

Methodology report 2026

LUC impact tool

Documentation of the LUC Impact Tool:
Methodology and basic principles

Mérieux NutriSciences | Blonk

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1. Introduction

This document details the methodology and data sources used to calculate land use change (LUC) emissions in the LUC Impact Tool (version 2026).

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Deforestation and land clearance represent substantial contributors to anthropogenic climate change within the global agricultural production system. About 5–14% of the global greenhouse gas (GHG) emissions are attributable to land use and land-use change (LULUCF / AFOLU) associated with agriculture (IPCC, 2019). Numerous scientific publications have focused on this issue and have provided solid global or country specific estimations of CO_2 emissions due to land use change based on available statistics and/or satellite imagery.

A fundamental challenge for practitioners of Life Cycle Assessments (LCA) is to translate macro-level impact of land use change into crop- and country-specific emissions factors when direct farm-level traceability is unavailable. Calculation methodologies are often not straightforward, even in the case when detailed information is available. The calculation becomes even more challenging when no specific information is available for the crop of interest. Our LUC Impact Tool and dataset aim to provide insights into the impact of land use change of a wide variety of crop-country combinations and is specifically designed to support LCA practitioners, sustainability analysts, and corporate footprint managers.

2. Calculation methodologies

Methodological Innovations Introduced in Version 2026:

1. **Harmonized Annual Crop Expansion Denominator:** In linear amortization modeling, annual land expansion increments are now divided by the harvested area of the assessment reference year rather than the rolling annual area. This mathematical correction eliminates multi-year compounding errors that historically produced expansion totals exceeding 100%.
2. **Default Exclusion of Carbon Removals (Stock Gains):** In compliance with the GHG Protocol Land Sector and Removals Guidance (LSRG Equation 7.6) and SBTi FLAG requirements, carbon stock increases (such as conversion of annual cropland to perennial agroforestry or managed pasture) are no longer permitted to offset gross deforestation emissions in statistical land use models by default.
3. **Spatially Explicit Land Occupation (LO):** The Land Occupation data architecture transitioned from aggregate FAOSTAT national ratios to spatially explicit, crop- and country-specific data derived from global agro-ecological modeling (MAPSPAM; Cao et al., 2026). In addition, the Fallow Land Index is capped at 1.33 based on empirical agronomic constraints.

Methodological Features Introduced in Version 2024:

1. **Managed Grassland Accounting**: Disaggregation of permanent pasture into managed (cultivated) pasture and natural grassland for countries with available statistical records (such as Brazil), preventing inaccurate attribution of crop expansion to primary forest clearance.
2. **Land Occupation Modeling**: Integration of multi-cropping accounting via the Land Occupation index (formerly termed Crop System Efficiency Index, CSEI) to account for harvest frequency and fallow cycles.

Four distinct calculation modules are implemented in the LUC Impact Tool:

- **Direct Land Use Change** (dLUC) when previous land use is known.
- **Statistical Land Use Change** (sLUC) when previous land use is unknown but country of cultivation is known.
- **Global Trade-Weighted** sLUC when both previous land use and country of origin are unknown.
- **Carbon Opportunity Cost** (COC) modeling.

2.1 Previous Land use Known (dLUC)

When the country of cultivation and both the current and previous land uses are known, the carbon stock change of a selected crop is calculated using IPCC tier-1 and tier-2 methodological defaults.

2.1.1 Calculation steps

1. Representative climate zones and soil classes for the jurisdiction under evaluation are assigned based on European Commission Joint Research Centre (JRC) and IPCC spatial layers. Baseline equilibrium carbon stocks are then determined across individual pools:
   a. Forest Land: Specific vegetation biomass carbon densities (encompassing above- and below-ground biomass, dead organic matter, and litter) are derived from the FAO Global Forest Resources Assessment 2020 (FRA 2020).
   b. Grassland: Biomass carbon stocks are assigned according to continental boundaries and agro-climatic classifications combining European Commission spatial data and IPCC values.

c. Cropland: Vegetation biomass is obtained from either the IPCC or PAS 2050, one value represents all annual crops and another all perennial crops (with some exceptions, described in the data sources chapter).
d. Soil Organic Carbon (SOC): baseline mineral soil organic carbon stocks are based on IPCC 2019 soil carbon defaults for climate regions and soil types, stock change factors from IPCC 2019 are used to calculate the soil carbon stock for different land use and land management practices.

2. Change in carbon stock between previous and current land use is multiplied with 44/12 to convert kg carbon to kg CO_2. If a land conversion results in a net carbon stock accumulation ($\Delta C > 0$, representing negative emissions or removals, such as transitioning from annual cropland to an orchard), this value is assume to be 0 by default in compliance with corporate greenhouse gas accounting guidelines. Users may selectively disable this restriction to account for net sequestration.
3. Direct N_2O emissions resulting from the mineralization of soil organic matter following soil carbon stock losses are calculated following IPCC 2019 refinement. In case of carbon sequestration in the soil, direct N_2O emissions are zero, and never negative.
4. Emissions are amortized over the amortization period following the selected approach:
    a. Equal (calculated & amortized w/ single calculation): Emissions are divided equally over amortization period; in practice this means that the total emissions are accounted for by only taking into consideration the year of reference and 20 years before the year of reference (20 years is the default amortization period, that can be modified). The total emissions are then divided by the amortization period. The conversion year does not influence the results, as long as it is within the amortization time from the assessment year. This method is in described in PAS:2050
    b. Equal (calculated & amortized equally each year): Emissions are divided equally over amortization period; in practice this means that the total emissions are accounted for by considering and summing emissions from each single year within the amortization period (20 years by default). The total emissions are then divided by the amortization period. The conversion year does not influence the results, as long as it is within the amortization time from the assessment year.
    c. Linear (calculated & amortized linearly each year): Emissions are linearly discounted over the amortization period, meaning that recent conversion will result in higher emissions compared to more historic conversion. The amortization percentage for the assessment year is equal to: (1 / amortization time (by default 20 years)) + (((amortization time / 2) - (((assessment year - conversion year) + 1) - (1 / 2))) * (2 / amortization time^2)). The emissions accounted for in the assessment year are obtained by multiplying the total emissions by the amortization percentage. This method is referred to in the LSRS/LRSG and recommended by SBTi FLAG.
5. The crop yield is derived from FAOSTAT and determines impact per kg of product.

2.1.2 Input parameters

The calculation is based on the main inputs: country and crop under study, year of assessment, conversion year (year in which the land use change occurred) and previous land use (land use before conversion to current land use for agriculture). Apart from these inputs, certain input parameters can be selected. These are described further in this section.

One of the most important parameters is the amortization period and method. Both these settings are prescribed in different LCA and GHG standards.

PAS2050: 20 years amortization period and equal amortization over 20 years. Emissions calculated and amortized in a single calculation over 20-year period. This basic methodology is described in the

PAS 2050-1 published by BSI (BSI, 2012) and now widely referenced in LCA guidelines, such as the Product Environmental Footprint (PEF) guidelines (Zampori & Pant, 2019) & Envifood protocol.

LSRS/LSRG: 20 years amortization period and with linear amortization. Emissions calculated and amortized for each year in the 20-year period.

SBTi/FLAG: 20 years amortization period and linear amortization. Emissions calculated and amortized for each year in the 20-year period (Christa Anderson et al., 2022).

An overview of all calculation input parameters is provided in the table below.

Table 1. Overview of input parameters for 'Previous land use known' calculation method.

Setting	Description	Consideration
Amortization method	This defines how LUC emissions from a LUC event (or within a certain year) are accounted for over the amortization time. More information on amortization method provided in section 2.2.2.1.	Assess the requirement set by the calculation standard you follow, as indicated above this table.
Amortization time	The amortization time defines over how many years emissions from a LUC event are divided. The lookback period (period over which land use change emissions are relevant for the assessment year) is equal to the amortization time.	Assess the requirement set by the calculation standard you follow, as indicated above this table.
Tillage	This defines the degree of soil disturbance due to tillage operations. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. Full: Substantial soil disturbance with intense tillage operations. Reduced: Primary and/or secondary tillage but with reduced soil disturbance. No till: Only minimal soil disturbance.	Select the option that best matches the cultivation system under study.
Organic matter input	This defines the degree of organic matter input, such as crop residues and manure. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. The choices are described as follows: Low: Low residue return due to removal of residues or production of crops yielding low residues. Medium: All crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. High without manure: Significantly greater crop residue inputs due to additional practices, such as production of high residue yielding crops, use of green manures, etc. High with manure: Significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.	Select the option that best matches the cultivation system under study.

Carbon stock method	Carbon stocks for annual and perennial cropland are proposed by both the IPCC and in the PAS2050-1 method. This parameter defines the choice for either of the two sources.	By default, we recommend the use of IPCC carbon stocks. In case the PAS2050 is to be followed, these values can be selected.
GWP factor N2O	It is possible to select other Global Warming Potential (GWP) factors for characterization of N_2O. IPCC AR5 and AR6 GWP 100 factors (incl. climate carbon feedback) can be selected.	Assess the requirement set by the calculation standard you follow. Most standards require to include the most recent IPCC GWP100 factor, which would be AR6 at the time of writing.
Allow negative values	Due to a higher carbon stock after a land use change (for example when conversion from annual to perennial crop land occurred), there might be a negative result. This signifies a carbon sequestration. This checkbox will set the negative values to zero or will allow negative values to be shown.	For a conservative approach, negative values are not allowed in the LUC Impact dataset.

