METHODOLOGY DOCUMENT

Understanding Satelligence dLUC, jdLUC & spatial sLUC methodology

A transparent and trusted approach aligned with SBTi FLAG and the GHG protocols (LSRS)

Satelligence

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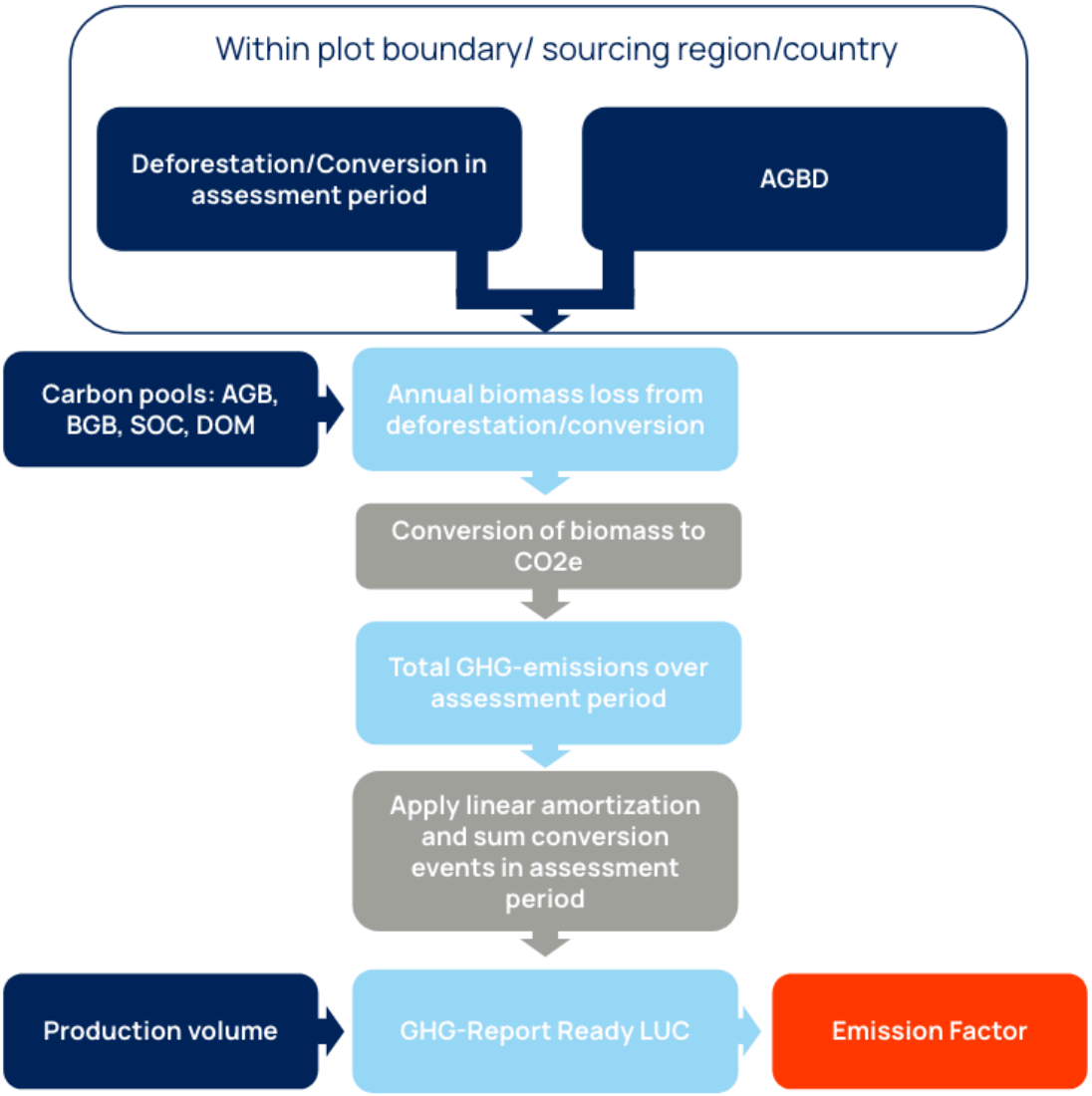
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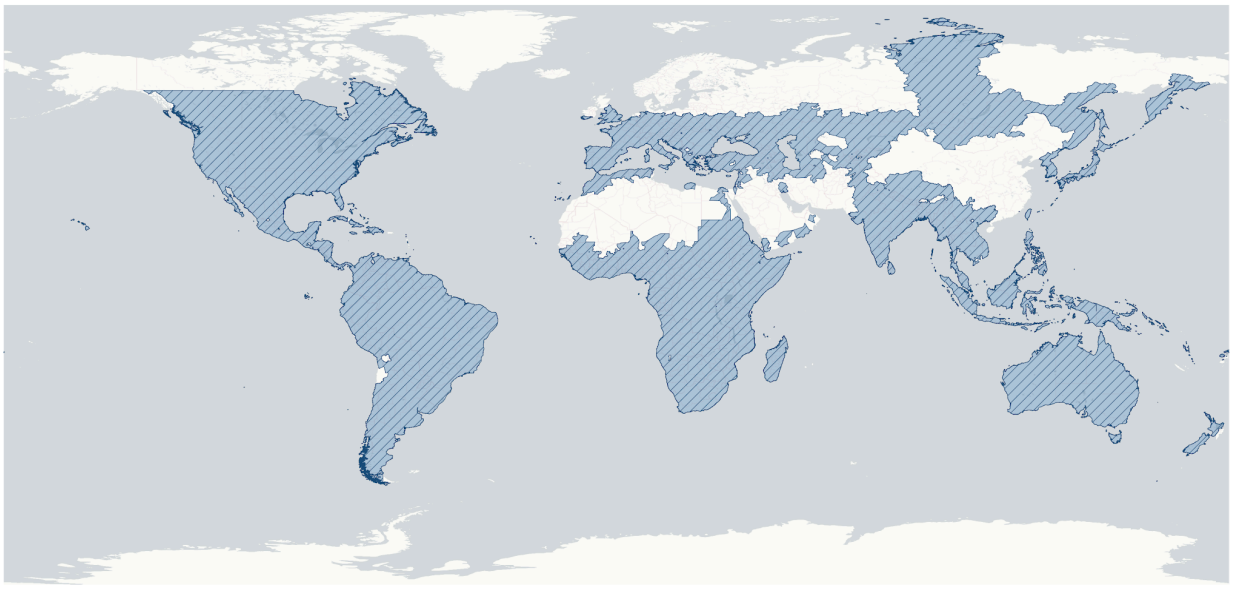
1 Overview

