregated at the jurisdictional level. On the Trase platform, we present commodity deforestation on the map and in the jurisdictional profiles (see the Appendix for details of geoprocessing and calculation for each commodity and country).

Commodity deforestation risk

Commodity deforestation risk (in hectares) is the deforestation that is allocated to a supply chain actor (a company or country) that sources the commodity from a jurisdiction in a given year. It is defined as a measure of risk as it estimates the extent to which a buyer sourcing from a specific region may be exposed to deforestation in their supply chain, given that we do not have farm-level information on their precise sourcing patterns. This is distinct from a measure of risk of future deforestation (commodity deforestation described above).

Commodity deforestation risk is a *backward*-looking indicator. It compares the area of production associated with a specific harvest and export of a commodity of interest to the recent deforestation (within the allocation period) that has directly contributed to the production of that harvest. Trase then shares this deforestation among actors sourcing from the jurisdiction to derive a measure of risk that estimates the extent to which a buyer sourcing from that jurisdiction may be exposed to deforestation in its supply chain.

Trase shares deforestation among these actors using Equation 2: Commodity deforestation risk (hectares) is defined for actor *a* and commodity *c* sourced from jurisdiction *j* in year *y.* It depends on $D_{c,j,y}$ as the sum of the deforestation (hectares) over the allocation period (*t* in years), exports of actor *a* $Exp_{a,c,j,y}$ (tonnes) and commodity production $Prod_{c,j,y}$ (tonnes).

$$\text{Commodity deforestation risk}_{a,c,j,y} = \frac{1}{t}\frac{Exp_{a,c,j,y}}{Prod_{c,j,y}}\sum_{y-t}^{y} D_{c,j,y} \qquad \text{Equation 2}$$

While commodity production can be obtained from official statistics, and exports per jurisdiction are obtained from Trase supply chain maps, deforestation ($D_{c,j,y}$) is obtained using spatial analysis. In cases where harvest or livestock slaughter and export are not expected to take place the same year, we consider an additional lag period between the last year of possible deforestation (e.g. 2017) and export (2018 soy harvest and export) (Figure 4).

For instance, if a company is sourcing 500 tonnes of soy from a Brazilian municipality that produces 1000 tonnes, and where 800 hectares of deforestation can be directly linked to soy production, the soy deforestation risk for that company in that municipality is 400 hectares (50% of the total). To allow comparisons among actors that source very different volumes of a commodity, a relative measure of deforestation risk is hectares per tonne of exports.

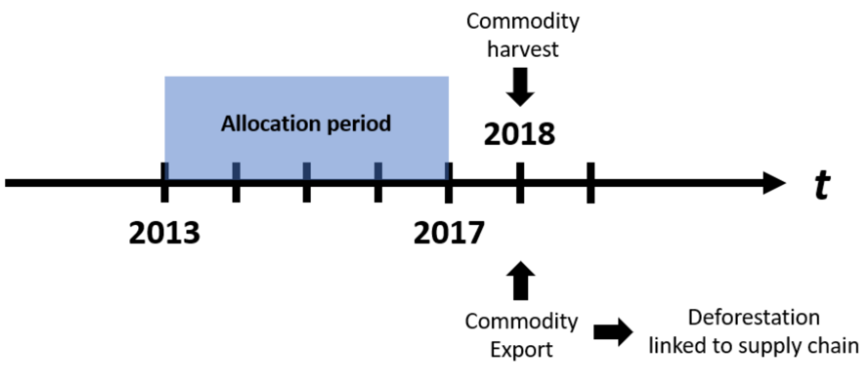

Figure 4: Representation of commodity deforestation risk for 2018 commodity exports. The indicator is backward-looking. First, deforestation is allocated to the commodity harvested and exported in 2018, if conversion of forest to commodity occurred in the preceding five-year allocation period (2013-2017 inclusive), considering a one year lag period between planting and harvest of the commodity. Trase aggregates total deforestation at the jurisdictional level, before

sharing it among actors in the supply chain of the 2018 exports. Each actor's share of this deforestation is directly proportional to that actor's share of total commodity exports.