2.2 Previous Land use Unknown, Country Known (sLUC)

When farm-specific historical land records are unavailable, statistical land use change (sLUC) is determined using country-level land dynamics published by FAOSTAT. Crop-specific expansion is evaluated against aggregate national shifts in forestland, grassland, annual cropland, and perennial cropland.

2.2.1 Calculation steps

The standardized sLUC calculation protocol adheres to PAS 2050-1:2012 (Section 5.2.3.3) and the GHG Protocol LSRG statistical land modeling framework.

When selecting the amortization method ‘Equal (calculated & amortized w/ single calculation)’, calculation steps 1 to 6 are performed once for the amortization period. When selecting the amortization method ‘Equal (calculated & amortized equally each year)’ or ‘Linear (calculated & amortized linearly each year)’, calculation steps 1 to 6 are performed for each year in the amortization period, obtaining multiple so-called ‘year-to-year’ LUC emissions by the beginning of step 7.

1. Expansion and contraction of forest and grassland per country (as defined in PAS 2050) are based on FAO land occupation change over the amortization period.
2. Expansion and contraction of specific crop is based on FAO harvested area change over the amortization period (corrected by LO). Cropland is either classified as perennial or annual cropland.
3. For each crop: transformation in hectares from forest, grassland, perennial crop and annual crop is calculated.
    a. The weighted average takes into account relative differences in crop expansion at the expense of forest, grassland, annual/perennial based on the expansion/contraction of forest, grassland and cropland.
    b. The normal average is a simple average of these options (all 1/3).
    c. All results are scaled to the relative amount of expansion of the crop. This is described in the PAS2050.
4. Representative climate zones and soil classes for the jurisdiction under evaluation are assigned based on European Commission Joint Research Centre (JRC) and IPCC spatial layers. Baseline equilibrium carbon stocks are then determined across individual pools:

a. Forest Land: Specific vegetation biomass carbon densities (encompassing above- and below-ground biomass, dead organic matter, and litter) are derived from the FAO Global Forest Resources Assessment 2020 (FRA 2020).
b. Grassland: Biomass carbon stocks are assigned according to continental boundaries and agro-climatic classifications combining European Commission spatial data and IPCC values.
c. Cropland: Vegetation biomass is obtained from either the IPCC or PAS 2050, one value represents all annual crops and another all perennial crops (with some exceptions, described in the data sources chapter).
d. Soil Organic Carbon (SOC): baseline mineral soil organic carbon stocks are based on IPCC 2019 soil carbon defaults for climate regions and soil types, stock change factors from IPCC 2019 are used to calculate the soil carbon stock for different land use and land management practices.

5. Change in carbon stock between previous and current land use is multiplied with 44/12 to convert kg carbon to kg CO_2. If a land conversion results in a net carbon stock accumulation ($\Delta C > 0$, representing negative emissions or removals, such as transitioning from annual cropland to an orchard), this value is assume to be 0 by default in compliance with corporate greenhouse gas accounting guidelines. Users may selectively disable this restriction to account for net sequestration.
6. Direct N_2O emissions resulting from the mineralization of soil organic matter following soil carbon stock losses are calculated following IPCC 2019 refinement. In case of carbon sequestration in the soil, direct N_2O emissions are zero, and never negative.
7. Emissions are amortized over the amortization period following the selected approach:

a. Equal (calculated & amortized w/ single calculation): Emissions calculated once for the entire amortization period and are divided equally over amortization period; in practice this means that the emissions accounted for in the assessment year are found by dividing the total emissions by the amortization period (which is 20 years by default).
b. Equal (calculated & amortized equally each year): Emissions are calculated for each year in the amortization period and divided equally over amortization period. In practice this means that the emissions accounted for in the assessment year are equal to the sum of all year-to-year LUC emission, divided by the amortization period (which is 20 years by default).
c. Linear (calculated & amortized linearly each year): Emissions are calculated for each year in the amortization period, and linearly discounted over the amortization period; meaning that recent conversions will result in higher emissions compared to more historic conversions. Each year-to-year emission thus corresponds to a different amortization percentage. The amortization percentage for the assessment year is equal to: (1 / amortization time (by default 20 years)) + (((amortization time / 2) - ((years from assessment year + 1) - (1 / 2))) * (2 / amortization time^2)). The emissions accounted for in the assessment year are the sum of the year-to-year emissions multiplied by their corresponding amortization percentage.

8. The crop yield is derived from FAOSTAT and determines impact per kg of product.

2.2.2 Input parameters

The calculation is based on the main inputs: country and crop under study and year of assessment. Apart from these inputs, certain input parameters can be selected. These are described further in this section.

One of the most important parameters is the amortization period and method. Both these settings are prescribed in different LCA and GHG standards.

PAS2050: 20 years amortization period and equal amortization over 20 years. Emissions calculated and amortized in a single calculation over 20-year period. This basic methodology is described in the PAS 2050-1 published by BSI (BSI, 2012) and now widely referenced in LCA guidelines, such as the Product Environmental Footprint (PEF) guidelines (Zampori & Pant, 2019) & Envifood protocol.

Draft GHG protocol for the land sector: 20 years amortization period and either equal or linear amortization. Emissions calculated and amortized for each year in the 20-year period.

SBTi/FLAG: 20 years amortization period and linear amortization. Emissions calculated and amortized for each year in the 20-year period (Christa Anderson et al., 2022).

An overview of all calculation input parameters is provided in the table below.

Table 2. Overview of input parameters for 'Previous land use known' calculation method.

Setting	Description	Consideration
Amortization method	This defines how LUC emissions from a LUC event (or within a certain year) are accounted for over the amortization time. More information on amortization method provided in section 2.2.2.1.	Assess the requirement set by the calculation standard you follow, as indicated above this table. More information on the amortization method is provided in the next section.
Amortization time	The amortization time defines over how many years emissions from a LUC event are divided. The lookback period (period over which land use change emissions are relevant for the assessment year) is equal to the amortization time.	Assess the requirement set by the calculation standard you follow, as indicated above this table.
Tillage	This defines the degree of soil disturbance due to tillage operations. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. Full: Substantial soil disturbance with intense tillage operations. Reduced: Primary and/or secondary tillage but with reduced soil disturbance. No till: Only minimal soil disturbance.	Select the option that best matches the cultivation system under study.
Organic matter input	This defines the degree of organic matter input, such as crop residues and manure. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. The choices are described as follows: Low: Low residue return due to removal of residues or production of crops yielding low residues. Medium: All crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. High without manure: Significantly greater crop residue inputs due to additional practices, such as production of high	Select the option that best matches the cultivation system under study.

	residue yielding crops, use of green manures, etc. High with manure: Significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.	
Carbon stock method	Carbon stocks for annual and perennial cropland are proposed by both the IPCC and in the PAS2050-1 method. This parameter defines the choice for either of the two sources.	By default, we recommend the use of IPCC carbon stocks. In case the PAS2050 is to be followed, these values can be selected.
GWP factor N2O	It is possible to select other Global Warming Potential (GWP) factors for characterization of N_2O. IPCC AR5 and AR6 GWP 100 factors (incl. climate carbon feedback) can be selected.	Assess the requirement set by the calculation standard you follow. Most standards require to include the most recent IPCC GWP100 factor, which would be AR6 at the time of writing.
Allow negative values	Due to a higher carbon stock after a land use change (for example when conversion from annual to perennial crop land occurred), there might be a negative result. This signifies a carbon sequestration. This checkbox will set the negative values to zero or will allow negative values to be shown.	For a conservative approach, negative values are not allowed in the LUC Impact dataset.
Include residues	Consider removals (due to carbon stock increase, negative emissions) that are caused by land transformation (e.g., from annual to perennial), that will offset other land use change emissions.	Following a conservative approach, by default this is not selected. Include for PAS 2050-1:2012 compliancy (PEFCR), exclude for FLAG compliancy (GHG protocol LSRS/LSRG).
Land Occupation (LO)	To represent multiple cropping practices more accurately in LUC and land occupation calculations, we propose the use of the 'Land Occupation' index (LO). What we are calculating with the LO, is the (average) length of the harvest cycle of temporary crops (in yr/harvest).	The index considers both land efficiency gains from multiple cropping, and optionally efficiency losses due to temporary fallow land. A possible solution for the calculation of land occupation and transformation related to crop production in countries with more precision will be proposed next, using a consistent and already-used data set (FAOSTAT).
Managed grassland	Also new in this update is the addition of managed grassland as a land use category and an additional crop type, included only for specific countries where data is available, such as Brazil.	Managed grassland are determined based on the sum of 'Temporary grassland' data in FAOstat 'Land Use' dataset & 'Permanent grassland – cultivated' data in FAOstat 'Land Use' dataset.

2.2.2.1 Amortization method

Results with equal and linear amortization

There are two versions of the dLUC dataset: a result dataset calculated with linear amortization and a result dataset calculated using equal amortization. The choice for equal or linear amortization in the

dLUC emission calculation is related to the guideline that the user wishes to comply to: the PAS2050-1 (and thus the European Commission's PEF guidance) prescribes the use of equal amortization; the recently published SBTi FLAG calculation guidance prescribes the use of linear amortization. The amortization method in direct Land Use Change defines how the impact of a land use change event (e.g., deforestation) is accounted for in the years following the event. In equal amortization, dLUC emissions are equal for each year after the land use change event, for the duration of the amortization period (in this case: 20 years). In linear amortization, dLUC emissions linearly decrease towards zero after the land use change event, for the duration of the amortization period (in this case: 20 years). Linear amortization thus implies that the years directly after a land use change event carry a larger burden compared to years further away from the land use change event. This implies that for the emission calculation not only the question *if* land use change in the last 20 years is related to a specific crop-country combination is relevant, but also *when* the land use changes took place.

