THE GLOBAL BIODIVERSITY SCORE

GBS Review: Crops CommoTool

July 2020 – Corrected version

CDC BIODIVERSITÉ | Caisse des Dépôts GROUPE

Content

Note to the reader

Global Biodiversity Score (GBS) review reports are not completely independent from each other. Readers of this report are advised to read the reports dedicated to **Terrestrial pressures on biodiversity** (CDC Biodiversité 2020b) and **Aquatic pressures on biodiversity** (CDC Biodiversité 2019c) to ensure a good overall comprehension of the tool and the present report. The sections describing default assessment as well as the limitation sections are especially recommended.

The following colour code is used in the report to highlight:

- Assumptions

- Important sections

- Developments of the GBS planned in the future

The GBS review reports are aimed at technical experts looking for an in-depth understanding of the tool and contribute to the transparency that CDC Biodiversité considers key in the development of such a tool. They focus on technical assumptions and principles. Readers looking for a short and easy-to-understand explanation of the GBS or for an overview of existing metrics and tools should instead read the general audience reports published by CDC Biodiversité (CDC Biodiversité 2017; CDC Biodiversité, ASN Bank, and ACTIAM 2018; CDC Biodiversité 2019d).

1 Crops CommoTool overview

1.1 Crop production context

A WHY ASSESS THE BIODIVERSITY IMPACTS OF CROP PRODUCTION?

Agriculture is a major user of natural resources today: over one third of the terrestrial land surface is used for crop production or animal husbandry, and three quarters of the available freshwater resources are devoted to crop or livestock production. Crop production is continuously increasing, its value has tripled since 1970 to reach $2.6 trillion in 2016 according to the IPBES (Díaz et al., 2019), and will continue to rise with the growing world population and food demand. This will emphasize agriculture expansion, which is the most widespread form of land use change – first of the five main direct pressures on biodiversity pointed out by the IPBES – and accentuate as well the other direct pressures on biodiversity, namely direct exploitation (*i.e.* here biomass extraction), climate change, pollution and invasive alien species. Figure 1 provides an estimation of food production share for terrestrial biodiversity impacts.

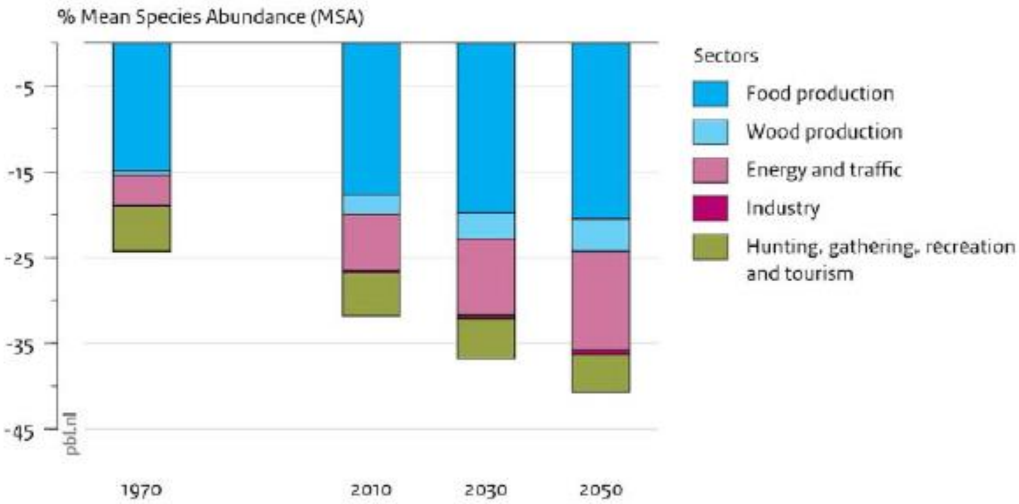

Figure 1: Attribution of terrestrial biodiversity impacts in MSA% to different production sectors under the Trend scenario (Kok et al., 2014)

B PLACE OF THE CROPS COMMOTOOL IN THE GBS STEPWISE APPROACH

As a reminder, the evaluation of biodiversity impacts of economic activities with the GBS follows a stepwise approach according to the best data available at each step of the impact assessment (CDC Biodiversité, 2020a). The crops CommoTool (and other commodity family modules such as wood logs or metal ores) fits in this stepwise framework in two ways, described in the Figure 2.

