LUC impact
a Blonk solution

2023

Documentation LUC Impact Tool

Methodology and basic principles

Blonk
CONSULTANTS

About us

Blonk 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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1. Introduction

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

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Deforestation is one of the major issues caused by the global agriculture production system, with as much as 8% of global CO_2 emissions being attributable to land use change. 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.

Updated dLUC Excel-tool discontinued, web-tool available

We transitioned from the Excel-based tool to a more extensive web-based tool, to provide the user with a reliable, complete, and well-maintained calculation application for different land use change accounting methodologies. In the web-based LUC tool we aim to provide the user with more freedom regarding calculation parameters (such as amortization method and amortization time), facilitate comparison of different results and result calculating following novel methodologies which are recommended in leading LCA and carbon footprint guidelines. As the development of the web-based tool is our priority, the updates of the Excel-based tool are discontinued.

2. Calculation methodology

Four LUC calculation methods are implemented in the LUC Impact tool. Each of the methods is explained in more detail in the following paragraphs.

2.1 Previous Land use Known

In case the country and both the current and the previous land use is known, the carbon stock change of a selected crop is calculated using mainly IPCC defaults.

2.1.1 Calculation steps

1. Based on worldwide climate and soil types provided by EU, 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 (with some exceptions, described in the data sources chapter).

2. Change in carbon stock between previous and current land use is multiplied with 44/12 to convert kg carbon to kg CO_2.

3. Direct N_2O emissions, which occur as a direct results of soil carbon stock losses are calculated following IPCC 2019. 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 emissions accounted for in the assessment year are found by dividing the total emissions by the amortization period (which is 20 years by default). 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 emissions accounted for in the assessment year are found by dividing the total emissions by the amortization period (which is 20 years by default). The conversion year does not influence the results, as long as it is within the amortization time from the assessment year. This method is referred in the draft GHG protocol.

   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 in the draft GHG protocol 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.

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 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.	Select the option that best matches the cultivation system under study.

	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.

2.2   Previous Land use Unknown, Country Known

The calculation is based on country-level statistics of the expansion and contraction of forestland, grassland, annual cropland, and perennial cropland (FAO). The land use change of a selected crop is based on country-level statistics on the relative expansion of the selected crop (FAOSTAT).

2.2.1 Calculation steps

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".

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. 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 EU, 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 (with some exceptions, described in the data sources chapter).

5.   Change in carbon stock between previous and current land use is multiplied with 44/12 to convert kg carbon to kg CO_2.

6.   Direct N_2O emissions, which occur as a direct results of soil carbon stock losses are calculated following IPCC 2019. 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 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	For a conservative approach, negative values are not allowed in the LUC Impact dataset.

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.

2.2.2.1 Amortization method
New in 2022: Results with equal and linear amortization

Starting from 2022 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 (difference 2018-2020 compared to 2017-2019) will be multiplied by the highest percentage, and the results found for the most historic years (difference 1997-1999 compared to 1998-2000) 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)).

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.

	FLAG	Draft 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

2.3 Previous Land use Unknown, Country Unknown

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 3. 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 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.

2.4 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.

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 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	Select the option that best matches the cultivation system under study.

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

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 2022 dataset are summarized in the table below.

Methodological aspect	Methodology in 2022 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 2023 version of tool or dataset.
Emissions from biomass burning	Not included	Plan to include in 2023 tool and dataset.
Double cropping	No correction is made for double cropping. This results in an overestimation of the total harvested area for certain crops in certain countries. In case the total harvested area of crop-country combinations expanded in the last 20 years due to increased implementation of double cropping, the emissions from land use change are overestimated. This situation is, among others, applicable for the cultivation of soybeans in Brazil.	Plan to include in 2023 tool and dataset. (We recognize that accounting for double cropping in our dLUC tool and dataset is required to best represent the land transformation situation in the results. Internal research is ongoing to find a suitable way to account for double cropping correctly and consistently for all crop-country combinations.)
LUC emissions for grazing grassland and mangroves	LUC for grazing grassland 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

3. Data sources

The current results are based on the average FAO statistics (harvested area) of 2018-2020 and 1998-2000.

3.1 Areas

Forest and grassland area

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

- Item: Land under perm. meadows and pastures, FAO item: 6655, FAO element: 5110
- Item: Forest land, FAO item: 6646, FAO element: 5110

Data is downloaded in August 2022 and contains data up to and including 2020.