Summing commodity deforestation risk over space and time

The deforestation risk associated with the harvest and export of adjacent years is based on overlapping allocation periods. Using soy as an example, this means that a single pixel of deforestation that occurred, say in 2010, is allocated to the soy harvested on that land in each of, say 2013, 2014, and 2015. In this sense, the single pixel of deforestation is being counted more than once. Summing the total deforestation allocated to soy exports from a single parcel of land across years would therefore return a larger area than the area of initially deforested (three times in this example).

If the objective is to assess the total deforestation linked to the soy harvested and exported in a single year for a single buyer, then it makes sense to sum the deforestation observed across the full allocation period. However, if the objective is to compare changes in deforestation risk associated with soy exports over time, then it makes more sense to allocate each pixel of deforestation to exports only once (and therefore avoid double counting of deforestation across export years).

To adjust for this and account for the problem of double-counting deforestation pixels over time, Trase annualises the deforestation risk for each year and each region by dividing the total by the allocation period (in other words, five years in the case of soy in South America; see the Appendix for details for other commodities).

Special case: cattle deforestation risk

Following the above definition of commodity deforestation risk, 'cattle deforestation risk' (in hectares) is the deforestation allocated to a beef supply chain actor (company, country). As defined above it is a *backward*-looking measure. It needs to consider both an allocation period between deforestation and pasture, as well as the lifespan of the animal. To calculate cattle deforestation risk, we follow the two steps described below.

1. Estimation of deforestation for cattle

The first step is to estimate the area of direct conversion of deforested land into pasture, looking back in time, considering both the deforestation-to-pasture allocation period (five years in South America), as well as the lifespan of the cattle (also five years in South America). This means we estimate deforestation for pasture over a period of five years prior to beef export. In other words, for each year in the animal's five years of life, we perform an annual evaluation of direct conversion of forest into pasture, using a five-year allocation period (Figure 5). We then aggregate results at the jurisdiction level, and then over the animal's lifespan to provide a measure of deforestation for cattle to be used in Step 2.

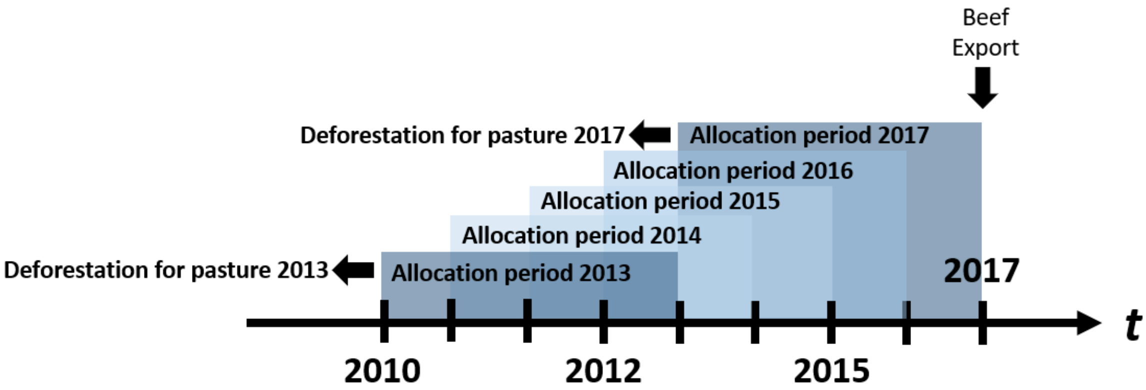

Figure 5: Example of calculation of deforestation for cattle, as the first step towards calculating cattle deforestation risk. Over a five-year period prior to 2017 (the beef export year), we estimate deforestation for pasture using a five-year allocation period (in blue) to provide annual deforestation for pasture between 2013 and 2017. Deforestation for cattle is then the sum of deforestation for pasture in each of the five years preceding the beef export year (2013-2017).

2. Cattle deforestation per tonne of carcass and cattle deforestation risk

We use Equation 3 to calculate cattle deforestation (hectares per tonne of carcass) in jurisdiction *j* and year *y*, as $D_{C,j,y}$, by dividing deforestation for cattle $D_{P,j,y}$ (hectares) by the annual cattle production (tonnes of carcass and offal) $C_{j,y}$.

$$D_{C,j,y} = \frac{D_{P,j,y}}{C_{j,y}} \quad \text{Equation 3}$$

When compared to Equation 2, $D_{C,j,y}$ represents the ratio $\frac{1}{Prod_{c,j,y}} \sum_{y-t}^{y} D_{c,j,y}$.