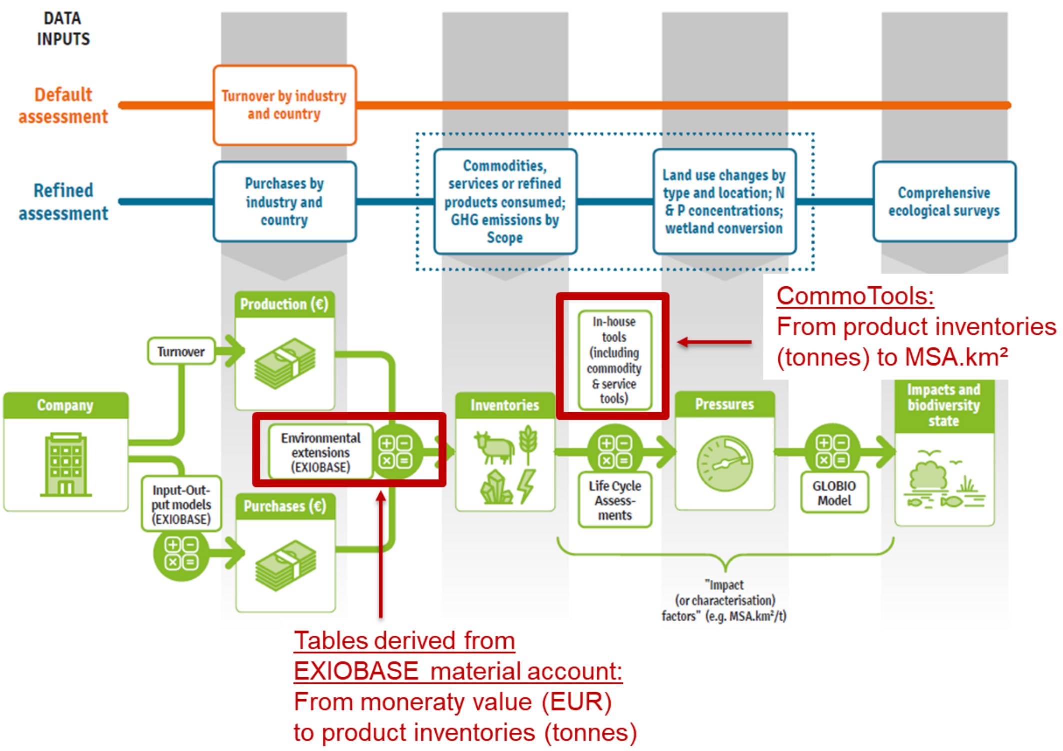

Figure 2: The crops CommoTool in the GBS stepwise approach

During the **refined assessment**, if at the "Inventories" step, data like crop commodities quantities are available, biodiversity impact factors from the crops CommoTool linking tonnages of crop commodities to impacts on biodiversity in MSA.km² can be applied to compute the impact of the crops purchased. These factors are gathered in the output database of the crops CommoTool.

If **monetary data** are available (such as purchases or turnovers in the default assessment), we can apply biodiversity impact factors from the crops CommoTool to raw material inventories provided by EXIOBASE.

The goal of the crops CommoTool is to determine the **biodiversity impacts of a given tonnage of crop commodity.** This document explains how the biodiversity impact factors database is built.

C CROPS COMMOTOOL PERIMETER

1.1.C.1 Pressures considered

As a reminder, the pressures listed below are covered in the GBS. They are further detailed in GBS review report on terrestrial pressures (CDC Biodiversité, 2020e) and GBS review report on aquatic pressures (CDC Biodiversité, 2020b). They are all included in the pressures assessed by the crops CommoTool:

- **Terrestrial pressures**: land use (LU), encroachment (E), fragmentation (F), atmospheric nitrogen deposition (N), climate change (CC)
- **Aquatic freshwater pressures:** land use in catchment of rivers (LUR) and wetlands (LUW), wetland conversion (WC), hydrological disturbance (HD_{Water}, HD_{Infra} and HD_{CC}), freshwater eutrophication (FE)

1.1.C.2 Items considered

Figure 3 represents the global land uses distribution with a focus on agricultural land, especially destined to vegetal crops and grazing (in millions of km²) to give an order of magnitudes of crop production. The crops CommoTool covers the 14.8 million km² of primary crops and 0.6 million km² of fodder crops, the remaining land and grazing areas are out of the scope of this document, the latter will be treated in the livestock CommoTool (CDC Biodiversité, 2020c).

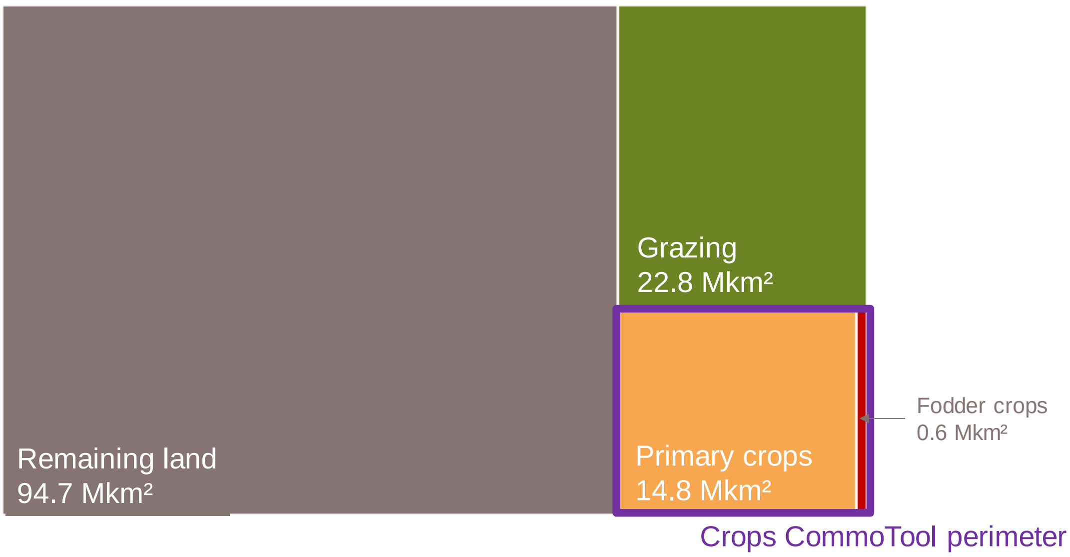

Figure 3: Global surfaces distributions and areas covered by the crop CommoTool[1]

[1] Agricultural areas are taken from the land accounts in EXIOBASE "resources" Environmental Extensions. The remaining land area is inferred by subtracting EXIOBASE resources data from GLOBIO total land area (133 million km² excluding Antarctica and Greenland in GLOBIO 3.5).

Crop products directly extracted from the field, namely **Primary crops and Fodder crops**, are treated in the "dimensioning" section of the present document (section 2). The attribution of impacts to **crop residues** is tackled in the "attributing" section (section 4).

1.2 Crops CommoTool methodology overview

The methodology used to construct the biodiversity impact factors database consists in determining the contribution of crop production processes to each terrestrial and aquatic pressure listed in the previous section. The methodology follows the steps described by Figure 4.