Below is a high level diagram of the approach to calculate LUC emissions on a plot level (or any other level of traceability). The approach is aligned with the Science Based Targets initiative (SBTi) FLAG framework and GHG protocol.



2 Coverage

The above ground biomass data, and as a consequence our dLUC & jdLUC product, currently extends to 51.6 degrees North and South of the equator.



Coverage of our dLUC & jdLUC product

3 Primary inputs

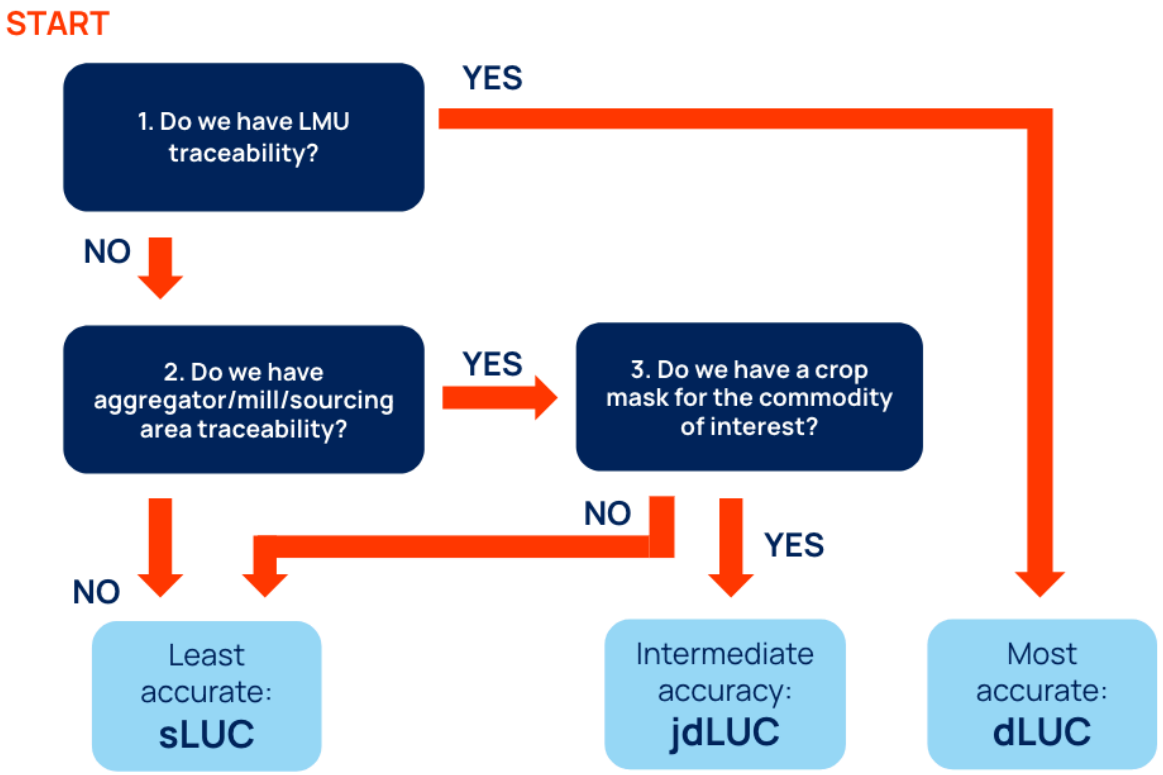
Find below an overview of the primary inputs used to calculate the annual land use change (LUC) emissions.

3.1 Land cover

The input for the land cover data changes depending on the availability of sourcing traceability. The GHG protocol LSRS provides a hierarchy of approaches to derive LUC-related GHG-emissions.

- **Most accurate**: dLUC - Land Management Unit (LMU) traceability available
- **Intermediate accuracy**: jdLUC -Jurisdictional or sourcing region traceability available
- **Least accurate**: sLUC - Traceability limited AND/OR no crop-mask data available

Decision tree for LUC emission traceability



3.1.1 Direct & Jurisdictional LUC - Harmonized Nature and Commodity Baseline

The Satelligence Harmonized Nature and Commodity baseline (H-NCB) is one of the proprietary input datasets. The H-NCB is a 10m resolution global landcover map that includes the presence of different forest types and other native vegetation classes, as well as the presence of different

commodities. Satelligence creates the best in class land cover maps because it is fundamental to all derived products like change detection and biomass estimations. In a 2025 evaluation, The Alliance of Bioversity International and CIAT concluded the Satelligence H-NCB offers the most robust and comprehensive land cover map available.

Satelligence uses a hybrid approach for nature and commodity baseline creation. Meaning that both i) open data such as the Tropical Moist Forest Layers from JRC, as well as ii) Satelligence proprietary data, are used. Open data layers are curated, quality controlled and class types are harmonized to match our final classification scheme prior to combining the open data with the proprietary data to end up with the final H-NCB. A detailed explanation of the creation of the Satelligence H-NCB can be found on the Satelligence Resource Center.

Different assumptions are applied to a commodity depending on their characteristics. Perennial crops (e.g. Cocoa, Oil Palm, Coffee) are assumed to remain stable on the landscape, allowing them to be mapped specifically and tracked accurately over the assessment period. Conversely, annual crops (e.g Soy, Cereals) must be tracked using generic proxy classifications because frequent crop rotations make it difficult to guarantee that the same crop is replanted year after year. As a result, applying standard perennial workflows to annual crops is inherently limited and highlights the need for crop-rotation data to better track LUC emissions related to annual crops. We are currently working on improving the methodology for annuals.