Harvested area

For each crop and country, we use FAO data from "Crops and livestock products", obtained from FAOstat in August 2022. The area harvested over the last 20 years is downloaded and contains data up to and including 2020.

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 2006 (no refinements in IPCC 2019 refinements) 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 4. FROM IPCC 2006 (NO REFINEMENTS IN IPCC 2019 REFINEMENTS) VOLUME 4, TABLE 2.3. ALL VALUES IN TONNES C/HA IN 0-30 CM DEPTH.

Climate region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
Boreal, dry	68	28,5	10	117	20	146
Boreal, wet	68	74	10	117	20	146
Boreal, moist	68	74	10	117	20	146
Cold temperate, dry	50	33	34	116	20	87
Cold temperate, moist	95	85	71	115	130	87
Cold temperate, wet	95	85	71	115	130	87
Warm temperate, dry	38	24	19	116	70	88
Warm temperate, moist	88	63	34	116	80	88
Warm temperate, wet	88	63	34	116	80	88
Tropical, dry	38	35	31	116	50	86
Tropical, moist	65	47	39	116	70	86
Tropical, wet	44	60	66	116	130	86
Tropical montane	88	63	34	116	80	86

TABLE 5. 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 6. 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 7. 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. 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.

TABLE 8. 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 9. 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**

TABLE 10. DEVIATIONS FROM STANDARD CROP VEGETATION CARBON STOCK. TABLE 12 OF THE EC DECISION.

Climate region	Crop type	Cveg (tonnes C/ha)
All	Coconuts	75
All	Jatropha	17,5
All	Jojoba Seeds	2,4
All	Jojoba seed	2,4
All	Oil palm fruit	60
All	Oil, palm fruit	60
All	Sugar cane	4,5

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 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 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.

4.2   Differences compared to previous years

Appendix I and II show the main differences in results between the 2021 and 2022 version of the LUC dataset (Appendix I) and main differences for between the 2018 and 2021 version of the LUC dataset (Appendix II). In general, main drivers for differences are the following:

Main 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.

Differences between 2021 and 2022

For the difference between 2021 and 2022 the same timeframe is considered. Due to the update from an Excel based tool to the web-based tool, some differences occur. Also, the FAO data which is downloaded in 2022 contains deviations from the FAO data downloaded in 2021, also for historic data. Main reasons for deviations between the 2021 and 2022 dataset, when calculated over the same period of time are:

- Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)
- Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)
- Resolved small issue with lookup of climate and soil type in the Excel-based tool (effects only three countries).
- Difference in methodology compared to Excel tool: difference in carbon stock between perennial cropland and this crop is not set to 0, as carbon stock for vegetation has a non-standard value for this crop.
- Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.
- A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

For all results, differences between the 2021 and 2022 dataset occur due to the availability of two additional years in the FAO data, and thus emission calculation for 2020, instead of for 2018.

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.

6. References

BSI. (2012). *PAS 2050-1: 2012 Assessment of life cycle greenhouse gas emissions from horticultural products*. BSI.

Christa Anderson, Tereza Bicalho, Elizabeth Wallace, Tim Letts, & Martha Stevenson. (2022). *FOREST, LAND, AND AGRICULTURE SCIENCEBASED TARGET SETTING GUIDANCE*. 1–43. https://sciencebasedtargets.org/resources/files/SBTiFLAGGuidance.pdf

FAO. (2020). *Global Forest Resources Assessment 2020: Main report*. FAO Rome, Italy.

Friedlingstein, P., Andrew, R. M., Rogelj, J., Peters, G. P., Canadell, J. G., Knutti, R., Luderer, G., Raupach, M. R., Schaeffer, M., van Vuuren, D. P., & Le Quéré, C. (2014). Persistent growth of CO2 emissions and implications for reaching climate targets. *Nature Geoscience*, 7(10), 709–715. https://doi.org/10.1038/ngeo2248

IPCC. (2019a). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 10). In *Volume 4: Agriculture, Forestry and Other Land Use* (Vol. 4). http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

IPCC. (2019b). *Climate Change and Land - An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. https://www.ipcc.ch/srccl-report-download-page/

IPCC. (2019c). *Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Introduction (Vol. 4 Chp. 1)*. https://doi.org/10.1016/S0166-526X(00)80011-2

Searchinger, T. D., Wirsenius, S., Beringer, T., & Dumas, P. (2018). Assessing the efficiency of changes in land use for mitigating climate change. *Nature*, 564(7735), 249–253.