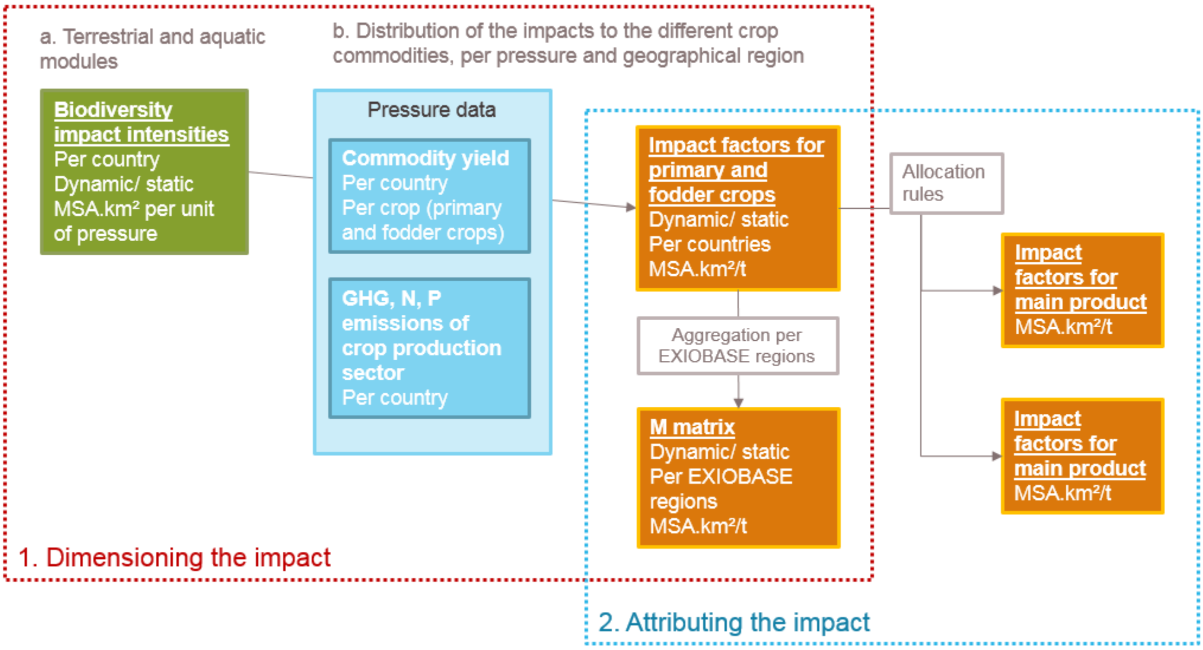

Figure 4: Crops CommoTool methodology overview

A DIMENSIONING THE BIODIVERSITY IMPACTS OF CROP PRODUCTION

In the crops CommoTool, the dimensioning step determines the contribution of crops production (primary and fodder crops) sector to the biodiversity impact in each selected geographical region. As described in Figure 4, the general concept is that biodiversity impact factors (expressed in MSA.km² per unit of pressure) calculated for terrestrial and freshwater biodiversity (step a) are combined to relevant data related to crops such as crop yields, land conversion or emission of P-eq. per tonne of crop produced (step b).At the end of the computation process, the biodiversity impact factors obtained (in MSA.km² per tonne of crop commodity) can be declined at different geographical scales. For more details about terrestrial and aquatic biodiversity impacts intensities, please refer to dedicated review reports (CDC Biodiversité, 2020e, 2020b). Table 1 and Table 2 summarise the units of the intensities calculated in the terrestrial and aquatic modules.

Terrestrial Pressure	Land Use (LU)	Encroachment (E)	Fragmentation (F)	Atmospheric Nitrogen deposition (N)	Climate change (CC)
Biodiversity impact intensity unit	MSA.km²/km² of land use type	MSA.km²/km² of encroaching land use type	MSA.km²/km² of fragmenting land use type	MSA.km²/tonne PO_4-eq emitted	MSA.km²/kg CO_2-eq emitted

Table 1: Units of the terrestrial biodiversity impact factors

Freshwater pressure	Hydrological disturbance due to direct water use (HD_{Water})	Hydrological disturbance due to climate change (HD_{CC})	Land Use in catchment (impacting rivers and wetlands)	Wetland conversion	Freshwater eutrophication
Biodiversity impact intensity unit	MSA.km²/m³ withdrawn or consumed	MSA.km²/kg CO_2-eq emitted	Rivers: MSA.km²/km² of human land use Wetlands: MSA.km²/km² intensity weighted	MSA.km²/km² of agricultural land	MSA.km²/kg P-eq emitted

Table 2: Units of the aquatic (freshwater) biodiversity impact factors

To make a parallel with the LCA framework, the crops CommoTool uses several types of data and characterisation factors, as described in Figure 5. For instance, for land use, a given tonnage of crop plays the role of the **LCA inventory** data in the GBS. It is linked to an occupied area, which is a **midpoint**, through a **midpoint characterisation factor** based on the crop yield. The midpoint is linked to an **endpoint impact** in MSA.km² through a **midpoint to endpoint characterisation factor** which corresponds to the impact intensities in MSA.km²/unit of pressure (here the area dedicated to crops). The impact factors in MSA.km²/t constituting the crop CommoTool are a combination of the midpoint and **endpoint characterisation factors.**

