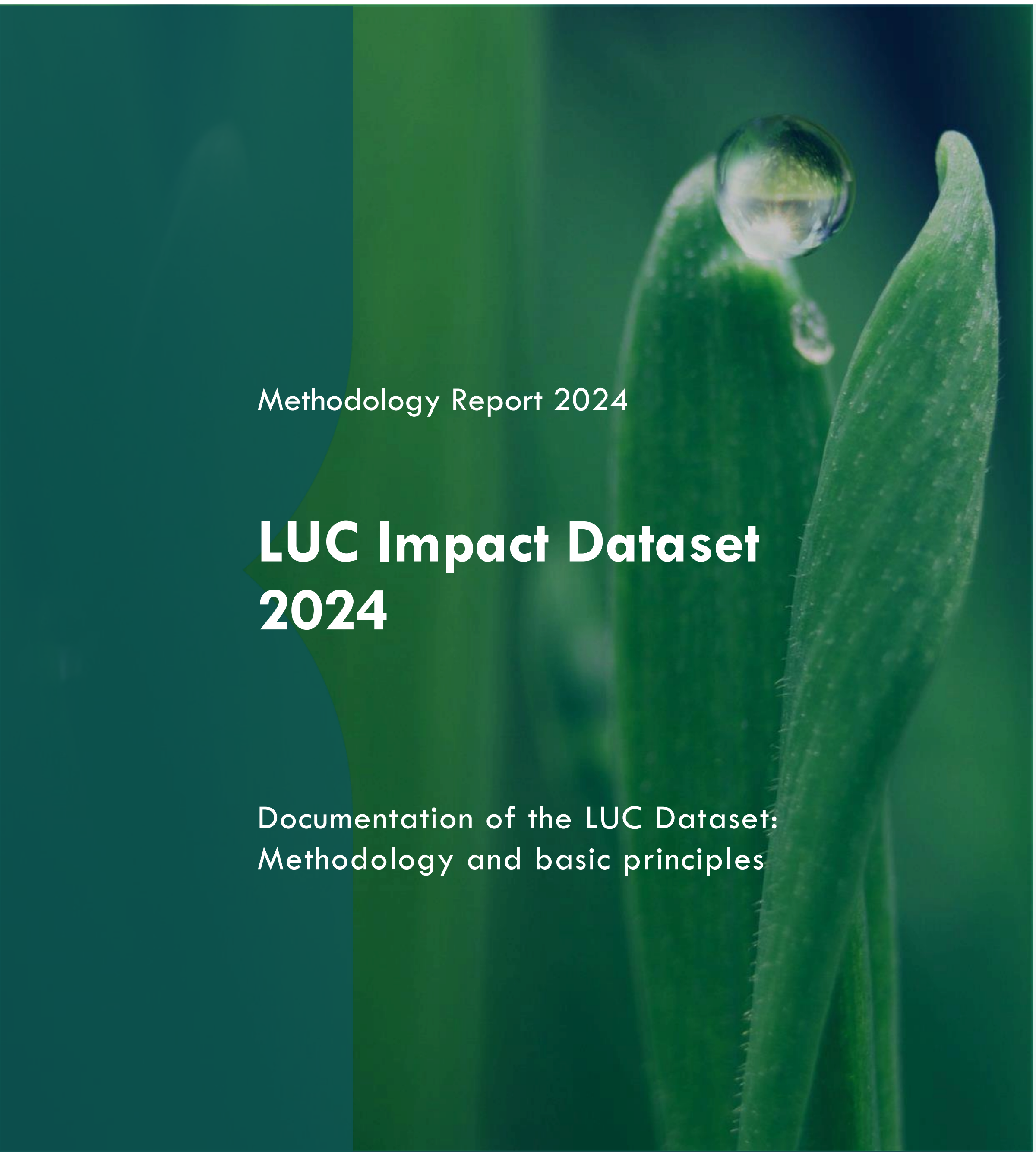

Methodology Report 2024

LUC Impact Dataset 2024

Documentation of the LUC Dataset: Methodology and basic principles

Blonk CONSULTANTS

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About us

Blonk, a Mérieux NutriSciences Company, is a leading international expert in food system sustainability, inspiring and enabling the agri-food sector to give shape to sustainability. Blonk's purpose is to create a sustainable and healthy planet for current and future generations. We support organizations in understanding their environmental impact in the agri-food value chain by offering advice and developing tailored software tools based on the latest scientific developments and data.