We calculate cattle production per jurisdiction and year ($C_{j,y}$) using Equation 4, where $H_{j,l}$ (heads) is the herd size in jurisdiction *j* across the cattle lifespan, $S_{s,y}$ is the slaughter rate in jurisdiction *j* and year *y*, and CW_j (tonnes per head) is the carcass weight in jurisdiction *j*.

$$C_{j,y} = \sum_{l} H_{j,l}\, S_{j,y} CW_j \quad \text{Equation 4}$$

We then calculate cattle deforestation risk using Equation 2, by multiplying the total carcass weight each actor exports by the cattle deforestation per tonne of carcass.

Appendix: Context-specific indicators, data sources and methods

The following pages provide more information on the data sources and methods that Trase uses in each context (commodity and country of production). We have not included this information for Colombian coffee (for which there is no deforestation).

Argentinian soy

Datasets used

Dataset	Data source	Dataset coverage
Soy crop extent	*Global Land Analysis & Discovery (GLAD); University of Maryland https://glad.umd.edu/	2000/2001 to 2018/2019 (annual)
Land use and cover	*Humboldt-Universität zu Berlin (HBU), Conservation Biogeography Lab	2010-2018 (annual)

*forthcoming publication

Parameters used

Allocation period: Five years

Lag period between deforestation and soy harvest: One year

Lag period between soy harvest and export: None

Export period: 2016-2018

Geoprocessing

Deforestation increment map

We created a Chaco-specific deforestation increment map (30 m resolution) using a 'vegetation mask'[1] constructed from the land use and cover image collection from HBU over the 2003-2009 period. First, we reclassified the nine classes of the data into three:

- Land use
- Vegetation *sensu lato* (broad sense)
- Vegetation *sensu stricto* (narrow sense)

The 'land use' class is a reclassification of pasture and soy, while the two 'vegetation' classes contained merged classes of primary vegetation. Vegetation *sensu lato* and *sensu stricto* differ in cases of selective extraction of vegetation (e.g. forest logging), which is only included in 'vegetation *sensu lato*'.

We followed two rules when creating the vegetation mask:

[1] The vegetation mask is the vegetation coverage in a given year. Ideally, the vegetation mask should contain only the primary forest, but in practice, it may also include areas with secondary vegetation growth. The vegetation mask delimits the area that could be deforested, which we compare to annual deforestation maps to avoid counting the same deforestation more than once. Because the mask is designed to describe only the primary vegetation, it does not allow the incorporation of new vegetation areas (due to reforestation, for example), meaning that the method assumes a decrease in total vegetation over time.

1. **Stability of the vegetation class**: If a given pixel was classified as 'vegetation' for part of the time series, and was then detected as 'deforested' before returning as 'vegetation', we did not use that pixel to compose the vegetation mask.
2. **Mandatory presence of the *sensu stricto* class**: We only included a pixel classified as vegetation *sensu lato* in the vegetation mask if it was previously classified as vegetation *sensu stricto* (to reduce the occurrence of false-positive cases of deforestation). We implemented this rule as the conversion from vegetation *sensu stricto* to *sensu lato* can represent initiated — but not consolidated — cases of deforestation.

We then used the vegetation mask to identify annual deforestation increments, based on the overlap of the vegetation mask (2003-2009) with both cropland and pasture classes identified for 2010-onward.

Deforestation indicators

First, we processed annual maps of soy extent (30 m resolution) to remove soy fragments of less than five hectares, before assigning the maps an annual soy coverage to compare to the annual deforestation increment maps:

- Looking forward in time from the year of deforestation to estimate **soy deforestation**: We compared deforestation increment maps in year *y* to the total conversion of deforested land to soy over the following five-year period (Equation 1).
- Looking back in time from the year of soy harvest and export to estimate **soy deforestation risk**: We compared total soy coverage in year *y* to historical deforestation increment maps over the preceding five-year period (Equation 2).

In both cases, we used an allocation period of five years to reflect the time required to prepare land after deforestation, including processes of acquiring, preparing and selling the land before soy is typically planted. Data analysis on soy expansion onto deforested land suggests a peak in year 5 after original clearance. We assumed that soy planting takes place as early as one year after a deforestation event, and we also assumed a period of one year between deforestation and soy harvest/export.