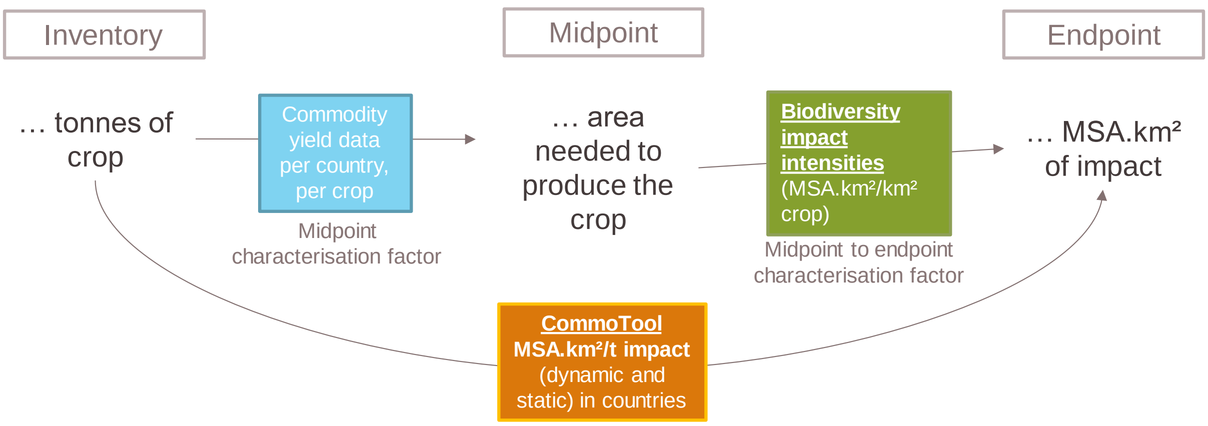

Figure 5: Impact factors used or constructed in thecrops CommoTool within the LCA framework

B ATTRIBUTING THE BIODIVERSITY IMPACTS TO THE DIFFERENT SYSTEM OUTPUTS

Crop production is a multifunctional process, meaning that the process delivers several goods and/or services. It has multiple unavoidable outputs other than the **main products** (primary crops and fodder crops), which are called the **co-products**. The co-products designate the **crop residues** and the **unused crops.** This notion of multifunctionality is important for our methodology, as the biodiversity impact needs to be attributed to the different outputs produced.

If the impact is attributed according to the area occupied by each product, there is a risk to double count the biodiversity impacts between the main crop products and its co-products. Hence, different attribution approaches can be considered based, among other things, on the economic value or the tonnage of each product. In GBS 1.0, we use an economical approach and we consider that crop residues have a low economical value and that unused products are outside of the economy so considered as wastes. Therefore, for now, the dimensioned biodiversity impacts in described in section 2 are fully allocated to the main products (primary and fodder crops). The repartition rules are further explained in section 4.

2 Dimensioning the crop production impacts – Default assessments

2.1 Underlying data

A CROP PRODUCTION DATA

For crop production data, we use FAOSTAT data. This corporate statistical database of the Food and Agriculture Organization **documents yield, production and harvested area per crop in each country** (FAOSTAT, 2019b). FAOSTAT definition of the terms production, harvested areas and yield data are reproduced below:

<u>Production:</u> production data refers to the actual harvested production of the selected crop from the field/orchard in the selected **country, excluding the losses and parts of the crops not harvested for any reason** (Production questionnaire in May 2017 in (FAO Statistics Division, 2019)). It includes both the quantities of each commodity sold on the market, and the quantities that serve auto-consumption. If the production period is in between two calendar years, the production quantity will be allocated to either both pro rata the production, or most often to the year accounting for most of the production.

<u>Harvested area:</u> these areas concern the harvested crops so that areas **without harvest due to damage, failure etc., even though sown or planted, are not considered** (FAOSTAT definitions and standards, Element 5312 in (FAOSTAT, 2019b) and Production questionnaire in May 2017 in (FAO Statistics Division, 2019)). If the studied crop is harvested more than once due to successive cropping (such as for lettuce), the area is counted as many times as harvested. Within the case of the same standing crop that is harvested multiple times a year (such as apple trees), the harvested area will be recorded only once. For mixed crops, areas are reported separately, so that a same field could be counted multiple times.

<u>Yield:</u> yield is the ratio of production over harvested area. Most of the time, yield data is not collected directly and is computed instead (FAOSTAT definitions and standards, Element 5419 in (FAOSTAT, 2019b)).

2.1.A.1 Primary crops

<u>Primary crops</u> are defined in FAOSTAT as the crops coming directly from the land without being processed, apart from being cleaned (item 99003 in the Standards and Definitions (FAOSTAT, 2019b)). FAOSTAT data for primary crops covers **160 crops in 210 countries, for years between 1961 and 2017.** This dataset will be regularly updated in the GBS tool following FAOSTAT datasets updates.

For each {crop; country} pair, the most recent data is kept[2]. FAOSTAT data is formatted in the GBS through the `crop_FAO_data_builder()` function. Formatting operations mainly consist in renaming items, matching FAO countries with GLOBIO countries (the correspondence table is provided in the Appendix document (CDC Biodiversité, 2019a)), and excluding aggregated items (sums of other lines).

2.1.A.2 Fodder crops

<u>Fodder crops</u> are crops cultivated primarily for animal feed. Fodder crops may be classified as either **temporary** (cultivated like any other crop) or **permanent crops** (the land is used for five years or more) for herbaceous forage crops. Fodder crops may include some parts of forest land if it is used for grazing. Temporary crops grown intensively with multiple cuttings per year include three major groups of fodder: grasses, including cereals that are harvested green; legumes, including pulses that are harvested green; and root crops that are cultivated for fodder. All three types are fed to animals, either as green feed, as hay, *i.e.* crops harvested dry or dried after harvesting, or as silage products.

2.1.A.2.1 Data source

Collecting production data on fodder crops is not as straightforward as for primary crops.

The fodder crops items list is based on the items listed in the material account of EXIOBASE 3.4, which are from previous reported data in FAOSTAT. Contacting FAOSTAT directly, we were able to retrieve fodder crops production data (tonnage, harvested areas) not displayed on the public website anymore due to low response rates. In the most recent years (ranging from 2014 to 2017) data, only 133 combinations of {fodder crop, country} can be found. For the missing combinations of {fodder crop, country} and for EXIOBASE (previously FAOSTAT) crop fodder items without FAOSTAT direct equivalent in the production data, rules of thumb were used in order to estimate production data. Those rules are detailed in the next sub-section.