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Table of contents

1. Introduction

Through this document we share the methodology and data sources used to calculate land use change (LUC) emissions presented in the 2024 LUC Impact dataset.

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Deforestation is one of the major issues caused by the global agriculture production system. About 5–14% of the global greenhouse gas (GHG) emissions are attributable to land use and land-use change due to the global food system (LULUC) (IPCC, 2019). Many 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 big challenge for practitioners of Life Cycle Assessments (LCA) is to translate this impact of land use change to specific crops from specific countries when little primary data is available. 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 and other professionals or academics.

2. Calculation methodology

New in 2024: Results with managed grassland and crop system efficiency index (CSEI)

Starting from 2024, there are two versions of the dLUC dataset: 1) one resulting from calculations with managed grassland using equal and linear amortization, and 2) another resulting dataset without managed grassland, also using equal and linear amortization.

The selection of these parameters is driven by the availability of data on managed grassland area, which is accessible for only certain countries in FAO statistics. Managed grassland area has been available for select countries in FAO statistics since 2001.

Equal or linear amortization in the dLUC emission calculation is related to the guideline that the user wishes to comply to: 1) the PAS2050-1 (and thus the European Commission's PEF guidance) prescribes the use of equal amortization; and 2) 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.

2.1 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.

A summary of the procedure to calculate emissions from dLUC when country of cultivation is known and the previous land use is unknown, is provided below. 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".

1. Expansion and contraction of forest and grassland per country (as defined in PAS 2050) are based on FAO land occupation change in 20 years.
2. Expansion and contraction of specific crop is based on FAO harvested area change in 20 years. 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. Based on worldwide climate and soil types provided by IPCC (2006), climate zone and soil types are selected which are representable for the country. With this, carbon stock can be calculated. For forest land, specific biomass is obtained per country from the Global forest resources assessment 2020. For grassland, biomass is derived from continent and climate condition (based on European commission data and IPCC values). 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.
5. Change in carbon stock between previous and current land use is multiplied with 44/12 to obtain kg CO_2. This is divided equally over 20 years (multiplied with 1/20).
6. The crop yield is derived from FAOSTAT and determines impact per kg of product.

2.2 Linear amortization

For the calculation of dLUC emissions through linear amortization, the exact same steps are taken 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 (difference 2019-2021 compared to 2018-2020) will be multiplied by the highest percentage, and the results found for the most historic years (difference 1998-2000 compared to 1999-2001) is 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)).

2.3 Compliance to standards

The compliance to different standards is transparently summarized in the table below.

	FLAG	Compliance	Draft GHG protocol	Compliance	PAS 2050	Compliance
Amortization period	20 years	Fully compliant	20 years	Fully compliant	20 years	Fully compliant
Amortization method	Linear discounting	Fully compliant	Linear or equal discounting	Fully compliant	Equal allocation	Fully compliant
Approach	Shared responsibility or Product specific	Compliant (only product specific implemented)	Shared responsibility and/or Product specific	Compliant (only product specific implemented)	Product specific	Fully compliant

Separately report GHG	Not mentioned	N.A	Should be separately reported	Fully compliant	Not mentioned	N.A
Emissions from biomass burning	Not mentioned	N.A	Should be included	Not included; not compliant	Not mentioned	N.A
Emissions from peatland drainage	Not mentioned	N.A	Should be included	Not included; not compliant	Not mentioned	N.A

2.4 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 2024 dataset are summarized in the table below.