Soy deforestation

We compared deforestation pixels in year *y* to the total annual soy extent over the following five-year allocation period (to *y+5*), following Equation 1. Due to the lack of direct observations in the five years following the 2015-2018 period, we derived soy deforestation by extrapolating the conversion of deforested land to soy ($C_{c,j,y+t}$) obtained in 2014. We then summed soy deforestation at the Argentina department level and presented it on the Trase platform on the map and in the jurisdiction profiles.

Soy deforestation risk

First, we compared soybean extent in year *y* to deforestation in the preceding five years to derive the deforestation for soybean summed for each Argentinean department ($\sum_{y-t}^{y} D_{c,j,y}$ in Equation 2). We then calculated soy deforestation risk using Equation 2, by multiplying deforestation for soy per department by the volume of soy each actor exported from the department, annualised over the time period ($\frac{1}{t}$ in Equation 2). On the Trase platform, we display soy deforestation risk in the interactive trade flows and actor profiles.

Brazilian beef

Datasets used

Dataset	Data source	Dataset coverage
Pasture extent	MapBiomas vs. 4.0 — class 15 www.mapbiomas.org/en	1985-2018 (annual)
Deforestation	INPE Prodes Amazon http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	1998-2019 (annual)
	INPE Prodes Cerrado http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	2000-2012 (every two years); 2013-2019 (annual)
	SOS-Mata Atlantica www.sosma.org.br	2000-2005 (every six years); 2006-2008 (every three years); 2008-2010 (every two years); 2011-2016 (annual)
	SOS-Pantanal www.sospantanal.org.br	2003-2008 (every six years); 2009-2016 (every two years) 2017 (annual)

Parameters used

Allocation period: Five years

Lag period between deforestation and slaughter: None

Lag period between slaughter and export: None

Export period: 2015-2017

Geoprocessing

Deforestation increment maps

We created an annual deforestation increment map combining Amazon, Cerrado, Atlantic Forest and Pantanal deforestation (30 m resolution). In cases where data was not available annually (for example for earlier years of Cerrado time series, or for Atlantic Forest), we obtained the annual mean deforestation by dividing per-pixel deforestation by the timeframe between two deforestation datasets (expressed as a percentage).

Deforestation indicators

We assigned annual maps of pasture extent (30 m resolution) as pasture coverage to compare to annual deforestation increment maps:

- Looking forward in time from the year of deforestation to estimate **pasture deforestation**: We compared deforestation increment maps in year *y* to the total conversion of deforestation to pasture over the next five years, following Equation 1.

- Looking back in time from the year of cattle slaughter and export to estimate **cattle deforestation risk**: We compared pasture area in year *y* to historical deforestation increment maps in the previous five years, following Equation 2, prior to allocating deforestation over the lifespan of cattle (Equations 3 and 4).

We assumed the year of cattle slaughter to be the same as the year of beef export.

Pasture deforestation

We compared deforestation pixels in year *y* to the total annual pasture extent over the following five-year allocation period (to *y+5*), using Equation 1. For example, to calculate pasture deforestation in 2014, we multiplied deforestation in 2014 by the total conversion to pasture ($C_{c,j,y+t}$ in Equation 1) in the 2015-2019 period in a given Brazilian municipality. Due to the lack of direct observations in years closer to the present day (2015 to 2018), we derived pasture deforestation by extrapolating the conversion of deforestation to pasture ($C_{c,j,y+t}$) obtained in 2014. Pasture deforestation is finally summed and presented on the Trase platform in the map and jurisdiction profiles, at the Brazilian municipality level.

Cattle deforestation risk

We assume a cattle life cycle of five years in Brazil because the cattle herd as a whole has an offtake rate of around 20% (Barbosa et al. 2015; ABIEC 2018). Therefore, the herd is effectively replaced every five years. For 2017 exports, for example, we calculated deforestation for cattle (hectares) over the 2013-2017 period.

We calculated cattle deforestation per tonne of carcass for each municipality following Equations 3 and 4. We used year and state-specific estimates of the slaughter rate *S* (Equation 4), calculated as the number of cattle slaughtered per state divided by the herd size per state (IBGE 2015; IEG FNP Agribusiness 2019), accounting for inter-state movements to slaughter.