For production data on FAOSTAT website only trade data (import/export quantity/monetary value) is available. Contacting FAOSTAT directly, we were able to retrieve production data (tonnage, harvested

[2] For the central value, we are going to switch the yield used from "the most recent" to a "running average over the last 5 years". Our aim with the default approach and the central calculation mode is indeed to assess a risk of impact based on an average situation (for the conservative and optimist calculation modes, we could use another value in the distribution of yields over the last 5 years). This idea to take into account the variability of this parameter is also mentioned in the Limits and perspectives section. It means we will use for instance the 2013-2017 average yield to screen risks of impacts in 2020. To switch to a more "impact assessment" rather than "risk screening" approach, companies will have to access actual yields during the year assessed (*e.g.* from their suppliers).

areas) not displayed on the public website anymore due to low response rates. In the most recent years (ranging from 2014 to 2017) data, **only 133 combinations of {fodder crop, country} can be found**. Therefore, for the missing combinations of {fodder crop, country} and for EXIOBASE crop fodder items without FAOSTAT direct equivalent, rules of thumb were used in order to estimate production data. Those rules are detailed in the next sub-section.

2.1.A.2.2 How to deal with data gaps

> ASSUMPTION
>
> Yield data from primary crop can be reused for fodder crops, but production and harvested area data cannot be substituted: we do not know the actual production quantities of a fodder crop in a country, but we suppose that a similar / related primary crop would follow the same growing parameters than the fodder crop in the same country.

The general principle is to replace when needed and when possible the lacking {fodder crops, countries} yield data by similar primary crops data in the same country. Table 3 lists the corresponding proxy primary crop of each fodder crop, a more detailed tables with associated justifications is available the review report general appendix (CDC Biodiversité, 2019a). To build the matching table, fodder[3] and primary crops items definitions from FAOSTAT are compared in terms of definitions and/or included species. If the proxy primary crop is in the same subspecies / species than the fodder crop, then its yield is applied to the fodder crop. If not, the yield of the candidate proxy primary crop is cross-checked with yields of the corresponding fodder crop from feed and agronomic databases (Feedipedia - joint project developed by INRA, CIRAD, AFZ and FAO -, Ecoport…) when possible. When proxy yield is not found for a pair {fodder crop, country}, that pair is excluded from the assessment. The corresponding pairs and associated estimated tonnages are detailed in Figure 6.

We will look for other data sources in order to improve the yield data coverage in the future.

Missing yields are filled through the function `crop_fodder_yield_builder()`.

[3] http://www.fao.org/economic/ess/ess-standards/comm-items/en/?chapter=11 though data on fodder crop are not displayed anymore on the website.

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Table 3: Proxy primary crop summary table (descriptions of the fodder crops are referred in [3])

Fodder Crop name (EXIOBASE nomenclature)	FAO ID	Proxy primary crop (FAO nomenclature)
Alfalfa for Forage and Silage	641	*Not found*
Beets for Fodder	647	Sugar beet
Cabbage for Fodder		Cabbages and other brassicas
Carrots for Fodder		Carrots and turnips
Clover for Forage and Silage	640	*Not found*
Forage Products nec	651	*Not found*
Grasses nec for Forage and Silage	639	*Not found*
Green Oilseeds for Fodder		Oilseed nes
Leguminous nec for forage and Silage	643	Pulses, Total
Maize for Forage and Silage	636	Maize
Other grasses	639	*Not found*
Rye Grass, Forage and Silage		*Not found*
Sorghum for Forage and Silage		*Not found*
Swedes for Fodder		Vegetables, fresh nes
Turnips for Fodder		Carrots and turnips
Vegetables and Roots, Fodder	655	*Not found*

Figure 6 synthetises the number of fodder yield data retrieved per fodder crop item, depending on their source type. Red shares represent the data directly provided by FAOSTAT, blue shares represent proxy data. In total, **1073 pairs are generated in the fodder crops yields table**, combinations among **15 fodder crop items and 202 unique countries**. Fodder crop item **« grasses nec for forage and silage »** from EXIOBASE is not included as no FAOSTAT yield or proxy yield was found. 940 values are proxy data, representing 87% of the values in the fodder yield table. Country coverage is quite disparate, from a few only to up to 200.