Methodological aspect	Methodology in 2024 dataset	Considerations
Soil nitrogen mineralization, related to soil carbon losses	Included, characterized using IPCC AR5 GWP 100 factors (incl. climate carbon feedback): 298 kg CO_2eq./kg N_2O.	In 2024 version of tool, it is possible to select other GWP factors for characterization of N_2O.
Emissions from peat oxidation and mineralization	Not included. The tool is applicable for mineral soils only.	No direct plans to include in 2024 version of tool or dataset.
Emissions from biomass burning	Not included.	Due to limited data availability, no plan to include in 2024 tool and dataset.
Crop system efficiency index (CSEI)	Included in this new version. We recognize that accounting for multiple cropping and fallow land in our dLUC tool and dataset is required to best represent the land transformation situation in the results.	Included in 2024 dataset and will be included in the tool in April, 2024. In 2024 version of web tool, it will be possible to select data considering with or without CSEI.
Managed grassland	Included in this new version for some countries where data is available.	Included in 2024 dataset and will be included in the tool in April, 2024. In 2024 version of web tool, it will be possible to select data considering with or without managed grassland data.

3. Data sources

The current results are based on the average FAO statistics (harvested area) of 2019-2021 and 1999-2001.

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 2024 and contains data up to and including 2021.

Harvested area

For each crop and country, we use FAO data from “Crops and livestock products”, obtained from FAOstat in end February 2024. The area harvested over the last 20 years is downloaded and contains data up to and including 2021.

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. 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.

Tables are deleted in this version of the methodology description. A full version of this document is available for clients of the LUC impact tool or LUC impact dataset.

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, 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. In specific, values are obtained from C(2010) 3751: COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC, Official Journal of the European Union, L 151/19.

Tables are deleted in this version of the methodology description. A full version of this document is available for clients of the LUC impact tool or LUC impact dataset.

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 parameters

In the datasets, 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 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 managed grassland (%): Percentage of current harvested area of the crop under study, which was managed grassland 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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.
- Crop system efficiency 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 Crop system efficiency index

Implementation of the Crop System Efficiency 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. However, in the Land Use Change (LUC) methodology the multiple cropping scenarios have not been considered yet, 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 applying the 'Crop System Efficiency Index'. In this article we'd like to take a moment to explain the proposed methodology and the implementation for the latest LUC Impact Dataset.

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. 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.

More information regarding the implementation and calculation of the Crop System Efficiency Index can be found here: https://blonksustainability.nl/news/crop-system-efficiency-index

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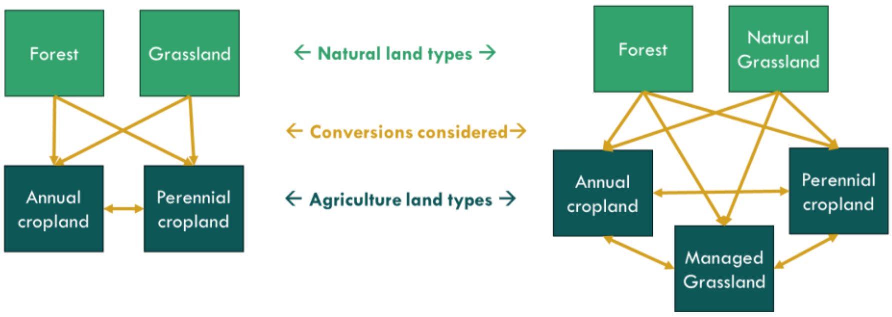
4.3 Implementation of Managed grassland LUC emissions calculation

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.

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).



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 Drivers for change compared to previous version

General drivers for change

When interpreting the data (differences), it is important to realize where (changes in) dLUC 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

- Difference in soil carbon stock from IPCC 2006 (used in previous version) and IPCC 2019 (used in current versions).
- Changes due to historic data for harvested area on some crops and countries combinations in in the new FAO download (February 2024).
- Changes due to the inclusion of managed grassland area and crop system efficiency index (CSEI).

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