World Resource Insitute. (2014). *CAIT Climate data explorer*. cait.wri.org

Zampori, L., & Pant, R. (2019). *Suggestions for updating the Product Environmental Footprint (PEF) method*.

Appendix I   Differences 2021 and 2022

50 largest differences between 2021 and 2022 results, calculated over same time period (1998 to 2018). Differences due to inclusion of 2019 and 2020 data is thus not considered.

Country	Crop	Difference weighed emissions (tonne CO2 eq./ha*yr)	Difference normal emissions (tonne CO2 eq./ha*yr)	Explanation from country land cover	Explanation from crop area	Explanation from soil/climate	Explanation from crop vegetation carbon stock	Explanation from changes in other crop data	Explanation from decimals
Argentina	Chick peas	-13,56	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Indonesia	Bastfibres, other	-12,91	-7,37	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Beans, green	-11,73	-1,86	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

								thus conversions are different.	
Argentina	Rapeseed	-11,29	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Lentils	-11,10	0,12	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Antigua and Barbuda	Carrots and turnips	-10,88	-5,15	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Barley	-10,62	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Peas, dry	-9,78	-0,39	Change in historic grassland and/or forest data for country in new FAO download (download in August	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

Country	Crop			(2022 compared to March 2021)	(August 2022 compared to March 2021)			(2021), the total expansion/contraction of cropland is different and thus conversions are different.	
Antigua and Barbuda	Maize	-9,49	-4,49	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Beans, green	-9,03	-3,83	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Soybeans	-8,86	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Kenya	Sunflower seed	-8,65	-3,82	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Olives	-8,56	0,00	Change in historic grassland and/or forest data for country in new	Change in historic cropland data (harvested area) for crop country	-	-	Due to changes in historic data for harvested area on other crops cultivated	A small error occurs due to rounding of values in

Country	Crop								
				FAO download (download in August 2022 compared to March 2021)	combination, in new FAO download (download in August 2022 compared to March 2021)			in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	the 2022 dataset to 2 decimals.
Argentina	Walnuts, with shell	-8,52	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Anise, badian, fennel, coriander	-8,36	0,05	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Potatoes	-8,31	-3,71	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Safflower seed	-8,26	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

Country	Crop								
United Republic of Tanzania	Ginger	7,62	5,12	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Bananas	-7,52	-2,39	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Maize	-7,18	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Antigua and Barbuda	Pineapples	-6,91	-1,66	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Antigua and Barbuda	Melons, other (inc.cantaloupes)	-6,79	-3,18	-	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

Country	Crop								
								cropland is different and thus conversions are different.	
Argentina	Asparagus	-6,57	-0,46	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Zambia	Barley	-6,17	-4,49	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Oranges	-5,99	-1,91	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Mangoes, mangosteens, guavas	-5,94	-1,89	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Lettuce and chicory	5,84	3,45	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

				August 2022 compared to March 2021)				2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	
Argentina	Cherries	-5,83	-0,10	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Cereals nes	-5,75	0,14	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Avocados	-5,68	-1,81	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Maize, green	5,63	3,78	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Bangladesh	Bastfibres, other	-5,43	-5,19	-	Change in historic cropland data (harvested	-	-	Due to changes in historic data for harvested area	A small error occurs due to rounding of values in

Country	Crop								
					area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)			on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	the 2022 dataset to 2 decimals.
Malawi	Peas, dry	5,35	3,60	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Spices nes	-5,32	-2,55	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Papua New Guinea	Sugar cane	5,22	1,95	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	Difference in methodology compared to Excel tool: difference in carbon stock between perennial cropland and this crop is not set to 0, as carbon stock for vegetation has a non-standard value for this crop.	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Peru	Apricots	-5,09	-0,91	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

								thus conversions are different.	
Timor-Leste	Cucumbers and gherkins	-5,04	-2,38	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Lupins	-5,02	-0,50	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Beans, dry	-4,98	0,00	Change in historic grassland and/or forest data for country in new FAO download (download in August 2022 compared to March 2021)	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Pumpkins, squash and gourds	4,88	3,42	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Argentina	Almonds, with shell	-4,61	-0,04	Change in historic grassland and/or forest data for country in new FAO download (download in August	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