Equal amortization

The Excel dataset gives the results of the three calculation methods from the 'country known, land use unknown' functionality of the tool. The weighted average takes into account relative differences in crop expansion at the expense of forest, grassland, annual/perennial. The normal average is a simple average of these options. All results are scaled to the relative amount of expansion of the crop. The worst case of the average and weighted average is used in the PAS2050-1 protocol. The Food SCP method requires the weighted average for the estimation of land use change emissions when previous land use is unknown. The GHG Protocol Product Standard requires that the method used to calculate land use change impacts, including the average approach, be included in the inventory report.

Following the PAS2050-1 protocol, implies that emissions are calculated over the net expansion of a specific crop-country combination over the last 20 years. In case the crop area expanded first, and then contracted to equal to, or less than the area 20 years ago, the net expansion is zero.

Linear amortization

For the calculation of dLUC emissions through linear amortization, the exact same steps are takes as described in section 2.1, with the important difference that the calculation is made 20 times over a 1-year period (although still with a three-year average). The results found for the most recent year (e.g, if reference year is 2021, difference 2019-2021 compared to 2018-2020) will be multiplied by the highest percentage, and the results found for the most historic years (e.g., difference 1998-2000 compared to 1999-2001) will be multiplied with the lowest percentage. The percentage of each year is calculated as: amortization percentage = (1 / amortization time (= 20 years)) + (((amortization time / 2) - ((conversion year + 1) - (1 / 2))) * (2 / amortization time^2)).

Following this calculation method implies that emissions are calculated for all (yearly) expansions which occurred of a specific crop-country combination in the last 20 years. In case the crop area expanded first, and then contracted to equal to, or less than the area 20 years ago, the total expansion is considered larger than zero. Due to fluctuations in cultivated area for crops in FAO statistics, most of the crop-country combinations are associated with some total expansion. For this reason, many crop-country combinations which lead to zero expansion (and thus zero emissions) when using equal amortization will be associated with some expansion (and thus emissions) when using linear amortization.

2.2.3 LUC calculation in standards

Different standards are transparently summarized in the table below.

Table 3. Overview of different standards.

	FLAG	GHG protocol	PAS 2050
Amortization period	20 years	20 years	20 years
Amortization method	Linear amortization	Linear or equal amortization	Equal amortization

Approach	Shared responsibility or Product specific	Shared responsibility and/or Product specific	Product specific
Separately report GHG	Not mentioned	Should be separately reported	Not mentioned
Emissions from biomass burning	Not mentioned	Should be included	Not mentioned
Emissions from peatland drainage	Not mentioned	Should be included	Not mentioned
Include residues	Not to be included in sLUC	Not to be included in sLUC	To be included

2.3 Previous Land use Unknown, Country Unknown (global sLUC)

2.3.1 Calculation steps

The ‘average’ LUC GHG emissions for a selected crop are determined by taking the weighted average of all producing countries, based on cultivated area obtained from FAO statistics for the year under study. The GHG emissions for each relevant country are determined through the methodology as described in ‘Previous Land use Unknown, Country Known’.

2.3.2 Input parameters

The same input parameters as defined in the paragraph on the ‘Previous Land use Unknown, Country Known’ methodology are used in this calculation.

The calculation is based on the main inputs: crop under study and year of assessment. Apart from these inputs, certain input parameters can be selected. These are described further in this section.

One of the most important parameters is the amortization period and method. Both these settings are prescribed in different LCA and GHG standards.

PAS2050: 20 years amortization period and equal amortization over 20 years. Emissions calculated and amortized in a single calculation over 20-year period. This basic methodology is described in the PAS 2050-1 published by BSI (BSI, 2012) and now widely referenced in LCA guidelines, such as the Product Environmental Footprint (PEF) guidelines (Zampori & Pant, 2019) & Envifood protocol.

Draft GHG protocol for the land sector: 20 years amortization period and either equal or linear amortization. Emissions calculated and amortized for each year in the 20-year period.

SBTi/FLAG: 20 years amortization period and linear amortization. Emissions calculated and amortized for each year in the 20-year period (Christa Anderson et al., 2022).

An overview of all calculation input parameters is provided in the table below.

Table 4. Overview of input parameters for 'Previous land use known' calculation method.

Setting	Description	Consideration
Amortization method	This defines how LUC emissions from a LUC event (or within a certain year) are accounted for over the amortization time. More information on amortization method provided in section 2.2.2.1.	Assess the requirement set by the calculation standard you follow, as indicated above this table. More information on the amortization method is provided in the next section.
Amortization time	The amortization time defines over how many years emissions from a LUC event are divided. The lookback period (period over which land use change emissions are relevant for the assessment year) is equal to the amortization time.	Assess the requirement set by the calculation standard you follow, as indicated above this table.
Tillage	This defines the degree of soil disturbance due to tillage operations. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019.	Select the option that best matches the cultivation system under study.

	Full: Substantial soil disturbance with intense tillage operations. Reduced: Primary and/or secondary tillage but with reduced soil disturbance. No till: Only minimal soil disturbance.	
Organic matter input	This defines the degree of organic matter input, such as crop residues and manure. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. The choices are described as follows: Low: Low residue return due to removal of residues or production of crops yielding low residues. Medium: All crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. High without manure: Significantly greater crop residue inputs due to additional practices, such as production of high residue yielding crops, use of green manures, etc. High with manure: Significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.	Select the option that best matches the cultivation system under study.
Carbon stock method	Carbon stocks for annual and perennial cropland are proposed by both the IPCC and in the PAS2050-1 method. This parameter defines the choice for either of the two sources.	By default, we recommend the use of IPCC carbon stocks. In case the PAS2050 is to be followed, these values can be selected.
GWP factor N2O	It is possible to select other Global Warming Potential (GWP) factors for characterization of N_2O. IPCC AR5 and AR6 GWP 100 factors (incl. climate carbon feedback) can be selected.	Assess the requirement set by the calculation standard you follow. Most standards require to include the most recent IPCC GWP100 factor, which would be AR6 at the time of writing.
Allow negative values	Due to a higher carbon stock after a land use change (for example when conversion from annual to perennial crop land occurred), there might be a negative result. This signifies a carbon sequestration. This checkbox will set the negative values to zero or will allow negative values to be shown.	For a conservative approach, negative values are not allowed in the LUC Impact dataset.
Include residues	Consider removals (due to carbon stock increase, negative emissions) that are caused by land transformation (e.g., from annual to perennial), that will offset other land use change emissions.	Following a conservative approach, by default this is not selected. Include for PAS 2050-1:2012 compliancy (PEFCR), exclude for FLAG compliancy (GHG protocol LSRS/LSRG).

Land Occupation (LO)	To represent multiple cropping practices more accurately in LUC and land occupation calculations, we propose the use of the 'Land Occupation' index (LO). What we are calculating with the LO, is the (average) length of the harvest cycle of temporary crops (in yr/harvest).	The index considers both land efficiency gains from multiple cropping, and optionally efficiency losses due to temporary fallow land. A possible solution for the calculation of land occupation and transformation related to crop production in countries with more precision will be proposed next, using a consistent and already-used data set (FAOSTAT).
Managed grassland	Also new in this update is the addition of managed grassland as a land use category and an additional crop type, included only for specific countries where data is available, such as Brazil.	Managed grassland are determined based on the sum of 'Temporary grassland' data in FAOstat 'Land Use' dataset & 'Permanent grassland – cultivated' data in FAOstat 'Land Use' dataset.

2.4 Carbon Opportunity Cost

A simplified version of the method proposed by (Searchinger et al., 2018), to account for the difference between the carbon stock (in soil and vegetation) potential natural situation (PNV)[1], compared to the current use as agricultural land. By default, the carbon stock difference is amortized over 30 years, approximating the amortization method suggested in (Searchinger et al., 2018).

2.4.1 Calculation steps

1. The carbon stock of the selected crop, in the selected country is calculated following the following approach: Based on worldwide climate and soil types provided by EU, climate zone and soil types are selected which are representable for the country. Soil carbon content is based on IPCC 2019 soil carbon defaults for climate regions and soil types, stock change factors from IPCC 2019 are used to calculate the soil carbon stock for different land use and land management practices. Biomass of crops is obtained from either the IPCC or PAS 2050, one value represents all annual crops and another all perennial crops (with some exceptions, described in the data sources chapter).
2. The carbon stock of the potential natural vegetation (PNV) environment is obtained from country averaged carbon stocks in soil and vegetation, derived from data provided in the supplementary materials of (Searchinger et al., 2018).
3. Change in carbon stock between PNV and current land use is multiplied with 44/12 to convert kg carbon to kg CO_2.
4. Direct N_2O emissions are not calculated in this method.
5. Emissions are amortized over the amortization period following equal amortization; in practice this means that the emissions accounted for in the assessment year are found by dividing the total emissions by the amortization period (which is 30 years by default).

2.4.2 Input parameters

The calculation is based on the main inputs: country and crop under study. Apart from these inputs, certain input parameters can be selected. An overview of all calculation input parameters is provided in the table below.

Table 5. Overview of input parameters for 'Carbon Opportunity Cost' calculation method.