Note 1: In accordance with the GHG Protocol LSRS and SBTi FLAG, the derivation of jdLUC is limited to the latest available crop mask.

Note 2: In cases of limited specific crop mask availability we resort to "proxy" commodities. For example, we proxy pasture land as the land cover class for cattle. Ask our team what applies for your commodity.

3.1.2 Spatial statistical LUC

For statistical land use change (sLUC) emissions, Satelligence adopts a methodology similar to the Technical note by the World Resources Institute (WRI) and Quantis (Fitts et al., 2025).

For sLUC, land cover is not spatially explicit. Instead, the FAO expansion ratio (also called product allocation factor) is applied on the total deforestation (hectares) in the region of Interest to allocate commodity-driven deforestation. The FAO expansion ratio describes the estimated relative annual expansion of the crop of interest compared to the total expansion of all crops. The expansion ratio is country-specific, for a specific year. The spatial component of the sLUC is incorporated during the derivation of the emission factor, when annual crop production (FAO, 2026 or company-reported data) is allocated using MapSPAM 2020 v2r2 spatial shares (IFPRI, 2026).

3.2 Land use change

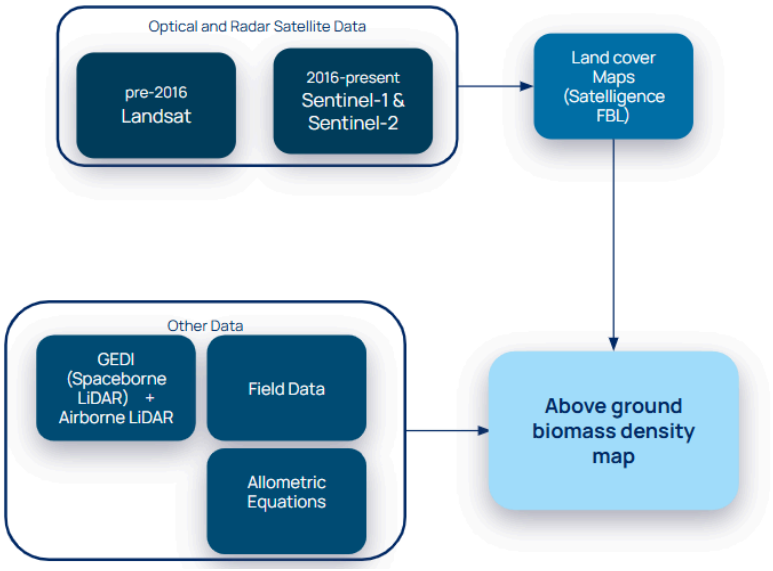
3.2.1 Deforestation

Deforestation detection consists of two basic components: ***knowing where the forest is located***, and knowing ***if and when it changed to a non-forest state, i.e. deforestation***.

Forest areas are identified based on the H-NCB. For knowing when forest changes into another state change detection algorithms are used. The system is fast and precise without the need for expensive commercial input data. A detailed explanation of the creation of the Satelligence H-NCB can be found on the Satelligence resource center.