				2022 compared to March 2021)	August 2022 compared to March 2021)			2021), the total expansion/contraction of cropland is different and thus conversions are different.	
Grenada	Sweet potatoes	4,58	3,95	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	Resolved small issue with lookup of climate and soil type in the Excel-based tool (effects only three countries).	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Chillies and peppers, green	4,55	3,14	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Eggplants (aubergines)	4,53	3,15	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Grenada	Tomatoes	4,50	-1,90	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	Resolved small issue with lookup of climate and soil type in the Excel-based tool (effects only three countries).	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Grenada	Cauliflowers and broccoli	4,48	-1,93	-	Change in historic cropland data (harvested area) for crop country	Resolved small issue with lookup of climate and soil type in the Excel-based	-	Due to changes in historic data for harvested area on other crops cultivated	A small error occurs due to rounding of values in

					combination, in new FAO download (download in August 2022 compared to March 2021)	tool (effects only three countries).		in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	the 2022 dataset to 2 decimals.
Grenada	Melons, other (inc.cantaloupes)	4,45	-1,93	-	-	Resolved small issue with lookup of climate and soil type in the Excel-based tool (effects only three countries).	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Timor-Leste	Coffee, green	-4,44	-1,41	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Brunei Darussalam	Watermelons	4,42	3,07	-	-	-	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.
Grenada	Cucumbers and gherkins	4,41	-1,98	-	Change in historic cropland data (harvested area) for crop country combination, in new FAO download (download in August 2022 compared to March 2021)	Resolved small issue with lookup of climate and soil type in the Excel-based tool (effects only three countries).	-	Due to changes in historic data for harvested area on other crops cultivated in this country in the new FAO download (August 2022 instead of March 2021), the total expansion/contraction of cropland is different and thus conversions are different.	A small error occurs due to rounding of values in the 2022 dataset to 2 decimals.

Appendix II Differences 2018 and 2021

In this update of the 'Direct Land Use Change Assessment Tool' we incorporated the latest data from FAO, up to and including 2018. New estimations of biomass carbon stock in forests are obtained from the Forest Resource Assessment (FRA) 2020 (FAO, 2020). In 2019, IPCC published refinements to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019a)(IPCC, 2019c). Soil carbon stock change factors are adapted accordingly. Some insights into the changes compared to the previous versions of the dLUC assessment tool are presented below.

MAIN DRIVERS OF 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 in the "country known, previous land use unknown"-scenario are mainly driven by four 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.
- *Is the forest carbon stock change very different in FRA 2020 compared to FRA 2015?*
  Due to the availability of newer and better data, the estimated carbon stock in forest changed significantly for several countries in FRA 2020 compared to the FRA 2015. A change in carbon stock in forest area will directly translate to a change in dLUC emissions and is especially important for crop-country combinations where expansion of the crop mainly goes at the expense of forest.

KEY DATA CHANGES

Crop data now include statistics from the FAO up to 2018, IPCC stock change factors are updated, and the FRA 2020 datasets are included. Several specific changes in the data sources (based on the main drivers for change as described above) are discussed to explain differences between the current and previous dataset.

Changes in forest and grassland area

Changes in the data can be due to the change of scope (inclusion of two additional years) or as the result of updated statistics. The latter can be the result of other data-sources or assessment models and can highly influence results.

For forest area, some notable differences are found for Côte d'Ivoire, where forest area is much lower in the recent FAO data compared to the previously used data, especially for recent years. This results in higher dLUC emissions compared to the previous dataset. Kenya also shows lower forest area values for recent years in the latest FAO data, which will also result in higher dLUC emissions. For Nicaragua, forest land is higher in the latest FAO data, however, as the recent years show a smaller increase compared to data from 20 years ago, dLUC emissions still increase. For grassland, Samoa shows much larger areas in recent years in the new FAO data. Guyana and Gabon show much smaller grassland areas for all years in the new FAO data. How changes in grassland area result in changes in dLUC emissions differs per crop-country combination, as grassland does not always have a higher or lower carbon stock compared to the expanding crop.