Setting	Description	Consideration
Amortization time	The amortization time defines over how many years emissions from a LUC event are divided.	By default, 30 years is recommended.
Tillage	This defines the degree of soil disturbance due to tillage operations. The level defines the soil carbon stock calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. Full: Substantial soil disturbance with intense tillage operations. Reduced: Primary and/or secondary tillage but with reduced soil disturbance. No till: Only minimal soil disturbance.	Select the option that best matches the cultivation system under study.
Organic matter input	This defines the degree of organic matter input, such as crop residues and manure. The level defines the soil carbon stock	Select the option that best matches the cultivation system under study.

[1] Potential natural vegetation is a theoretic representation of the vegetation following human abandonment, simulated under current climate conditions.

	calculation, as described in Section 3.2 of this document. Definition is obtained from IPCC 2019. The choices are described as follows: Low: Low residue return due to removal of residues or production of crops yielding low residues. Medium: All crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g., manure) is added. High without manure: Significantly greater crop residue inputs due to additional practices, such as production of high residue yielding crops, use of green manures, etc. High with manure: Significantly higher C input over medium C input cropping systems due to an additional practice of regular addition of animal manure.	
Carbon stock method	Carbon stocks for annual and perennial cropland are proposed by both the IPCC and in the PAS2050-1 method. This parameter defines the choice for either of the two sources.	By default, we recommend the use of IPCC carbon stocks. In case the PAS2050 is to be followed, these values can be selected.
Allow negative values	Due to a higher carbon stock after a land use change (for example when conversion from annual to perennial crop land occurred), there might be a negative result. This signifies a carbon sequestration. This checkbox will set the negative values to zero or will allow negative values to be shown.	For a conservative approach, negative values are not allowed in the LUC Impact dataset.

2.5 Methodological remarks

Our LUC calculation methodology is under constant development. Several important aspects to know about the current methodology, used to calculate the LUC emissions for the 2026 dataset are summarized in the table below.

Table 5. Overview of known limitations.

Methodological aspect	Methodology in 2026 dataset	Consideration for future version
Emissions from peat oxidation and mineralization	Not included. The tool is applicable for mineral soils only.	No direct plans to include in 2027 version of tool or dataset.
Emissions from biomass burning	Not included	No direct plans to include in 2027 version of tool or dataset.
LUC emissions for grazing grassland (for other countries) and mangroves	LUC for grazing grassland (for most countries) and mangroves cannot be calculated due to data availability limitations.	Land uses which fall outside of the currently defined land use categories should be included. Efforts will continue to enable accounting of LUC emissions related to such land uses, for example grazing grassland (for more countries) and mangrove.
Land management emissions reporting	Currently, emissions are included (e.g., transformation from perennial to annual) that should be reported as Land Management (LM) according to LSRS/LSRG reporting standard.	We are planning to update and disaggregate the reporting of LM and LUC in future versions of the database.

3. Data sources

The current results are based on the average FAO statistics (harvested area) up to 2022-2024 and 2002-2004.

3.1 Areas

Forest and grassland area

Forest and grassland area for all countries are obtained from FAOstat. The item definitions are:

- For grassland (Item: Land under perm. meadows and pastures, FAO item: 6655, FAO element: 5110)
- For managed grassland (Item: Land under perm. meadows & pastures – Cultivated, FAO item: 6656, FAO element: 5110)
- For forest (Item: Forest land, FAO item: 6646, FAO element: 5110)

Data is downloaded in end February 2026 and contains data up to and including 2024.

Harvested area

For each crop and country, we use FAO data from “Crops and livestock products”, obtained from FAOstat in end February 2026. The area harvested is downloaded and contains data form 1990 up to and including 2024.

3.2 Carbon stocks

Soil carbon stock

The carbon stock will depend on the country under study. Soil carbon content is based on IPCC 2019 soil carbon defaults for climate regions and soil types: From IPCC 2019 Volume 4, Table 2.3. Stock change factors from IPCC 2019 are used to calculate the soil carbon stock for different land use and land management practices: From IPCC 2019 refinements, Volume 4, Table 5.5 (IPCC, 2019a). The climate in a country is often described by a combination of multiple climate types, just as the soil is described by a combination of different soil types. We take into account the 2 most prevalent climate types and soil types to calculate the climate- and soil-specific soil carbon stock.

Table 6. Soil carbon stock. From IPCC 2019 refinements, Volume 4, Table 2.3. All values in tones C/ha in 0-30 cm depth.

Climate region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
Boreal, dry	63	26	10	117	20	116
Boreal, wet	63	65,5	10	117	20	116
Boreal, moist	63	65,5	10	117	20	116
Cold temperate, dry	43	33	13	NO	20	87
Cold temperate, moist	81	76	51	128	136	128
Cold temperate, wet	81	76	51	128	136	128
Warm temperate, dry	24	19	10	NO	84	74
Warm temperate, moist	64	55	36	143	138	135
Warm temperate, wet	64	55	36	143	138	135
Tropical, dry	21	19	9	143	50	22
Tropical, moist	40	38	27	143	70	68
Tropical, wet	60	52	46	143	77	49
Tropical montane	51	44	52	143	96	82

**** NO denotes that the soil type does not normally occur within a climate zone***

Table 7. Soil carbon Stock change factors for land use, From IPCC 2019 refinements, Volume 4, Table 5.5

Factor	Land use (FLU)			
Management option	Annual cropland	Paddy rice	Perennial cropland	Set aside (<20 years)
Boreal, dry	0,77	1,35	0,72	0,93
Boreal, moist	0,7	1,35	0,72	0,82
Boreal, wet	0,7	1,35	0,72	0,82
Cold temperate, dry	0,77	1,35	0,72	0,93
Cold temperate, moist	0,7	1,35	0,72	0,82
Cold temperate, wet	0,7	1,35	0,72	0,82
Warm temperate, dry	0,76	1,35	0,72	0,93
Warm temperate, moist	0,69	1,35	0,72	0,82
Warm temperate, wet	0,69	1,35	0,72	0,82
Tropical, dry	0,92	1,35	1,01	0,93
Tropical, moist	0,83	1,35	1,01	0,82
Tropical, wet	0,83	1,35	1,01	0,82
Tropical montane	0,805	1,35	1,01	0,88

Table 8. Soil carbon Stock change factors for tillage level, From IPCC 2019 refinements, Volume 4, Table 5.5.

Factor	Tillage level		
Management option	Full	Reduced	No-till
Boreal, dry	1	0,98	1,03
Boreal, moist	1	1,04	1,09
Boreal, wet	1	1,04	1,09
Cold temperate, dry	1	0,98	1,03
Cold temperate, moist	1	1,04	1,09
Cold temperate, wet	1	1,04	1,09
Warm temperate, dry	1	0,99	1,04
Warm temperate, moist	1	1,05	1,1
Warm temperate, wet	1	1,05	1,1
Tropical, dry	1	0,99	1,04
Tropical, moist	1	1,04	1,1
Tropical, wet	1	1,04	1,1
Tropical montane	1	1,02	1,07

Table 9. Soil carbon Stock change factors for organic input level, From IPCC 2019 refinements, Volume 4, Table 5.5.

Factor	Organic input level			
Management option	Low	Medium	High without manure	High with manure
Boreal, dry	0,95	1	1,04	1,37
Boreal, moist	0,92	1	1,11	1,44
Boreal, wet	0,92	1	1,11	1,44
Cold temperate, dry	0,95	1	1,04	1,37
Cold temperate, moist	0,92	1	1,11	1,44
Cold temperate, wet	0,92	1	1,11	1,44
Warm temperate, dry	0,95	1	1,04	1,37
Warm temperate, moist	0,92	1	1,11	1,44
Warm temperate, wet	0,92	1	1,11	1,44
Tropical, dry	0,95	1	1,04	1,37
Tropical, moist	0,92	1	1,11	1,44
Tropical, wet	0,92	1	1,11	1,44
Tropical montane	0,94	1	1,08	1,41

Forest vegetation carbon stock

Forest carbon stocks include above and below-ground biomass carbon stock and carbon stock in dead matter and litter. All of these carbon stocks are considered in the total vegetation carbon stock obtained from the Forest Resource Assessment (FRA) 2020 (FAO, 2020), published by the FAO. This assessment is updated every 5 years.

Grassland and vegetation carbon stock

For the calculation of the LUC dataset results, grassland carbon stocks of IPCC are used. For crops, values are obtained from the European Commission. The vegetation carbon stock for annual crops is taken to be 0 tonne C/ha, for perennials this value depends on the climate type.

Table 10. Table 2b, Grassland: IPCC 2006 Guidelines (no refinements in IPCC 2019 refinements), Volume 6, Table 6.4. All values in tonne C/ha, converted to carbon based on 47% carbon content of dry matter biomass (see for example section 6.2.1.4 of IPCC 2006).

Continent	Boreal grassland	Cold temperate dry grassland	Cold temperate wet grassland	Warm temperate dry grassland	Warm temperate wet grassland	Tropical dry grassland	Tropical moist & wet grassland
Africa	4,0	3,1	6,4	2,9	6,3	4,1	7,6
Asia (continental)	4,0	3,1	6,4	2,9	6,3	4,1	7,6
Asia (insular)	4,0	3,1	6,4	2,9	6,3	4,1	7,6
Europe	4,0	3,1	6,4	2,9	6,3	4,1	7,6
North America	4,0	3,1	6,4	2,9	6,3	4,1	7,6
New Zealand	4,0	3,1	6,4	2,9	6,3	4,1	7,6
South America	4,0	3,1	6,4	2,9	6,3	4,1	7,6
Average	**4,0**	**3,1**	**6,4**	**2,9**	**6,3**	**4,1**	**7,6**

Table 11. Table 2c, Crops: Cveg croplands, based on Table 11 of the European Commission decision. All values in tonne C/ha.