For São Paulo, where our calculations otherwise underestimated production, we corrected the slaughter rate to 0.4072 based on estimates from IEA (2018) and Dias (2007). We used state-level data on carcass weights by dividing the total production of cattle carcasses per state by the number of slaughtered heads for the 2015-2017 period (IBGE, 2019). In one state (Amapá), state carcass weights are not available, and so we used the nationwide average (0.234 tonnes per head).

We calculated cattle deforestation risk using Equation 2, by multiplying the volume of carcass weight each actor exported by the cattle deforestation per tonne of carcass.[2] The indicator is aggregated at the Brazilian municipality level and displayed on the Trase interactive trade flows and actor profiles.

[2] Note that cattle deforestation risk could contain double-counting with soy, because the same land could have been used for soy in the five-year window.

Brazilian soy

Datasets used

Dataset	Data source	Dataset coverage
Soy crop extent	*Global Land Analysis & Discovery (GLAD); University of Maryland https://glad.umd.edu/	2000/2001 to 2018/2019 (annual)
Deforestation	INPE Prodes Amazon http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	1998-2019 (annual)
	INPE Prodes Cerrado http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	2000-2012 (every two years); 2013-2019 (annual)
	SOS-Mata Atlantica www.sosma.org.br	2000-2005 (every six years); 2006-2008 (every three years); 2008-2010 (every two years); 2011-2016 (annual)
	SOS-Pantanal www.sospantanal.org.br	2003-2008 (every six years); 2009-2016 (every two years) 2017 (annual)

*forthcoming publication

Parameters used

Allocation period: Five years

Lag period between deforestation and soy harvest: One year

Lag period between soy harvest and export: None

Export period: 2004-2018

Geoprocessing

Deforestation increment map

We created an annual deforestation increment map (30 m resolution) combining Amazon, Cerrado, Atlantic Forest and Pantanal deforestation. In cases where data was not available annually (for example, for earlier years of the Cerrado time series, and for the Atlantic Forest), we obtained the annual mean deforestation by dividing per-pixel deforestation by the timeframe between two deforestation datasets.

Deforestation indicators

First, we processed annual maps of soy extent (30 m resolution) to remove fragments less than 20 hectares, before being assigning the maps a soy coverage to compare to the annual deforestation increment maps:

- Looking forward in time from the year of deforestation to estimate **soy deforestation**: We compared deforestation increment maps in year *y* to the total conversion of deforested land to soy over the following five-year period (Equation 1).
- Looking back in time from the year of soy harvest and export to estimate **soy deforestation risk**: We compared total soy coverage in year *y* to historical deforestation increment maps over the preceding five-year period (Equation 2).

In both cases, we used an allocation period of five years to reflect the time required to prepare land after deforestation, including processes of acquiring, preparing and selling the land before soy is typically planted. Data analysis on soy expansion onto deforested land suggests a peak in year 5 after original clearance. We assumed that soy planting takes place as early as one year after a deforestation event, and we also assumed a period of one year between deforestation and soy harvest/export.

Soy deforestation

We compared deforestation pixels in year *y* to the total annual soy extent over the following five-year allocation period (to *y+5*), following Equation 1. For example, to calculate soy deforestation in 2014, we multiplied deforestation in 2014 by the total conversion to soy ($C_{c,j,y+t}$ in Equation 1) in the 2015-2019 period in a given Brazilian municipality. Due to the lack of direct observations in years closer to the present day (2015 to 2018), we derived soy deforestation by extrapolating the conversion of deforestation to soy ($C_{c,j,y+t}$) obtained in 2014. We then summed soy deforestation at the Brazilian municipality level and presented it on the Trase platform on the map and in the jurisdiction profiles.

Soy deforestation risk

First, we compared soybean extent in year *y* to deforestation in the previous five years to derive the deforestation for soybean summed for each Brazilian municipality ($\sum_{y-t}^{y} D_{c,j,y}$ in Equation 2). We then calculated soy deforestation risk using Equation 2 by multiplying deforestation for soy in each municipality by the volume of soy each actor exported from the municipality and annualised over the time period ($\frac{1}{t}$ in Equation 2). Trase displays soy deforestation risk on the interactive trade flows and actor profiles.