Changes in total cultivated area

The global cultivated area expanded from $1.38*10^9$ ha in 2016 (dLUC tool v2018) to $1.42*10^9$ ha in 2018 (dLUC tool v2021). This is an expansion of crop area of 3% compared to the previous dataset (2018). When the expansion is calculated over a 20-year period for both the old and the new dataset, the increase is from +17% to +19%.

Changes in cultivated area of investigated crop

As in the case of the other data sources: changes in the data can be due to the change of scope (inclusion of two additional years) or as the result of updated statistics. For conciseness, we will not discuss changes for specific crop-country combinations. Contact us in case of specific questions that cannot be explained within this document.

Changes in forest carbon stock
In the FRA 2020 datasets, the forest carbon stock (sum of living and dead biomass carbon) increased and therefore influences results for Ethiopia; Suriname; Philippines; Myanmar; Antigua and Barbuda and to a lesser extend for Cameroon and the Democratic Republic of the Congo. In the FRA 2020 datasets, the forest carbon stock vastly decreased and therefore highly influences results for Côte d'Ivoire; the United Republic of Tanzania; Paraguay; Ghana; Nicaragua; Samoa; Angola; Nigeria; Papua New Guinea and to a lesser extend for Pakistan; Niue; Kenya; Zambia; Indonesia; Dominica; Sierra Leone; Burkina Faso; Guinea; Togo and Belize.

Changes in IPCC soil carbon stock change factors
The stock change factors changed significantly compared to 2006 through enhanced databases, refined techniques of data analysis and enhanced computational capacity over the last 15 years. Changes in these factors influence the soil carbon stock of the expanding crop and the reference situation of annual and perennial cropland. An increase in carbon stock of the expanding crop relates to lower dLUC emissions, a decrease relates to higher dLUC emissions.
Soil carbon stock increases for: annual cropland in tropical regions and paddy rice cultivation in every climate region. Soil carbon stock decreases strongly for perennial cropland in every climate region except tropical regions and decreases slightly for reduced and no-tillage practices on cropland in all regions with a stronger decrease in tropical regions.

TOTAL EMISSIONS FROM LAND USE CHANGE
The global average calculated emissions from direct land use change have slightly lowered in the latest update including crop data of 2017 and 2018: from 2.3 to 1.9 ton CO_2 eq./ha. For the total dataset under consideration, this adds up to the emission of roughly 2.6 Gt CO_2/year. Although the cultivated area expansion is larger compared to the 2018 tool version, total emissions are lower than the figure found in the previous version: 3.2 Gt CO_2/year.

FAOSTAT calculated global GHG emissions resulting from lang management activities, these values are also noted in IPCC's recent publication on Climate Change and Land (IPCC, 2019b). Accounting for all emissions (thus excluding removals) and excluding emissions from cropland (as these are mostly related to oxidation of peatland), the total yearly emissions in 2018 of Forestry and Other Land Use is 2.9 Gt CO_2e/year. Other sources indicate values in the same order magnitude: a total of 3.15 Gt CO_2e/year (World Resource Insitute, 2014) and 3.3 ± 1.8 GtCO_2e/year for 2003-2014 (Friedlingstein et al., 2014) for land-use change and forestry emissions are reported. It can be concluded that the total global emissions resulting from land use change found in the tool lie within ranges from other global estimates. For individual countries there are likely larger differences to be found.

KEY CROPS AND CHANGES IN LUC EMISSIONS
The tables below list the results of the 'Direct Land Use Change Assessment Tool' for several crop-county combinations. In both tables, the results of the current tool are compared to the results from the previous tool (version 2018, including FAO data up to 2016).

Table 1 shows the top 30 of the crop-country combinations that are the largest contributors to the global impact of land use change due to the cultivation of crops. Table 2 shows the top 30 land use change emission factors per hectare of cultivated area.

TABLE 11. TOP 30 CROP-COUNTRY COMBINATIONS THAT ARE THE LARGEST CONTRIBUTORS TO THE GLOBAL IMPACT OF LAND USE CHANGE DUE TO THE CULTIVATION OF CROPS.