Continent	Perennial cropland (Temperate)	Perennial cropland (Tropical, dry)	Perennial cropland (Tropical, moist)	Perennial cropland (Tropical, wet)	Annual cropland
Africa	43,2	6,2	14,4	34,3	0,0
Asia (continental)	43,2	6,2	14,4	34,3	0,0
Asia (insular)	43,2	6,2	14,4	34,3	0,0
Europe	43,2	6,2	14,4	34,3	0,0
North America	43,2	6,2	14,4	34,3	0,0
New Zealand	43,2	6,2	14,4	34,3	0,0
South America	43,2	6,2	14,4	34,3	0,0
Average	**43,2**	**6,2**	**14,4**	**34,3**	**0,0**

Natural carbon stock for carbon opportunity cost calculation

Reference state calculated by Blonk using the country average of overlaying country borders on top of data from (Searchinger et al., 2018) supplementary material: Extended Data Fig. 3 and 4.

4. Results

4.1 Definitions

Weighted average, normal average and worst case

Definitions of the three results are provided below:

- **Weighted average**: conversions of forestland to cropland and grassland to cropland and conversions between annual and perennial cropland are based on statistics of expansion/contraction of forestland, grassland and annual/perennial cropland. This is the methodology as described in chapter 2 of this document. The exact calculation method is described in the PAS 2050-1:2012 (horticulture), in section 5.2.3.3 “Assessment of average GHG emissions from land use change when the previous land use is not Known”.
- **Normal average**: conversion of forestland to cropland and grassland to cropland and conversions between annual and perennial cropland are all set to 1/3rd of the converted area. This means that a normal average of the emissions related to each of the three types of conversions is taken. This is also described in the PAS 2050.
- **Worst case** is the highest of the two above. It is prescribed by the PAS 2050 to take the highest of these two calculation methods.

Additional (intermediate) parameters

In the datasets where equal amortization is applied, additional parameters are provided. These parameters provide the user with insights into the main intermediate calculation parameters for the emissions from land use change, the additional parameters can also be used as an input for other calculations or other applications. The parameters which are included, in addition to the normal average and weighted average emissions from land use change, are the following:

- Crop expansion (%): Percentage of current harvested area of the crop under study which was not in use for cultivation of this crop 20 years ago.
- Expansion at expense of forest to analyzed crop (%): Percentage of current harvested area of the crop under study, which was forest 20 years ago.
- Expansion at expense of grassland to analyzed crop (%): Percentage of current harvested area of the crop under study, which was grassland 20 years ago.
- Expansion at expense of managed grassland (%): Percentage of current harvested area of the crop under study, which was managed grassland 20 years ago.
- Expansion at expense of perennials to analyzed crop (%): Percentage of current harvested area of the crop under study, which was perennial cropland 20 years ago.
- Expansion at expense of annuals to analyzed crop (%): Percentage of current harvested area of the crop under study, which was annual cropland 20 years ago.
- Emissions from conversion of forest (tonne CO2 eq per hectare): Emissions related to the conversion of a hectare forest to the type of cropland under study (annual or perennial), for the selected country.
- Emissions from conversion of grassland (tonne CO2 eq per hectare): Emissions related to the conversion of a hectare grassland to the type of cropland under study (annual or perennial), for the selected country.
- Emissions from conversion of perennials (tonne CO2 eq per hectare): Emissions related to the conversion of a hectare perennial cropland to the type of cropland under study (annual or perennial), for the selected country.
- Emissions from conversion of annuals (tonne CO2 eq per hectare): Emissions related to the conversion of a hectare annual cropland to the type of cropland under study (annual or perennial), for the selected country.
- Land occupation index (yr/harvest): (average) length of the harvest cycle of temporary crops (in yr/harvest).

- Managed grassland data available: TRUE means managed grassland was included in the LUC results or FALSE means no managed grassland was included in the assessment.

4.2 Land occupation

Implementation of the Land Occupation index

With increasing global food demand, land use efficiency gains are part of the solution to halt deforestation and other natural land conversions for agricultural land. Multiple cropping is a practice, where a plot of land is subsequently planted with varying crops and harvested multiple times in a year. This practice is increasingly applied worldwide, contributing to increasing harvested areas without demanding additional agricultural land. Sometimes multiple crops are grown at the same time on a field; called intercropping. The most common goal of intercropping is to increase the yield of a cropland, for example by growing crops next to the trees in an orchard. However, in the Land Use Change (LUC) methodology the multiple cropping scenarios have not been considered before 2024 version, leading to inaccurate LUC emission calculations, especially for areas in the world where multiple cropping practices are often applied. Therefore, we've investigated the opportunities to include multiple cropping and make more fair calculations, by including consideration of 'Land Occupation'. In this article we'd like to take a moment to explain the proposed methodology and the implementation for the latest LUC Impact Dataset (2024 onward).

Multiple cropping and LUC emissions
Currently there is no uniform guideline on how to account for multiple cropping in LUC methodologies. Within Life Cycle Assessment (LCA) studies it is often required to report the emissions emerging from LUC, such as the clearance of forests to cultivate crops, separately. Blonk's LUC Impact tool is a web-based solution, supporting the calculation of direct and statistical LUC emissions. It also provides the LUC emission inputs for Lifecycle Inventory databases, such Agri-footprint and GFLI. However, multiple cropping activities have previously not been considered in the implemented methodology (before 2024). The assumption that the occupation duration for a harvest of temporary crops is always 1 year, led to an overestimation of both the LUC emissions and the land occupation impact, especially in countries where multiple cropping practices are ubiquitous. Multiple cropping primarily occurs in tropical and subtropical regions where there is a sufficient long rainy season or suitable irrigation to cultivate two or three crops sequentially within a single agricultural year. An example is a crop rotation system of planting soybeans during the summer months, harvesting the crops in late summer or early fall, and planting maize in the same field after and harvesting this in early spring.

Implementation of Land Occupation
To represent multiple cropping practices more accurately in LUC and land occupation calculations, we propose the account for the 'Land Occupation' (LO). What we are calculating with the Land Occupation, is the (average) length of the harvest cycle of temporary crops (in yr/harvest). The index considers both land efficiency gains from multiple cropping, and optionally efficiency losses due to temporary fallow land.

Calculating the Land Occupation

There are two components that define the actual land occupation to harvest one hectare (the functional unit). Land occupation is calculated with the equation below:

$$Land\ occupation\ (ha * year) = \frac{Fallow\ land\ index\ (-)}{Cropping\ frequency\ (year^{-1})} * 1ha$$

Where:

- *Fallow land index*: Accounts for the rest periods allocated to temporary cropland cycles. This parameter is optional in the LUC impact tool, and could be excluded (set to 1 by default).
- *Cropping frequency* (year -1): Measures how often a physical area is harvested per year.

Cropping frequency is defined as how many harvests are taking place on a physical hectare of cropland in one year. E.g. if in one year on one hectare first soybeans are grown and later wheat, the cropping frequency of that hectare is 2. Which would result in a cropping frequency of 2 (year-1) for both the soybean and the wheat. Intercropping also results in a higher cropping frequency. For example, if in between one hectare of an olive orchard also some legumes are grown, there are also 2 hectares of harvest within one physical hectare, leading to a cropping frequency of 2.

$$Cropping\ Frequency\ [yr^{-1}] = \frac{Harvested\ area\ [ha/yr]}{Physical\ cropland\ area\ [ha]}$$

To calculate the cropping frequency of a crop in a country, the Spatial Production Allocation Model (MAPSPAM) was used (Cao et al., 2026). MAPSPAM reports both the physical area and the harvested area of crops within a country. Because the crops are reported individually, it is now possible to create a cropping frequency that is crop & country specific. MAPSPAM indicates it is sometimes limited to information about multi-cropping. For crops where multi-cropping is not clearly reported, it often simply falls back to a cropping frequency of 1.

Optionally, it is possible to also include fallow land. As fallow land is associated with crop rotation and multiple cropping, it is allocated to all Temporary Cropland. This is expressed in the Fallow Land Index (FI). The optionality of it is provided by a toggle in the tool that allows for Land Occupation with or without consideration of fallow land.

$$Fallow\ land\ Index\ (FI)[-] = \frac{Temporary\ Fallow\ Land\ [ha * yr]}{Temporary\ Cropland\ [ha * yr]}$$

The values used to calculate the fallow land index were derived from land use data as reported by the FAO (FAO, 2026e). Currently only one value for fallow land is reported per country, meaning that this average value represents the fallow land index for all temporary crops in that country. In some countries, high amounts of fallow land are reported in FAO. Based on expert judgement, a maximum limit on the Fallow land index was established on 1.33. This would represent a system where one hectare of land is harvested for three years and then put to rest for one year. For permanent crops the Fallow Land index is 1, as that hectare is never put to rest. To determine if a crop is temporary or permanent the FAO definitions are used:

Possible results:

- LO < 1: Multiple cropping is the case, more than one crop is produced and harvested per year, per hectare.
- CSEI = 1: There is no multiple cropping, or the efficiency gains from multiple cropping are counteracted by efficiency losses from fallow land.
- LO > 1: Per hectare harvested, more than 1 hectare should be destined to this process, due to fallow land. If fallow land is excluded from the calculation it should not be possible to have a LO > 1.