Brazilian chicken and pork

Datasets used

Dataset	Data source	Dataset coverage
Deforestation	INPE Prodes Amazon http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	1998-2019 (annual)
	INPE Prodes Cerrado http://terrabrasilis.dpi.inpe.br/app/dashboard/deforestation/biomes/legal_amazon/increments	2000-2012 (every two years); 2013-2019 (annual)
	SOS-Mata Atlantica www.sosma.org.br	2000-2005 (every six years); 2006-2008 (every three years); 2008-2010 (every two years); 2011-2016 (annual)
	SOS-Pantanal www.sospantanal.org.br	2003-2008 (every six years); 2009-2016 (every two years) 2017 (annual)
Soy deforestation risk	As derived for Brazilian soy (see above)	2015-2018

Parameters used

Lag period between deforestation and slaughter: None

Lag period between slaughter and export: None

Export period: 2015-2018

Soy deforestation risk for feed

We derived the annual soy deforestation risk for feed consumed by both chicken and pigs from the Brazil soy deforestation risk linked to Brazil's domestic consumption. We derived the origin of soy for each municipality of chicken and pork production using optimisation of distances through linear programming, using the following:

- Soy for domestic consumption, available from Trase's sub-national supply-chain mapping of Brazilian soy exports
- Demand for soy from all forms of animal production, including chicken, pork, beef, eggs, dairy and aquaculture (aggregated consumption of soy per animal and year is available from the National Union of the Animal Feed Industry, and we obtained the production of each animal per municipality from IBGE).
- Demand for soy feed from chicken and pork production, including for both export and domestic consumption.

We assumed the year of animal slaughter to be the same as the year of chicken / pork export.

Indonesian palm oil

Datasets used

Dataset	Data source	Dataset coverage
Oil palm extent	Gunarso et al. (2013) http://www.tropenbos.org/file.php/1343/4_oil_palm_and_land_use_change_gunarso_et_al.pdf	2000, 2005 and 2010
	Indonesian Ministry of Agriculture (2016 and 2019)	2016 and 2018
Deforestation	Global Forest Change (University of Maryland) https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.3.html	2001-2018 (annual)

Parameters used

Allocation period: Three years for oil palm deforestation; four years for oil palm deforestation risk

Lag period between oil palm harvest and export: None

Export period: 2015

Geoprocessing

Territorial deforestation

We created annual territorial deforestation maps (30 m resolution; 2001-2018) using the area with more than 90% forest cover in 2000 (from Global Forest Change; University of Maryland), from which we removed areas of vegetation classified in 2000 as oil palm plantations by Gunarso et al. (2013). We used the resulting annual territorial deforestation maps as a vegetation mask to derive the deforestation indicators (see footnote under Argentinian soy for a description of a vegetation mask).

Deforestation indicators

We then compared palm extent maps to the territorial deforestation maps:

- Looking forward in time from the year of deforestation to estimate **oil palm deforestation**: We compared deforestation maps in year *y* to the total conversion of deforested land to oil palm after three years, following Equation 1.
- Looking back in time from the year of palm oil harvest and export to estimate **oil palm deforestation risk**: We compared total oil palm coverage in year *y* to historical territorial deforestation maps in the previous three and four years, following Equation 2.

The allocation period between deforestation and the oil palm plantation maps was three years for oil palm deforestation. To estimate oil palm deforestation risk, we used the average of three-year and four-year allocation periods. We assumed the year of harvest to be the same as the year of palm oil export.

Oil palm deforestation

We calculated oil palm deforestation by overlapping the oil palm plantation coverage in 2018 with the territorial deforestation in 2015. We then summed the resulting area at the district (*kabupaten*) level, and presented it on the Trase map and in the jurisdiction profiles.

Oil palm deforestation risk

We calculated oil palm deforestation risk considering two allocation periods (three and four years) of deforestation for palm, meaning that the 2015 exports of palm oil are associated with deforestation in 2011 and 2012, averaged across these two years for an annualised rate.[3] We then used these results to derive oil palm deforestation risk using Equation 2 by multiplying deforestation for oil palm in each district by the volume of palm oil each actor exported from the district. The indicator is aggregated at the district (*kabupaten*) level and displayed on the Trase interactive trade flows and actor profiles.

[3] While 2013 and 2014 also fall in the four-year period before 2015 exports, maps are not available for those years.