Country	Crop	Current area (ha)	Weighted average ton CO2 eq./ha v2021	Weighted average ton CO2 eq./ha v2018	Relative difference (%)
Brazil	Soybeans	3,40E+07	12,62	15,58	-19%
Argentina	Soybeans	1,77E+07	12,00	14,84	-19%
Brazil	Sugar cane	1,01E+07	8,58	9,79	-12%
Brazil	Maize	1,62E+07	5,31	3,21	66%
Democratic Republic of the Congo	Cassava	4,57E+06	16,04	0,00	∞
Indonesia	Oil, palm fruit	1,32E+07	5,34	8,89	-40%
Argentina	Maize	6,34E+06	9,72	10,41	-7%

Country	Crop				
Nigeria	Yams	6,20E+06	8,20	14,04	-42%
Nigeria	Cassava	6,41E+06	7,19	12,46	-42%
Democratic Republic of the Congo	Maize	2,78E+06	14,29	0,25	5622%
Nigeria	Maize	6,89E+06	5,27	5,32	-1%
Indonesia	Maize	5,22E+06	5,73	2,15	167%
Myanmar	Beans, dry	3,13E+06	8,96	9,98	-10%
Cameroon	Maize	1,27E+06	20,03	19,89	1%
Paraguay	Soybeans	3,42E+06	7,14	24,58	-71%
Democratic Republic of the Congo	Rice, paddy	1,58E+06	15,36	0,00	∞
Nigeria	Rice, paddy	5,48E+06	4,24	6,75	-37%
Canada	Rapeseed	8,89E+06	2,49	1,39	79%
Côte d'Ivoire	Cocoa, beans	4,05E+06	5,25	0,00	∞
Democratic Republic of the Congo	Plantains	1,09E+06	18,61	0,00	∞
United Republic of Tanzania	Maize	3,75E+06	5,30	19,68	-73%
Ethiopia	Maize	2,86E+06	6,90	3,33	107%
Nigeria	Sweet potatoes	1,60E+06	10,62	19,82	-46%
Ethiopia	Cereals, nes	3,04E+06	5,35	4,58	17%
Nigeria	Groundnuts, with shell	3,61E+06	4,49	7,54	-40%
Argentina	Barley	1,11E+06	14,38	16,92	-15%
Kenya	Maize	2,23E+06	7,12	0,05	13449%
Indonesia	Rubber, natural	3,66E+06	4,30	6,14	-30%
Côte d'Ivoire	Cashew nuts, with shell	1,67E+06	9,25	0,00	∞

TABLE 12. TOP 30 LAND USE CHANGE EMISSION FACTORS PER HECTARE CULTIVATED AREA.

Country	Crop	Weighted average ton CO2 eq./ha v2021	Weighted average ton CO2 eq./ha v2018	Relative difference (%)
Democratic Republic of the Congo	Pulses, nes	27,12	2,24	1108%
Peru	Artichokes	25,94	26,40	-2%
Cameroon	Ginger	25,92	27,91	-7%
Cameroon	Chillies and peppers, green	25,78	27,22	-5%
Cameroon	Tomatoes	23,97	25,24	-5%
Cameroon	Nuts, nes	23,66	4,02	489%
Cameroon	Watermelons	23,51	23,94	-2%
Cameroon	Cow peas, dry	23,49	27,73	-15%
Cameroon	Bambara beans	23,46	24,11	-3%
Cameroon	Sweet potatoes	21,60	21,02	3%
Peru	Linseed	21,27	27,58	-23%
Cameroon	Chillies and peppers, dry	20,95	19,11	10%
Kenya	Vegetables, leguminous nes	20,82	0,16	13107%
Kenya	Cauliflowers and broccoli	20,70	0,08	25685%
Cameroon	Cucumbers and gherkins	20,70	22,48	-8%
Kenya	Watermelons	20,64	0,15	13301%
Cameroon	Onions, dry	20,51	21,66	-5%
Suriname	Beans, green	20,42	4,46	358%
Peru	Spices, nes	20,04	23,20	-14%
Cameroon	Maize	20,03	19,89	1%

Cameroon	Sesame seed	19,97	19,13	4%
Kenya	Lettuce and chicory	19,80	0,15	13520%
Cameroon	Rice, paddy	19,61	20,20	-3%
Congo	Tobacco, unmanufactured	19,59	25,69	-24%
Kenya	Cucumbers and gherkins	19,56	0,13	14508%
Democratic Republic of the Congo	Roots and Tubers, nes	19,52	1,79	991%
Peru	Cauliflowers and broccoli	19,44	7,80	149%
Belize	Onions, shallots, green	18,84	29,50	-36%
Democratic Republic of the Congo	Plantains	18,61	0,00	#DIV/0!