Separate box: Definitions & Concepts

Temporary Fallow Land: Land that is not seeded for one or more growing seasons. The maximum idle period is usually less than 5 years. Land is also considered as 'temporary fallow' if it is sown for the exclusive production of green manure. Land remaining fallow for too long may acquire characteristics requiring it to be reclassified, as for instance "Permanent meadows and pastures" if used for grazing or haying.

Harvested area of temporary crops: Surface of crops harvested with a productive period < 5 years between seedling and the final harvesting of the crop. This category includes both annual and perennial crops, like Maize and Banana.

Application of the Land Occupation

One key step is to determine in which cases the Land Occupation improves the results, and in which cases the use of the index is unsuitable. The LO should affect only the environmental impact linked to a proportion of time that the land is occupied by a harvested crop. An example is emissions linked to Land Use Change: if there are 2 crops produced in a year per hectare, the amount of LUC emissions will be split by 2 (50 % for each crop). Within Blonk we apply the LO in various models, such as Land Use Change, Peat, Land Occupation, Carbon Sequestration and Land Transformation.

Calculation approach and interpretation

a. Calculation of crop expansion of crop under study
    i. Multiply previous land area of crop with LO related to previous year.
    ii. Multiply current land area of crop with LO related to current year.
    iii. Calculate expansion of crop in selected country based on LO corrected areas.
b. Calculation of overall cropland expansion and contraction
    i. For each crop in the list of crops, the LO corrected previous and current area is determined (following steps above). The total sum of expansions and contractions of annual cropland and perennial cropland is computed based on the LO corrected areas.
c. Interpretation of results
    i. LUC Emissions: kg CO2eq./ha*yr
    ii. Transformations (per previous and current land use type): m2/ha*yr
    iii. LO of current year (average of nr of years as defined in input, default 3 years): ha*yr
d. As part of crop inventory
    i. LUC emissions from LUC Impact dataset are reported as [kg CO2eq./ha*yr] and should be multiplied with the LO [ha*yr] to obtain the emissions and transformation impact related to the harvest.
    ii. Land occupation related to the harvest is equal to the LO [ha*yr].

Difference between 2024 and 2026 versions

In 2024 LUC impact tool, the Land Occupation was called differently, and it was referred to as Crop System Efficacy Index (CSEI). The way of calculating the factor did not change, but it was renamed for clarity.

A major update was related to the background data used to calculate the LO: in 2024 the Cropping Frequency was calculated fully with FAOstat data, and was a country-specific but crop-generic index. In 2026, the use of GIS spatial data allows the calculation of a crop-country-specific factor.

Furthermore, in 2026 a limit on the Fallow land index was established on 1.33 (in 2024 there was no limit considered).

4.3 Implementation of Managed grassland LUC emissions calculation

Prerequisites for calculation:

- Availability of ‘Temporary grassland’ data in FAOstat ‘Land Use’ dataset.

- Availability of ‘Permanent grassland – cultivated’ (or similar: slightly different naming in different FAO versions) data in FAOstat ‘Land Use’ dataset.
- Availability of ‘Permanent grassland – naturally growing’ (or similar: slightly different naming in different FAO versions) data in FAOstat ‘Land Use’ dataset.

If this data is not available, the tool will not be able to provide results for managed grassland, and will not consider managed grassland as a separate category (left situation in the figure below). If the data is available, results for managed grassland can be provided, and managed grassland is considered as a separate land use category for the LUC calculation of any crop (right situation in the figure below).

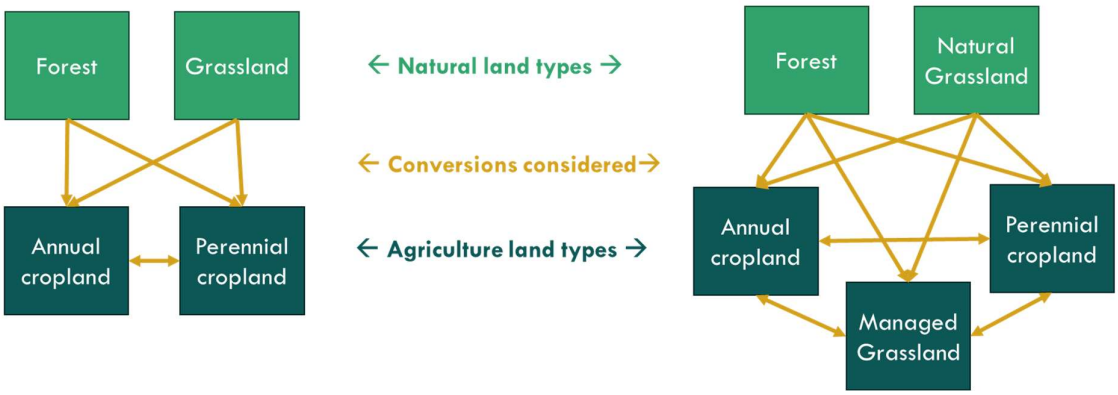


Figure 1. Graphical representation of managed grassland inclusion.

Calculation steps

If data is available, the calculation for ‘country known, previous land use unknown’ is adjusted as follows:

- The previous and current area of ‘Managed grassland’ are determined based on the sum of ‘Temporary grassland’ data in FAOstat ‘Land Use’ dataset & ‘Permanent grassland – cultivated’ (or similar: slightly different naming in different FAO versions) data in FAOstat ‘Land Use’ dataset.
    - This data is directly used to determine the expansion rate of ‘Managed grassland’, if this is the crop under study.
    - The ‘Managed grassland’ area is considered part of the ‘Total agricultural land area’, which is used in the first step of the conversion calculation to determine whether expansion of a crop happens at the expense of natural land, or other agricultural land.
    - The ‘Managed grassland’ area is considered a separate category of agricultural land area, which means that conversions from ‘Managed grassland’ to the selected crop are calculated and reported.
- The previous and current area of ‘Natural grassland’ is derived from ‘Permanent grassland – naturally growing’ (or similar: slightly different naming in different FAO versions) data in FAOstat ‘Land Use’ dataset.
    - The ‘Natural grassland’ area is considered part of the ‘Total natural land area’, and replaces the ‘Grassland’ area as used in the calculation when data is not available (default methodology before 2024).
- In the quantification of emissions from conversions to- and from managed grassland and natural grassland, the carbon stock of both soil and vegetation are considered equal for managed and natural grassland. This is a limitation which may be refined in upcoming updates of the LUC tool and dataset. *If both items which are considered in the ‘Managed grassland’ category (temporary grassland and cultivated permanent grassland) would be kept separate, it would be possible to assign a different carbon stock to the temporary grassland area compared to the cultivated permanent area.*

4.4 Crop expansion update for linear calculation

Crop expansion according to PAS 2050 (BSI, 2012) has been calculated in previous version of the LUC tool as:

$$Crop\ expansion\ [\%] = \frac{Current\ area\ [ha * yr]\ -\ previous\ area\ [ha * yr]}{Current\ area\ [ha * yr]}$$

This is logical for a 20-years single calculation, where the current year is e.g., 2020 and the previous year is e.g., 2020 - 20 = 2000.

On the other hand, for year-by-year calculation, such an approach is fallacious, and can result in crop expansions that are higher than 100% even though there has been no shrinking in land for the specific crop under study. Below an example for Palm Oil in Indonesia:

Table 13. Example of the new year-by-year crop expansion calculation using Palm oil in Indonesia (relevant for linear amortization).

Year	Palm oil harvested area in Indonesia (PO_ha)	3 years average of harvested area (PO_3ha)	Absolute expansion (E_ha = PO_3ha_current_year - PO_3ha_previous_year)	Crop expansion OLD (CE_old_% = E_ha/ PO_3ha_current_year)	Crop expansion NEW (CE_new_% = E_ha/ PO_3ha_reference_year)
1999	1847000				
2000	2014000				
2001	2200000	2020333			
2002	2790000	2334667	314333	13%	2%
2003	3040000	2676667	342000	13%	3%
2004	3320000	3050000	373333	12%	3%
2005	3690000	3350000	300000	9%	2%
2006	4110000	3706667	356667	10%	3%
2007	4560000	4120000	413333	10%	3%
2008	4980000	4550000	430000	9%	3%
2009	5000000	4846667	296667	6%	2%
2010	5780000	5253333	406667	8%	3%
2011	6170000	5650000	396667	7%	3%
2012	6650000	6200000	550000	9%	4%
2013	7720000	6846667	646667	9%	5%
2014	8150000	7506667	660000	9%	5%
2015	8650000	8173333	666667	8%	5%
2016	9720000	8840000	666667	8%	5%
2017	11000000	9790000	950000	10%	7%
2018	12200000	10973333	1183333	11%	9%
2019	12880000	12026667	1053333	9%	8%
2020	13250000	12776667	750000	6%	6%
2021	13670000	13266667	490000	4%	4%
20-years				**179%**	**85%**

As an example, we could analyze the crop expansion reported for year 2007:

The 3-years average of harvested hectares of palm oil in Indonesia is 13.27 million hectares in 2021 (average of 2019-2021) and 4.12 million in 2007. In 2007 the area expanded by 0.41 million hectares in one year (difference between 3-years average harvested area of 2007 and 2006).

- The old approach was dividing 0.41 by 4.12, calculating a 10% crop expansion.
- The new approach is dividing 0.41 by 13.27, calculating a 3% crop expansion.

Summing the 20 years expansions results in a crop expansion of 85% in the new approach, meaning that 85% of current area is related to expansion, while the remaining 15% was already dedicated to

palm oil cultivation 20 years ago. The old approach sums a 179% overall crop expansion that is illogical (considering there are no fluctuations in harvested area) and ultimately wrong (overestimating the results).