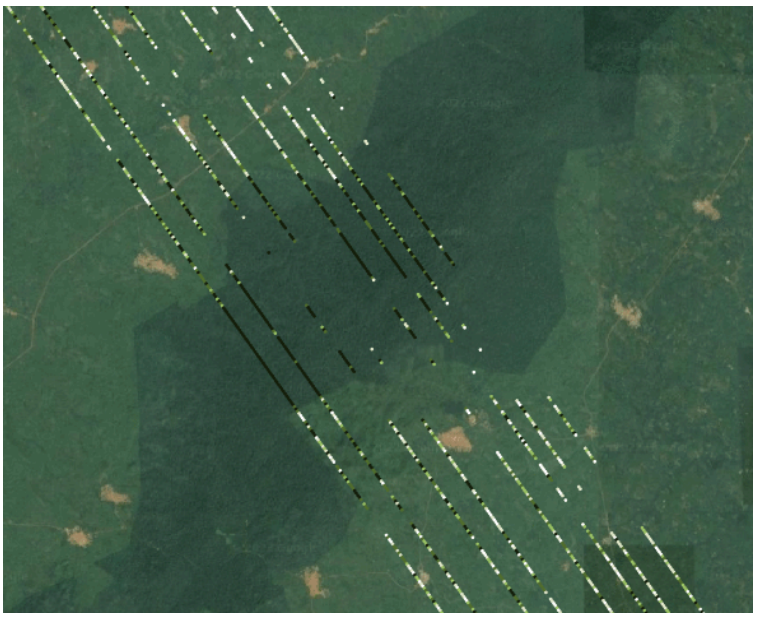
CARBON STOCK

For forests, carbon stock is derived from a **Above ground biomass density (AGBD)** map. The AGBD is estimated & monitored using satellite image-fed systems over large areas and timescales.



Land cover maps are used to select the right allometric equations. Allometric equations are used to convert the GEDI measurements into above ground biomass

The global vegetation height and structure dataset resulting from the GEDI spaceborne LIDAR mission is converted into above ground biomass, using the Satelligence land cover maps and allometric equations. Field data can be used as an addition or replacement for GEDI data. The resulting biomass values are combined with our H-NCB to calculate the average biomass density of each forest class (tons aboveground biomass / ha).



GEDI based biomass measurements over a landscape. Darker green values represent higher above ground biomass and lighter shades of green represent lower above ground biomass.

3.2.2 Deforestation over peatland

Emissions due to peatland degradation are reported separately from the forest emissions. The extent of peatland degradation is determined by overlying the deforestation within the plot locations [dLUC]/commodity mask [jdLUC/sLUC] with peatland maps. Every deforested peatland pixel inside your plot locations[dLUC]/commodity mask [jdLUC/sLUC] will be accounted for as peatland degradation.

CARBON STOCK

Peatland degradation is an annual source of emissions. Following the IPCC Wetlands supplement, a fixed value of 61 tCO2e/ha/year is applied for the assessment period. After which peatland emissions are not considered LUC emissions, but should be reported under land management emissions.

3.2.3 Grassland conversion

Grassland conversion is based on the Global Pasture Watch dataset (Parente et al., 2024) annual grassland class and grassland extent maps at 30-m resolution, available via OpenLandMap. A pixel is flagged as a grassland conversion event in the year when natural or semi-natural grasslands are converted into cultivated grassland or other land.

CARBON STOCK

A fixed value of 44 tCO_2e/ha is applied to all grassland conversions, based on IPCC (2019). This differs from forest conversion, where pixel-level biomass maps are used.

4 Process

4.1 Deforestation-related GHG emissions

The [loss of] carbon stock in forest ecosystems is calculated by accounting for the carbon pools above ground biomass (AGB), below ground biomass (BGB), dead organic matter (DOM) and soil organic carbon (SOC). For the calculation of [loss of] grassland and peatland carbon stock, see section 4.2.5 and 4.2.6.

4.1.1 Above ground biomass loss

To convert the above ground biomass density (AGBD) map into AGB loss, the density is overlaid with the Satelligence deforestation detections. The combined AGB for all deforestation (ha) in the plot/concession/jurisdiction/mill gives the total AGB loss for a given year or time period.

4.1.2 Below ground biomass

Below ground biomass (BGB) is calculated by applying a root-to-shoot ratio to the AGB values, as specified in the GHG accounting manual for cocoa. Refer to the document for a detailed explanation of the calculation steps and data sources.

Dataset used: Supporting data and code for A global map of root biomass across the world's forests

To determine the BGB loss per pixel for a given year, the AGB is multiplied with the root-to-shoot ratio and the pixels converted for that year.

4.1.3 Dead organic matter

Dead organic matter (DOM) is calculated as a fraction of AGBD.