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Paraguayan soy

Datasets used

Dataset	Data source	Dataset coverage
Soy crop extent	*Global Land Analysis & Discovery (GLAD); University of Maryland https://glad.umd.edu/	2000/2001 to 2018/2019 annual
Deforestation and land use and cover	WWF (Atlantic Forest)	2009-2016 annual
	*Humboldt-Universität zu Berlin (HBU), Conservation Biogeography Lab	2010-2018 annual

*forthcoming publication

Parameters used

Allocation period: Five years

Lag period between deforestation and soy harvest : One year

Lag period between soy harvest and export: None

Export period: 2015-2018

Geoprocessing

Deforestation increment maps

We obtained (from WWF) an ecoregion-wide annual deforestation increment map (30 m resolution) for the Atlantic Forest, but had to create such a map for the Chaco using the land use and cover image collection from HBU.

We created a Chaco-specific deforestation increment map (30 m resolution) using a vegetation mask constructed from the land use and cover image collection over the 2003-2009 period. First, we reclassified the nine classes of the data collection into three:

- Land use
- Vegetation *sensu lato*
- Vegetation *sensu stricto*

The 'land use' class is a reclassification of pasture and soy, while the 'vegetation' classes contained merged classes of native vegetation. Vegetation *sensu lato* and *sensu stricto* differ in cases of selective extraction of vegetation (e.g. forest logging) ,which is only included in 'vegetation *sensu lato*'.

We followed two rules when creating the vegetation mask:

1. **Stability of the vegetation class**: If a given pixel was classified as 'vegetation' for part of the time series, and was then detected as 'deforested' before returning as 'vegetation', we did not use that pixel to compose the vegetation mask. See footnote under Argentinian soy for a description of a vegetation mask.
2. **Mandatory presence of the *sensu stricto* class**: We only included a pixel classified as vegetation *lato sensu* in the vegetation mask if it was previously classified as vegetation *sensu stricto* (to reduce the occurrence of false-positive cases of deforestation). We

implemented this rule as the conversion from vegetation *sensu stricto* to *sensu lato* can represent initiated — but not consolidated — cases of deforestation.

We then used the vegetation mask to identify annual deforestation increments, based on the overlap of the vegetation mask (2003-2009) with both cropland and pasture classes identified for 2010-onward.

Deforestation indicators

First, we processed annual maps of soy extent (30 m resolution) to remove fragments of less than five hectares, before assigning the maps an annual soy coverage to compare to the annual deforestation increment maps:

- Looking forward in time from the year of deforestation to estimate **soy deforestation**: We compared deforestation increment maps in year *y* to the total conversion of deforested land to soy over the following five-year period (Equation 1).
- Looking back in time from the year of soy harvest and export to estimate **soy deforestation risk**: We compared total soy coverage in year *y* to historical deforestation increment maps over the preceding five-year period (Equation 2).

In both cases, we used an allocation period of five years to reflect the time required to prepare land after deforestation, including processes of acquiring, preparing and selling the land before soy is typically planted. Data analysis on soy expansion onto deforested land suggests a peak in year 5 after original clearance. We assumed that soy planting takes place as early as one year after a deforestation event, and we also assumed a period of one year between deforestation and soy harvest/export.

Soy deforestation

We compared deforestation pixels in year *y* to the total annual soy extent over the following five-year allocation period (to *y+5*), following Equation 1. For example, to calculate soy deforestation in 2014, we multiplied deforestation in 2014 by the total conversion to soy ($C_{c,j,y+t}$ in Equation 1) in the 2015-2019 period in a given Paraguayan department. Due to the lack of direct observations in years closer to the present day (2015 to 2018), we derived soy deforestation by extrapolating the conversion of deforested land to soy ($C_{c,j,y+t}$) obtained in 2014. We then summed soy deforestation at the Paraguayan department level and presented it on the Trase platform on the map and in the jurisdiction profiles.

Soy deforestation risk

There is a slight discrepancy between soy production estimated using the annual maps of soy extent and the official statistics reported by the Paraguayan Ministry of Agriculture, which we used to derive Trase's supply chain map. To obtain $\sum_{y-t}^{y} D_{c,j,y}$in soy deforestation risk from Equation 2, we first calculated a fixed ratio of deforestation for soy production in each department using remote sensing. We then multiplied this ratio by the official soy production statistics to obtain deforestation for soy from the official statistics. We then followed Equation 2, by multiplying the value of deforestation for soy in each department by the volume of soy each actor exported from the department, annualised over the time period ($\frac{1}{t}$ in Equation 2). On the Trase platform, we display soy deforestation risk on the interactive trade flows and actor profiles.