It is important to realize that:

1. The change in approach only matters for linear amortization (and equal every year), and not for equal amortization (single year), where a single calculator is applied.
2. The example presented shows how due to continuous crop expansion the old approach was overestimating the crop expansion, and therefore the final results. On the other hand, if a crop had an expansion in the past 20 years (e.g., Linseed in Belgium in figure below), but then declined to a lower harvested area (harvested area fluctuations), the old approach was underestimating the crop expansion. In the latter case it would be possible to have a crop expansion that is higher than 100%.
3. Historically, the issue in the old way of approaching crop expansion was related to fitting a yearly calculation (as prescribed by LSRS/LSRG) to a crop expansion-based modelling (as prescribed by PAS 2050-2012). The new approach is better aligned with LSRG guidance, where the 20-years total emissions (for the harvested hectares of the crop under considerations) are summed considering linear amortization, and then divided by the reference year total production. Still, moving from a crop expansion approach to a gross country emissions approach would be advisable for the future to fully align with LSRG calculation flow.

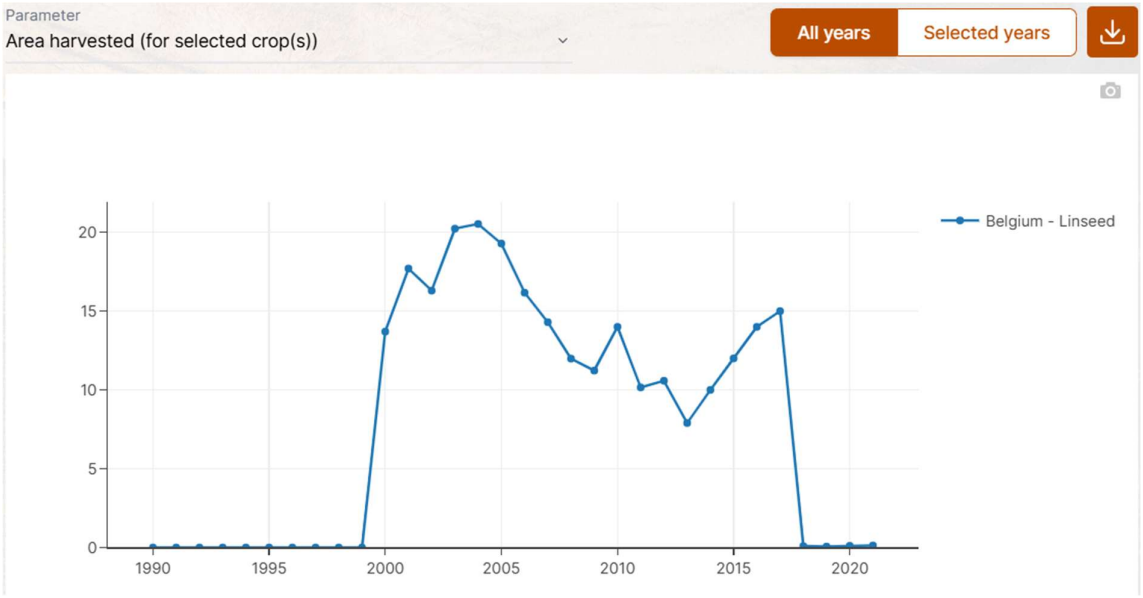


Figure 2. Data for area harvested of Linseed in Belgium.

4.5 Drivers for change compared to previous version

General drivers for change

When interpreting the data (differences), it is important to realize where (changes in) sLUC emissions originate from. The changes in direct land use change emissions compared to previous years for a crop-country combination are mainly driven by three questions:

- *Did the total forest area in a country contract over the last 20 years?*
  Conversion from forest area to cropland results in the largest loss of carbon stock, compared to conversion from grassland or changes between annual and perennial croplands. Therefore, if the total forest area in a country did not reduce compared to 20 years ago, the emissions factors due to direct land use change will generally be low.

- *Did the total area for crop cultivation increase in a country?*
  If there is no increase in the total area used for crop cultivation, according to the PAS-2050-1, it can be assumed that no contractions of forest or grass land are caused by an increase of cropland. Therefore, the emissions factors for that country will generally be low.
- *Did the total area harvested for the crop under investigation expand?*
  If the area harvested for a crop under investigation did not increase over the last 20 years, there is no land use change. If there is an increase, the emissions due to land use change will be mainly driven by the factors mentioned above. For crops that are rapidly expanding, this can result in large changes in emissions factors between the chosen 20 year interval.

Other drivers for change

- The Land Occupation calculation is now based on GIS spatially explicit data instead of FAOstat data. In particular, the index is not crop—country-specific (while before crop-generic).
- Changes due to historic data for harvested area on some crops and countries combinations in the new FAO download (February 2026).
- Now, by default off-setting of emissions by considering removals (negative emissions due to carbon stock increase) is not considered. This generally results in an increase for orchard and managed grassland land categories.

The consideration of Land Occupation (introduced in 2024, updated in 2026)

The table below illustrates the LO results over the years for Soybean in Brazil, Soybean in Argentina, Wheat the Netherlands and Wheat in China. It can be observed, from 2001 to 2021, a decrease in the LO of approximately 15% for Soy in Brazil, 17% for Soy in Argentina and 9% for Wheat in China. Insignificant variances are noted for Wheat in the Netherlands. This indicates that there was an increase in crop efficiency for Brazil, Argentina and China for the relevant crops. Consequently, crop expansion will decrease with subsequent lower overall LUC emissions.

Table 14. Land Occupation (LO) over the last 20 years (2001-2021) for Wheat cultivated in Brazil, Argentina, Netherlands and China.

Year	LO Soy in Brazil	LO Soy in Argentina	LO Wheat in the Netherlands	LO Wheat in China
2001	1.28	1.12	1.03	0.81
2002	1.27	1.12	1.03	0.80
2003	1.27	1.10	1.03	0.80
2004	1.26	1.07	1.03	0.79
2005	1.25	1.03	1.03	0.79
2006	1.25	1.01	1.03	0.78
2007	1.24	0.99	1.03	0.78
2008	1.23	0.99	1.02	0.78
2009	1.22	1.00	1.01	0.77
2010	1.22	1.00	1.01	0.77
2011	1.20	1.00	1.01	0.77
2012	1.19	0.99	1.01	0.77
2013	1.18	0.99	1.01	0.76
2014	1.17	0.98	1.01	0.76
2015	1.16	0.98	1.01	0.76
2016	1.15	0.97	1.01	0.75
2017	1.14	0.97	1.01	0.75
2018	1.14	0.96	1.01	0.75
2019	1.13	0.96	1.01	0.75
2020	1.12	0.96	1.01	0.74
2021	1.11	0.96	1.01	0.74

It should also be noted that the presented wheat-specific LOs differ from the crop-generic LO used in the previous version (2024).

- Brazil LO when using FAOstat data is generically moving from 0.88 (in 2001) to 0.67 (in 2021). This is a 32% reduction, that is representative of the overall Brazil Land Occupation, but not of the soy specific LO in Brazil (calculated as a 15% reduction in LUC impact tool 2026).
- Argentina LO with FAOstat data was calculated at 0.96 (in 2001) and 1.03 (in 2021) in LUC impact tool 2024. This is an overall increase of 6%, that largely differ from the Argentinian soy-specific 17% reduction in LO in the 2026 latest version of the tool.
- Chinese LO with FAOstat data was calculated at 0.71 (in 2001) and 0.60 (in 2021) in LUC impact tool 2024. This is an overall reduction of 18%, that largely differ from the Chinese wheat-specific 9% reduction in LO in the 2026 latest version of the tool.
- The Netherlands does not see major difference between the 2024 and 2026 LO update.

The consideration of managed grassland (introduced in 2024)

For some countries, the consideration of managed grassland as a separate land use category has a major effect on the LUC emission results of all crops. This has to do with the sensitivity of the calculation method to contractions and expansions in land use categories: If a vast contraction in a land use category is observed, the method dictates that most of the expansion of a certain crop will probably be due to contraction of this land use category. Expansion of managed grassland and contraction of natural grassland in the same country was previously not observed as both grassland types are considered together in the general ‘grassland’ category. With the differentiation between the two types, the contraction of natural grassland becomes apparent.

For example: In Brazil, the total grassland area is not contacting considerably, while forest area shows a decline. Previously, crop expansions would mainly be considered to go at the expense of forest area. With the differentiation between natural and managed grassland, it becomes apparent that natural grassland is contracting considerably. Considering the differentiation, crop expansions would mainly be considered to go at the expense of natural grassland. While the conversion of any kind of natural land use are undesired, the carbon losses for the conversion of grassland are lower compared to the conversion of forest. For this reason, the differentiation in grassland types considerably lowers the LUC emissions of all crops in Brazil.

In the previous version, we classified total grassland as 'Permanent meadows and pastures,' resulting in very insignificant transformations from grassland for countries like Brazil (see Figure 3 below). Now that the distinction between managed (the sum of permanent meadows & pastures – cultivated and temporary meadows and pastures) and natural grassland (permanent meadows & pastures – natural growing) is available for Brazil (See figure 3), it can be observed that natural grassland area has decreased over the last 20 years, consequently resulting in lower transformations from forest and higher transformations from natural grassland compared to the previous version. Conversely, in the Netherlands, the opposite trend has occurred, with transformations from managed grassland now higher and natural grassland area being increasing over time (See Figure 4 below).