- DOM_frac = Dead organic matter as fraction of AGBD (-) = 0.07

To determine the DOM loss for a given year, the AGBD per pixel is multiplied with the DOM_frac and the pixels converted for that year.

Table 20: Dead organic matter (DOM), consisting of dead wood and litter, as a fraction of above-ground biomass (AGB), from UNFCCC, 2013. The recommended fraction to use is highlighted in bold. [Work in progress: Climate specific DOM fraction]

Climate	Elevation [m]	Precipitation [mm/year]	DOM fraction of ABG
Tropical	<2000	< 1000	6%
		1000-1600	2%
		> 1600	**7%**
	>2000	All	8%
Temperate/Boreal	All	All	12%

4.1.4 Soil organic carbon

Soil organic carbon (SOC) is determined using the SoilGrids (2020) dataset: → ***ocs_0-30cm_mean***. The result is SOC in tC/ha.

To determine SOC loss for a given year, SOC is multiplied with the pixels converted for that year.

4.2 Calculations

4.2.1 Total biomass density per pixel

$$BD = AGBD * (1 + RS_ratio + DOM_frac)$$

Where:

BD = Total biomass density (t/ha)

AGBD = Aboveground Biomass Density (t/ha)

RS_ratio = Root-to-shoot ratio used to compute BGBD as fraction of AGBD (-)

DOM_frac = Dead organic matter as fraction of AGBD (-) = 0.07

4.2.2 Total carbon density per pixel

$$C = BD * CF + SOC$$

Where:

C = Total carbon density (tC/ha)

BD = Biomass density (t/ha)

CF = Carbon fraction (-) = 0.47

SOC = Soil organic carbon (tC/ha)

4.2.3 Total emission density per pixel

$$CO2e = C * CCO2$$

Where:

CO_2e = Density of emissions (tCO_2e/ha)

C = Total carbon density (tC/ha)

CCO2 = Carbon to CO2 ratio is 44/12 = 3.67

4.2.4 Total annual LUC emissions

1. Compute emission density per pixel (tCO_2e/ha) [Section 4.2.1-4.2.3]
2. For each converted pixel, calculate its total emissions (tCO_2e) by multiplying the emission density (tCO_2e/ha) by the physical area of the pixel (ha).
3. Compute yearly emissions for each plot:
    a. For each year, sum the emissions of pixels converted in that year within plot boundaries → output is single value for LUC emissions per year for that plot (tCO_2e)

4.2.5 Grassland conversion

1. Fixed emission density of 44 tCO_2e/ha
2. Multiply the emission density per ha (44 tCO_2e/ha) with the area of the converted grassland pixels per year → output is the total annual grassland conversion in (tCO_2e)