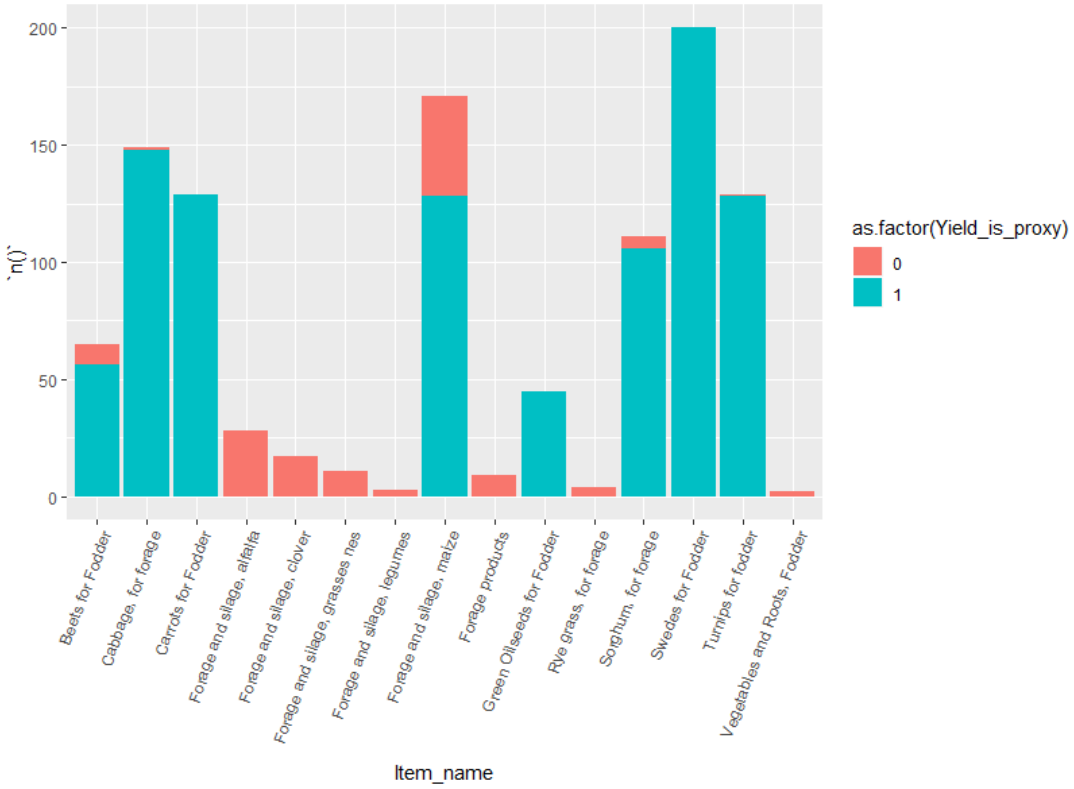


Figure 6: Number of fodder yield data retrieved per fodder crop item, depending on their source type.

Figure 7 illustrates the produced quantities of the fodder crops in the material account of the Environmental Extension of EXIOBASE. **"Maize for forage"** is the most material fodder crop according to the EXIOBASE data, and it is well covered in terms of proxy data availability according to Figure 6. Among the fodder crop items without a primary crop of substitution for yield data, important harvested tonnages are found for **"Alfalfa for Forage and Silage", "Forage Products nec", "Grasses nec for Forage and Silage"**, with more than 150 millions of tonnes harvested in all the regions. Other fodder crops without equivalent primary crop have less material harvested quantities compared to the three cited crops, such as **"Clover for Forage and Silage"**, **"Other grasses"** (no harvested quantity at all), **"Rye grass, Forage and Silage",** and **"Vegetable and Roots, Fodder"**, with less than 50 millions of tonnes. When searching for other yield data sources, we will prioritize the fodder crop yield data collection efforts on the material fodder crops (Alfalfa, Forage products, grasses nec).

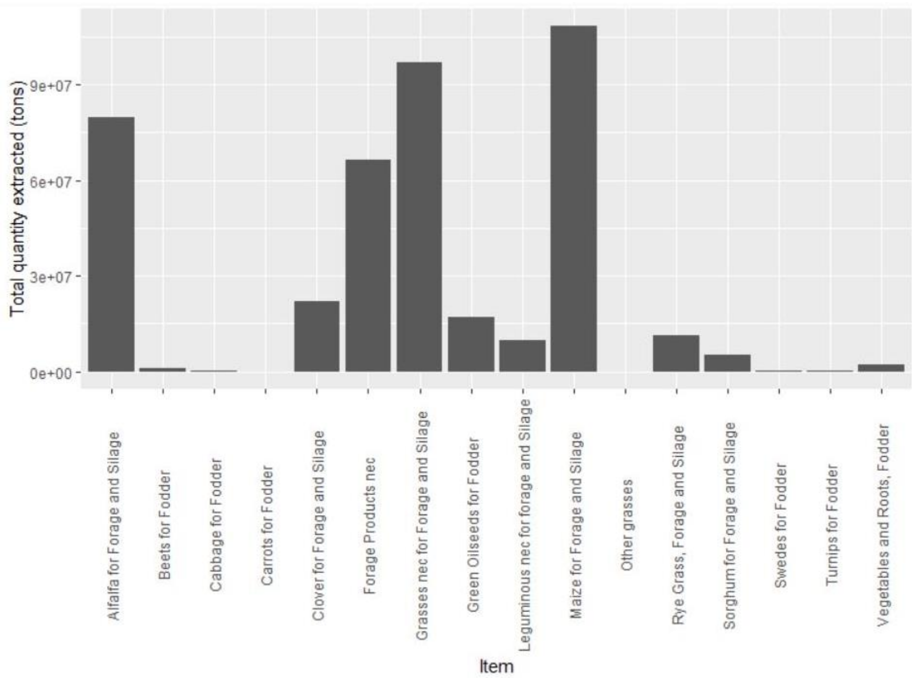


Figure 7: Total fodder crops production according to the material account of EXIOBASE environmental extension

Table 4 summarises the collected and computed yield data for primary and fodder crops:

	Fodder crops yield (t/ha)	Primary crops yield (t/ha)
Min	2,09	$3{,}2.10^{-3}$
1st Quartile	9,07	1,66
Median	22,7	5,31
Mean	**25,2**	**12,3**
3rd Quartile	37,3	13,7
Max	98,7	4761,9
Standard deviation	**18,8**	**564 851**
Number of observations	**1 073**	**9 187**

Table 4: Statistic summary of fodder and primary crops yields data

Fodder crop yields have the same order of magnitude as primary crop yields, as expected since they are mainly based on those primary crop yields. They are on average two times greater, probably because much data is retrieved from primary crops (maize, beets etc.) for which yields are higher.

B EMISSIONS DATA

2.1.B.1 Greenhouse gases (GHG) emissions

Data on GHG emissions of the agricultural sector are needed to compute climate change related biodiversity impact factors. We use FAOSTAT data (FAOSTAT, 2019a). Data treatment is detailed in section 2.2C.