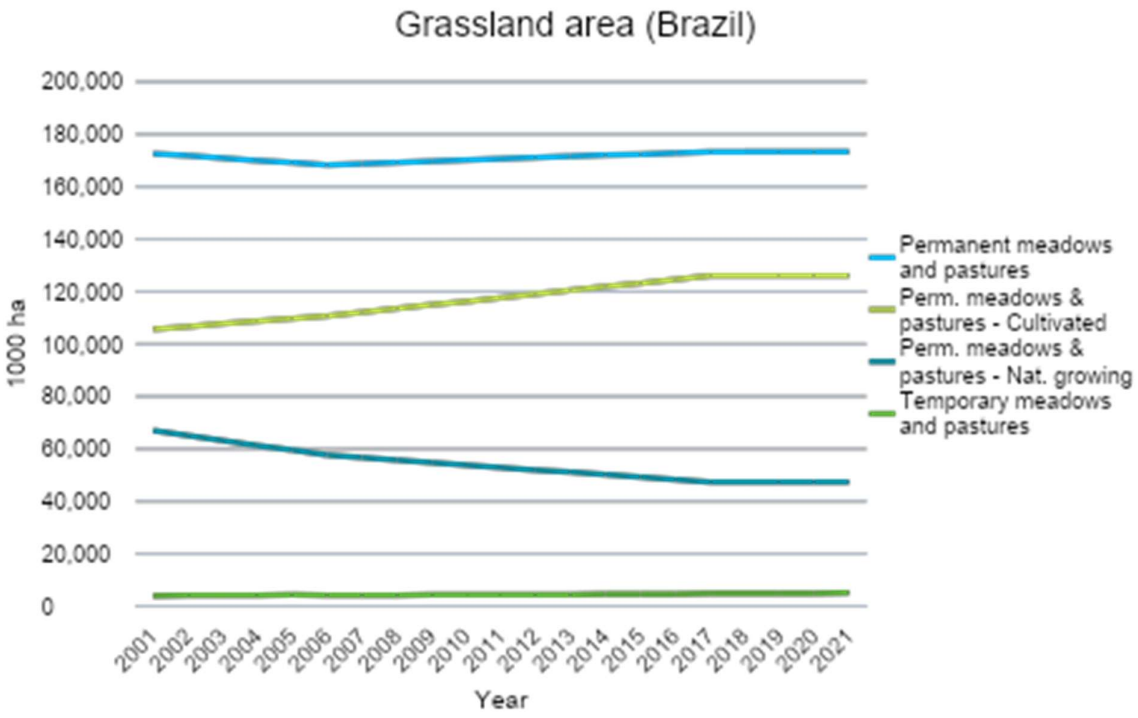


Figure 3. Grassland area over the last 20 years (2001-2021) in Brazil.

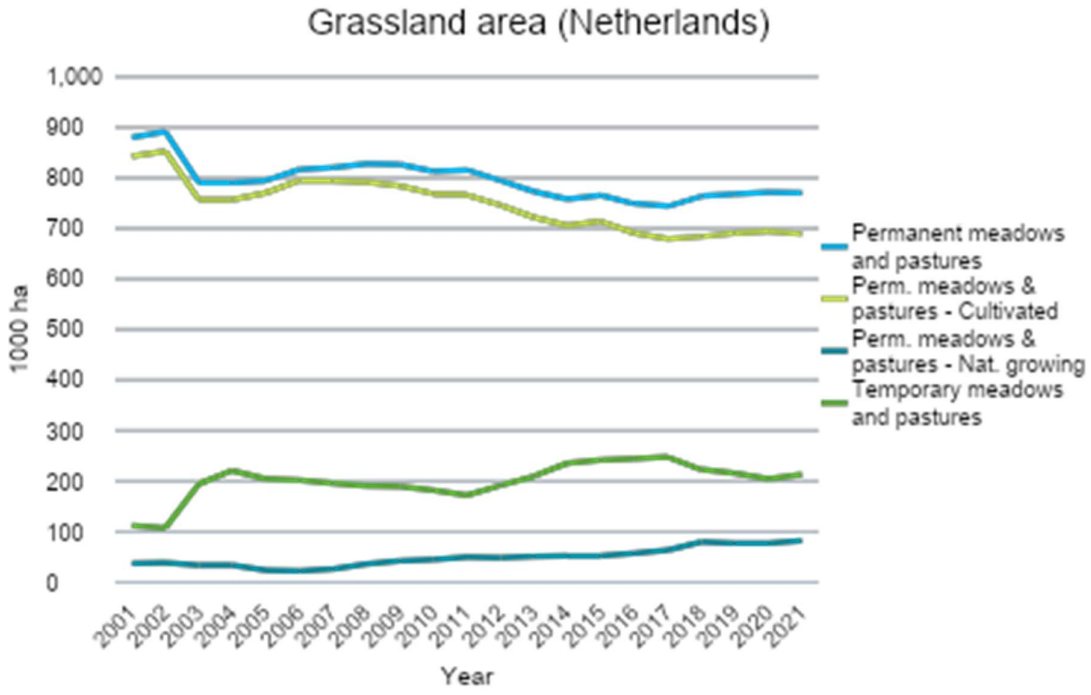


Figure 4. Grassland area over the last 20 years (2001-2021) in the Netherlands.

The consideration of updated crop expansion for linear amortization (introduced in 2026)

As presented (with examples) in chapter 4.4, the update in the way crop expansion is calculated can result in relevant reductions or increases in the final reported emissions. This is only relevant for linear amortization.

The default exclusion of removals (introduced in 2026)

This change is only relevant for perennials, Jojoba seed, rice paddy, sugar cane and for managed grassland.

Land transformation can sometimes result in carbon stock increase related to a positive difference between the previous and new land use (residuals). Representative main examples are:

- Transformation from annual to perennial
- Transformation from annual to managed grassland

Such transformations can offset the positive emissions related to other transformations (e.g., from forest to perennial). This is still allowed in the LUC impact tool, but the default option is rather to not allow for negative impact related to residuals. Exclusion of residuals is aligned with LSRS and LSRG standards.

As example we analyzed the linearly amortized LUC 2023 results for:

- **Oil palm in Indonesia:** including residuals (mostly related to the transformation to the expense of annual) completely offset forest-related transformation. Excluding residuals results in an overall footprint of 1.73 ton CO2 eq per ha*yr.
- **Sugar cane in Zimbabwe:** including residuals (mostly related to the transformation to the expense of annual) completely offset forest-related transformation. Excluding residuals results in an overall footprint of 1.06 ton CO2 eq per ha*yr.
- **Coconut in Philippines:** including residuals (mostly related to the transformation to the expense of annual) completely offset forest-related transformation. Excluding residuals results in an overall footprint of 0.31 ton CO2 eq per ha*yr.
- **Tea in Kenya:** including residuals (mostly related to the transformation to the expense of annual) partially offset forest-related transformation and results in an overall footprint of 1.90 ton CO2 eq per ha*yr. Excluding residuals results in an overall footprint of 2.42 ton CO2 eq per ha*yr (+27%).
- **Rice paddy in Bangladesh:** including residuals (mostly related to the transformation to the expense of annual) partially offset forest-related transformation and results in an overall footprint of 0.35 ton CO2 eq per ha*yr. Excluding residuals results in an overall footprint of 0.49 ton CO2 eq per ha*yr (+40%).

Country	Indonesia	Zimbabwe	Philippines	Kenya	Bangladesh
Crop	Oil palm fruit	Sugar cane	Coconuts	Tea	Rice, paddy
Year	2023	2023	2023	2023	2023
Linear emissions excluding residuals (ton CO2)	1.73	1.06	0.31	2.42	0.49
Linear emissions including residuals (ton CO2)	0.00	0.00	0.00	1.90	0.35
Expansion at expense of forest (%)	17.97	9.44	6.97	13.08	27.34
Expansion at expense of grassland (%)	3.8	0.0	0.0	0.0	0.0
Expansion at expense of perennials (%)	8.4	0.4	0.8	2.7	1.3
Expansion at expense of annuals (%)	27.9	51.4	3.2	25.2	6.9
Expansion at expense of managed grassland (%)	0.0	0.0	0.0	0.0	0.0

Emissions from conversion of forest (ton COW)	172	208	204	420	96
Emissions from conversion of grassland (ton CO2)	-194	4	-249	-12	-43
Emissions from conversion of perennials (ton CO2)	-104	21	-164	0	27
Emissions from conversion of annuals (ton CO2)	-255	-39	-308	-43	-105

5. Tips for use of LUC Impact tool

Some notes from the developers of the LUC tool, which might help the user to make optimal use of the tool.

- Click the results to view the details, intermediate calculated parameters are displayed here. Click the small triangles behind general descriptions to expand the details further.
- Use the ‘Download the results as Excel’ button on the right top of the results screen, to download all input parameters, results and intermediate parameters in a clear MS Excel document.
- When using the ‘Previous Land use Unknown, Country Known’ functionality, click the ‘Time series’ tab to view a graphic representation of data used in the calculation. This might provide insight to explain the results.
- Keyboard shortcuts also function in the LUC Impact Tool. Shortcuts which can help are:
    - Shift + click to select ranges: When aiming to select a range of years in the input parameters, click the first year of the range in the dropdown list, hold Shift, and press the last year in the dropdown list to select all intermediate years.
    - Shift + click to open in new browser tab: Hold Shift when clicking ‘Methodology & data’ to open this section in a new tab. This way, you can keep using the tool while looking up information.

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