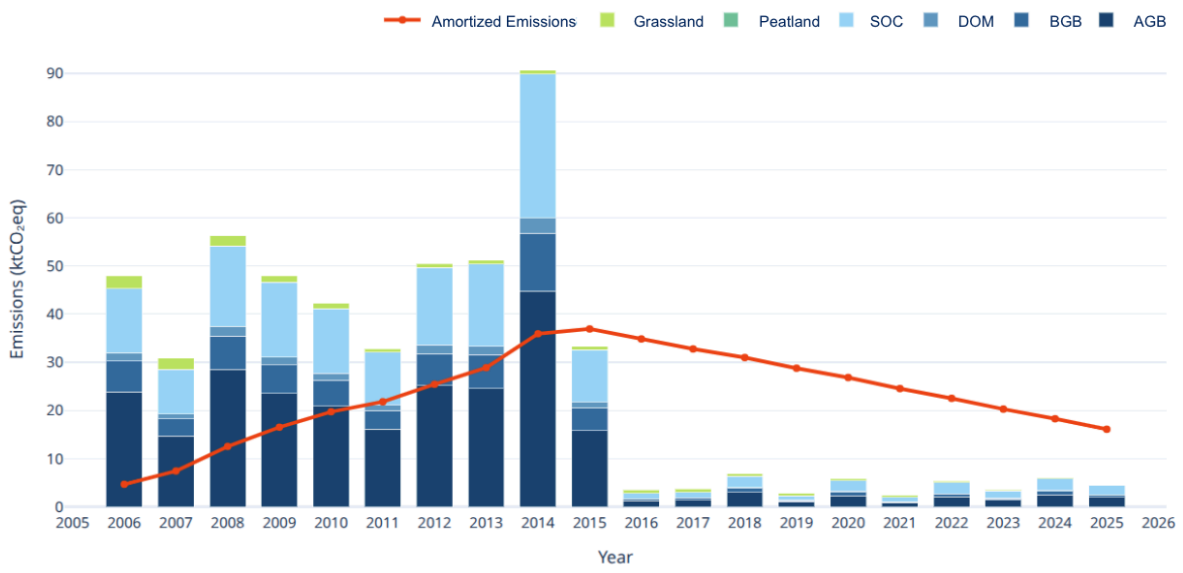
4.2.6 Peatland degradation

1. Fixed emission density of 61 $tCO_2e/ha/year$ → ED_peat
2. Converting peatland causes emissions every year after conversion. These emissions are not linearly amortized. Each hectare converted adds a fixed annual emission ($tCO_2e/ha/yr$), and that emission recurs every year for the length of the assessment period. A reporting year's total peatland emissions are therefore the emissions from that year's new conversions plus the continuing annual emissions from all conversions in earlier years of the assessment period. Once a conversion has been accounted for over the full assessment period, its emissions are no longer counted. From then on, older conversions drop out of the total year by year as they reach the end of the assessment period.

    Total peatland emissions in reporting year t = ED_peat × Σ (peatland area converted in year y), for all years y from t − (P − 1) to t, where P is the assessment period in years.

4.3 Linear amortization

Linear amortization means that not all deforestation/conversion-related GHG emissions are reported in the year of land use change. Instead, the GHG-emissions are amortized linearly from the year of conversion for the duration of the assessment period.



Example of linear amortization (previously linear discounting) over a 20 years assessment period

The general formula for the linear amortization factor for a year given year x from the reporting year is:

$$LAF_x = 2(AP - y_p - 0.5) / AP^2$$

Where:

LAF_x = Linear amortization factor (LAF) for year x of the LUC assessment period

AP = Number of years in the LUC assessment period

x = year in the LUC assessment period

y_p = Number of years between the reporting year and the year in the assessment period (x)

The most common length of an assessment period is 20 years. For crops with a rotation period/cultivation cycle of more than 20 years, for example timber and palm oil, an assessment period reflecting the growth period is used instead. *See example of the application of linear amortization factors for a 20 year assessment period below.*

Linear Amortization - 3 deforestation events have occurred in the assessment period

Reporting year: 2022
Assessment period: 20 years

1. **Assess the GHG-emissions (tCO_2e) per deforestation event**

Event1 (**2003**): 10,000 tCO_2e

Event 2(**2004**): 2,000 tCO_2e

Event 3(**2022**): 1,000 tCO_2e

2. **Apply the 2022 discounting factor to each event**
3. **Sum the amortized emissions**

2022 GHG report

Event 1* 0.0025 + Event 2*0.0075 + Event 3*0.0975
= 10,000* 0.0025 + 2,000* 0.0075 + 1,000*0.0975
= **137.5 tCO_2e**

Year	AY-20 (2003)	AY-19 (2004)	AY-18 (2005)	AY-17 (2006)	AY-16 (2007)	AY-15 (2008)	AY-14 (2009)	AY-13 (2010)	AY-12 (2011)	AY-11 (2012)
Factor	**0.25%**	**0.75%**	1.25%	1.75%	2.25%	2.75%	3.25%	3.75%	4.25%	4.75%
Year	AY-10 (2013)	AY-9 (2014)	AY-8 (2015)	AY-7 (2016)	AY-6 (2017)	AY-5 (2018)	AY-4 (2019)	AY-3 (2020)	AY-2 (2021)	Reporting year (2022)
Factor	5.25%	5.75%	6.25%	6.75%	7.25%	7.75%	8.25%	8.75%	9.25%	**9.75%**

4.4 Emission factors

Emission factors (EF) connect a plot or region's total LUC GHG emissions to its specific production The EF can be reported as LUC emissions per mass (kilogram or metric tonnes), volume (m3) or area (ha) unit, depending on preference and data availability. By expressing the climate impact as an intensity metric, the EFs serve as a tool for comparison between crops, production systems, and geographic spaces as well as a tool for understanding the impact of different emission sources contributing to the EF, essential for assessing reduction potential.