2.1.B.2 N-compound emissions

For N-compound emissions we use EDGAR emission database (Crippa et al., 2018). As explained in the review report dealing with terrestrial pressures ((CDC Biodiversité, 2020e), section 4.2), EDGAR sectorial emissions of the various N-compounds (NH3, N2O and NOx) are summed up using and eutrophication potentials from CML (CML - Department of Industrial Ecology, 2019) and allocated to GLOBIO cells. This process is done in the function `terrestrial_N_emissions_EDGAR_to_GLOBIO_builder()` From there, we use emission data at the cell level to compute national emissions quantities per sector that are used in the crops CommoTool.

2.1.B.1 Nutrient emissions for freshwater eutrophication

For nutrient emissions linked to freshwater eutrophication, we use emission data from EXIOBASE (`GBStoolbox::EE_data_emissions`). For agriculture sector, P and Pxx emissions in the water compartment are summed up using eutrophication potentials from ReCiPe (Huijbregts et al., 2017) expressed in kg P-eq. This process is done in the function `aquatic_get_freshwater_eutrophication_emissions()` and the output is a database of nutrients emissions linked to freshwater eutrophication for agriculture sector per EXIOBASE region.

2.1.B.2 Water withdrawal data

For water withdrawal data used for the pressure hydrological disturbance due to direct water use, we use data from AQUASTAT (FAO, 2016), FAO database documenting the quantity of water withdrawn for agriculture per country (10^9 m^3). The latest available year is kept, ranging from 1975 to 2017.

2.2 Methodology to construct the impact factors of the Crops CommoTool

Data treatment and computation steps related to the construction of the biodiversity impact factors database for crop production are detailed below. The biodiversity impact factors cover both terrestrial and aquatic biodiversity, they are crop-specific and available at the country level.

The "Steps" mentioned in the figures of this section refer to the concerned code blocs in the **`crop_builder()`** function. **`crop_data`** mentioned in the following code blocs is the matrix containing FAOSTAT data on primary and fodder crops production per country, with reported information on produced tonnage, harvested area (ha) and the corresponding yield.

A PRESSURES WITH IMPACT FACTORS EXPRESSED PER UNIT OF AREA

Land use (dynamic), fragmentation, encroachment, wetland conversion and land use change in catchment pressures have **biodiversity intensities expressed in MSA.km²/km² area of impacting land use type.**

To evaluate impacts factors associated to those pressure we therefore have to evaluate the area needed to produce a given quantity of crop. We use yield this area, as the ratio of quantity over yield, defined as the **implicit area**:

$$implicit\ area = \frac{quantity}{yield}$$

2.2.A.1 Terrestrial pressures

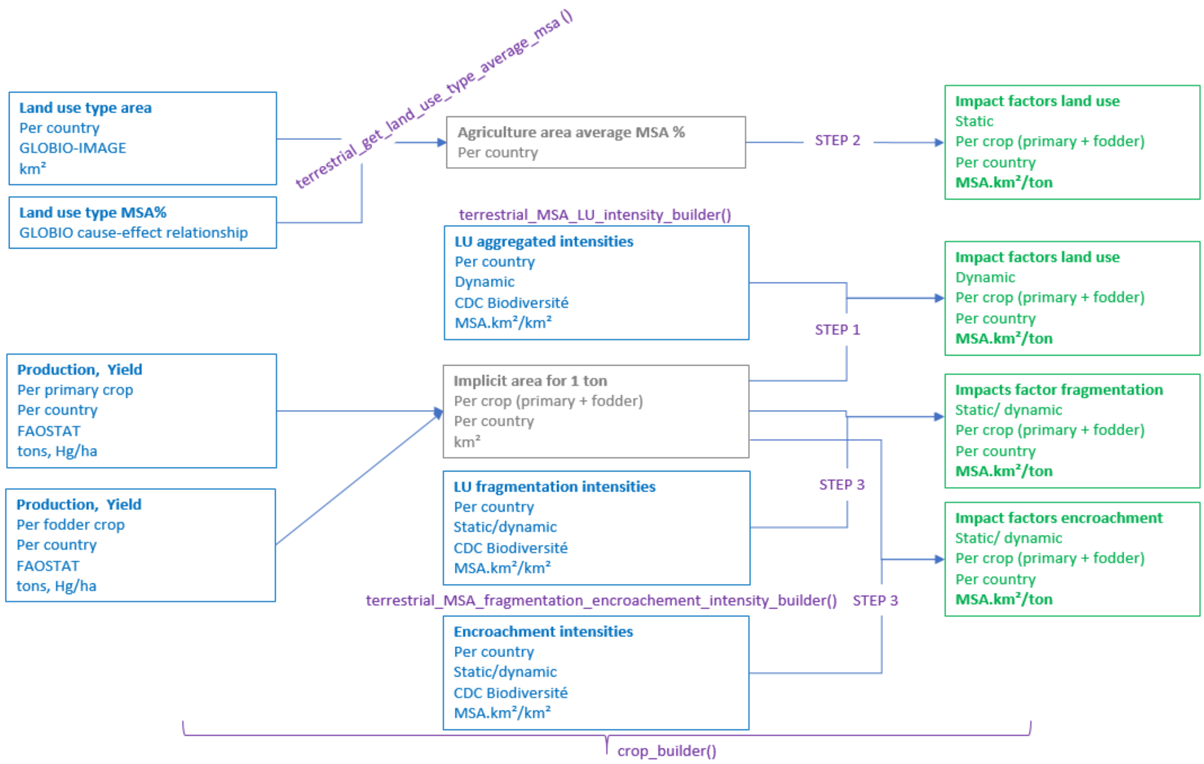


Figure 8: Overview of the construction of the terrestrial biodiversity impact factors of the crops CommoTool linked to intensities expressed per unit of area

Figure 8 describes the data treatment process to determine crops biodiversity impact factors in MSA.km²/tonne of crop related to **terrestrial land use, fragmentation and encroachment** pressures.