Paraguayan beef

Datasets considered

Dataset	Data source	Dataset coverage
Pasture extent	*Humboldt-Universität zu Berlin, Conservation Biogeography Lab	2003-2018 annual
Land use and cover	*Humboldt-Universität zu Berlin (HBU), Conservation Biogeography Lab	2010-2018 annual

*forthcoming publication

Parameters used

Allocation period: Five years

Lag period between deforestation and slaughter : None

Lag period between slaughter and export: None

Export period: 2015-2018

Geoprocessing

Deforestation increment maps

We created a Chaco-specific deforestation increment map (30 m resolution) using a vegetation mask constructed from the land use and cover image collection from HBU over the 2003-2009 period (see footnote under Argentinian soy for a description of a vegetation mask). First, we reclassified the nine classes of the data into three:

- Land use
- Vegetation *sensu lato*
- Vegetation *sensu stricto*

The 'land use' class is a reclassification of pasture and soy, while the two 'vegetation' classes contained merged classes of native vegetation. Vegetation *sensu lato* and *sensu stricto* differ in cases of selective extraction of vegetation (e.g. forest logging) which is only included in 'vegetation *sensu lato'.*

We followed two rules when creating the vegetation mask:

1. **Stability of the vegetation class**: If a given pixel was classified as 'vegetation' for part of the time series, and was then detected as 'deforested' before returning as 'vegetation', we did not use that pixel to compose the vegetation mask.
2. **Mandatory presence of the *sensu stricto* class**: We only included a pixel classified as vegetation *sensu lato* in the vegetation mask if it was previously classified as vegetation *sensu stricto* (to reduce the occurrence of false-positive cases of deforestation). We implemented this rule as the conversion from vegetation *stricto sensu* to *lato sensu* can represent initiated — but not consolidated — cases of deforestation.

We then used the vegetation mask to identify annual deforestation increments, based on the overlap of the vegetation mask (2003-2009) with both cropland and pasture classes identified for 2010-onward.

Deforestation indicators

First, we processed annual maps of pasture extent (30 m resolution) to remove fragments less than five hectares, before assigning the maps an annual pasture coverage to compare to annual deforestation increment maps:

- Looking forward from the year of deforestation to estimate **pasture deforestation**: We compared deforestation increment maps in year *y* to the total conversion of deforested land to pasture over the following five years, following Equation 1.
- Looking back in time from the year of cattle slaughter and export to estimate **cattle deforestation risk**: We compared pasture area in year *y* to historical deforestation increment maps in the preceding five years, following Equation 2, prior to allocating deforestation over the lifespan of cattle (Equations 3 and 4).

We assumed the year of cattle slaughter to be the same as the year of beef export.

Pasture deforestation

We compared deforestation pixels in year *y* to the total annual pasture extent over the following five-year allocation period (to *y+5*), following Equation 1. Due to the lack of direct observations in the five years following the 2014-2018 period, we derived pasture deforestation by extrapolating the conversion of deforestation to pasture ($C_{c,j,y+t}$) obtained in 2014. We then summed pasture deforestation at the Paraguayan department level and presented it on the Trase platform on the map and in the jurisdiction profiles.

Cattle deforestation risk

We obtained cattle deforestation per tonne for each department in Paraguay following Equations 3 and 4 using a five-year animal life cycle, and where:

- $H_{j,l}$ (heads) is the herd size in department *j* across the cattle life cycle (obtained from the Paraguayan Ministry of Agriculture).
- $S_{j,y}$ is the slaughter rate for a specific department *j* in year *y* (obtained from SENACSA [Servicio Nacional de Calidad y Salud Animal] as 0.175 in 2016 and 0.181 in 2017).
- CW_j is the carcass weight (assumed to be a constant 0.250 tonnes per head throughout Paraguay).

We then calculated cattle deforestation risk using Equation 2, by taking the total carcass weight each actor exported and multiplying it by cattle deforestation per tonne of carcass.[4] The indicator is aggregated at the Paraguayan department level and displayed on the Trase interactive trade flows and actor profiles.

[4] Note that cattle deforestation risk could contain double-counting with soy, because the same land could have been used for soy in the five-year window.

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