To accurately account for LUC emissions, especially in supply chains where side-selling to multiple buyers occurs, two kinds of product activity data is used to create a two-step calculation:

1. **Total production volume* (PV):** The total amortized LUC emissions are divided by the total production volume (PV) of the plot or region to establish the base emission intensity (the EF).
2. **Company-specific sourcing volume* (SV):** The EF is then multiplied by the company-specific sourcing volume (SV). This mass-based physical allocation ensures that buyers only assume responsibility for the emissions tied to their physical sourcing volumes.

**Volume referring to the activity data. This can be product volume or mass, but also the crop land area.*

Step 1: Emission Factor Calculation

$$EF(x) = GHG_LA(x) / PV$$

Where:

EF(x) = Emission factor (tCO_2e/kg) for reporting year x

GHG_LA(x) = Linearly amortized GHG-emissions for reporting year X (tCO_2e)

PV = Annual production of crop (kg or m3)

Step 2: Allocated Emissions Calculation

$$\text{Allocated LUC Emissions} = EF(x) * SV$$

Where:

SV = Company-specific sourcing volume (kg or m^3)

4.4.1 dLUC & jdLUC - Volume data

To calculate the base emission factor, the total production volume (PV) of the specific plot or jurisdiction must first be established. If primary PV data from the plot or region is unavailable, FAO (2024) data is used to estimate the baseline PV for most commodities. Once the EF is calculated, the best practice is to multiply it by the company-specific sourcing volume (SV) to determine the absolute emissions tied directly to the company's sourcing.

Note 3: If PV data for the requested commodity is not offered by the FAO, or if more reliable local alternatives exist, our team will always aim to incorporate the alternative for reliable PV establishment.

4.4.2 sLUC - Volume data

For sLUC, Satelligence uses country-level PV data from FAO (2024). Jurisdictional production is derived by allocating the national production using MapSPAM 2020 v2r2 spatial shares (IFPRI, 2026). MapSPAM is static to 2020 and does not vary by reporting year. Once the jurisdictional EF is calculated using this PV, the client's available sourcing volume (SV) is multiplied by the EF to calculate the final allocated emissions.

5 Output

5.1 SBTi FLAG and GHG Protocol

The Satelligence methodology as described above is compliant with the SBTi FLAG framework and GHG protocol. The outputs are linearly amortized, unless otherwise stated.

The GHG protocol supports several tiers of granularity for data sources. **Satelligence delivers the most granular data (Tier 3) for the Deforestation and AGB components**, which are the major and most dynamic components in tropical eco-regions.

The described methodology is also in line with the Quantis GHG accounting manual for cocoa, commissioned by the World Cocoa Foundation.

5.2 File formats

LUC emissions are provided by Satelligence in two output formats.

- **Executive report** (.pdf) covering strategic takeaways, methodology, key metrics, and visual maps and charts highlighting historical trends and spatial hotspots.
- **Raw, auditable Excel workbooks** (.xlsx) containing the complete underlying data trail. For technical auditing, these workbooks feature audit-level detail covering raw event-year land conversion (full_detail_non-discounted) and linearly amortized emissions calculated per GHG Protocol standards (full_detail_unaggregated). They also include aggregated insights via temporal summaries to track historical deforestation and conversion trends (emissions_breakdown_per_year) and spatial breakdowns by plot or jurisdiction for risk prioritization (emissions_breakdown_per_geom). Finally, assessment-year emission factors ($kgCO_2eq/kg$) are provided in the emissions_factors sheet.