2.2.A.1.1 Land use

In STEP 1, terrestrial land use pressure intensity for agriculture land use types is multiplied by the implicit area to obtain the **land use dynamic impact factor (MSA.km²/ton).**

In STEP 2, **land use static impact factor** is computed by multiplying implicit area by difference of 1 and the national average MSA% for agricultural lands[4].

```
    #STEP 1: Terrestrial: land use dynamic section
    mutate(msa_land_use_dynamic = All_Agriculture_msa_intensity / yield) %>%

[…]
    #STEP 2: Terrestrial: land use static section
    mutate(msa_land_use_static = (1 - average_msa) / yield) %>%
```

The computed impact factors fall into data quality tier 2, because they use national crop yields from FAOSTAT that are country specific linear factors. In this version we only have an average estimation of the impact factor. In later versions conservative and optimistic assessments will be introduced.

2.2.A.1.2 Fragmentation and encroachment (F and E)

In STEP 3, static and dynamic intensities for fragmentation and encroachment are multiplied by the implicit area to obtain corresponding impact factors expressed in MSA.km²/ton.

```
    #STEP 3: Terrestrial: fragmentation and encroachment section
    mutate(msa_fragmentation_dynamic = msa_fragmentation_intensity_dynamic / yield,
           msa_fragmentation_static = msa_fragmentation_intensity_static / yield,
           msa_encroachment_dynamic = msa_encroachment_intensity_dynamic/ yield,
           msa_encroachment_static = msa_encroachment_intensity_static / yield)
```

The computed impact factors fall into data quality tier 2, as they rely on national crop yields from FAOSTAT that are country specific linear factors. In this version of the GBS, we only have an average estimation of the impact factor. In later versions conservative and optimistic assessments will be introduced.

2.2.A.2 Aquatic pressures

[4] National average MSA% for agricultural lands is the average biodiversity state (MSA) in % on the agricultural crops land uses in the current year in a given country, derived from the interpolation of GLOBIO data between 2010 and 2050 (further explained in the terrestrial module (CDC Biodiversité, 2020e)).

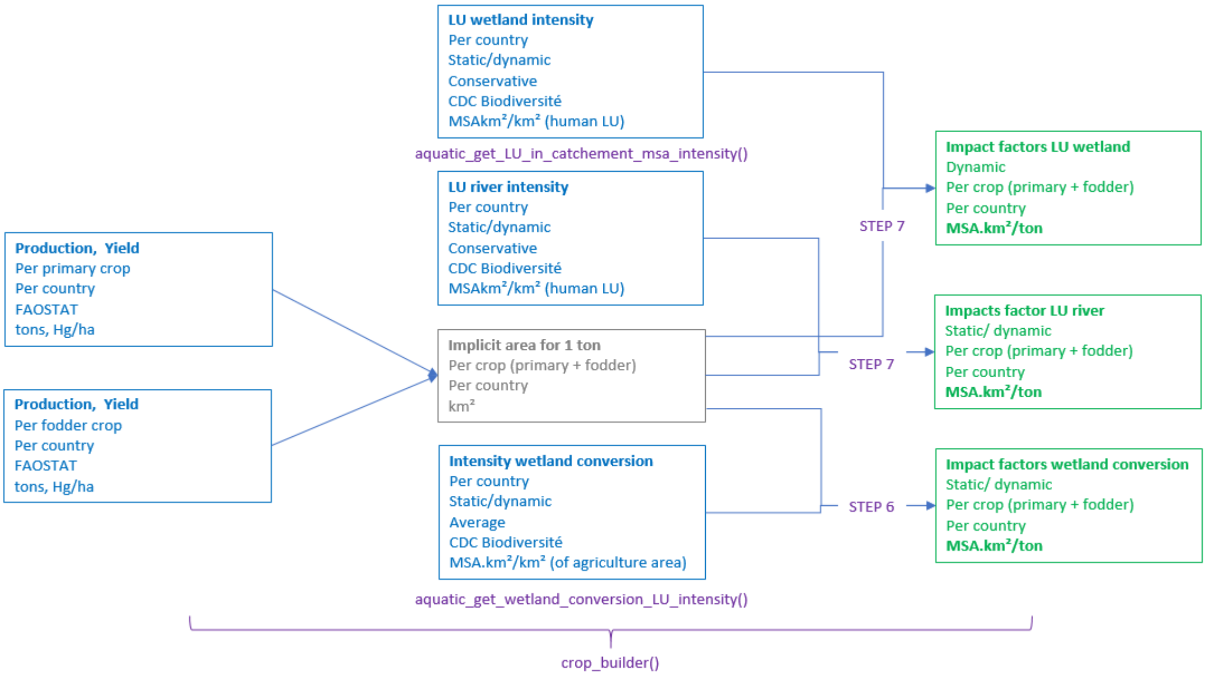


Figure 9: Overview of the construction of the freshwater biodiversity impact factors of the crops CommoTool linked to intensities expressed per unit of area

Figure 9 describes the data treatment process followed to compute the crops CommoTool factors in MSA.km²/tonne of crop related to **aquatic pressures "land use in catchment" for rivers and for wetlands and "wetland conversion".**

2.2.A.2.1 Wetland conversion

In STEP 6, dynamic and static intensities for wetland conversion (MSA.km^2/t of cropland area) are multiplied by the implicit area to obtain the corresponding impact factors.

```
    #STEP 6: Aquatic: wetland conversion section
    mutate(msa_aquatic_wetland_conversion_static = MSA_intensity_wetland_conversion_static
/ yield) %>%
    mutate(msa_aquatic_wetland_conversion_dynamic =
MSA_intensity_wetland_conversion_dynamic / yield) %>%
```

The computed impact factors fall into data quality tier 2, because they rely on national crop yields from FAOSTAT that are country specific linear factors. In this version of the GBS, we only have an average estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

2.2.A.2.2 Land use change in catchment

Static and dynamic, average and conservative, intensities for land use in catchment for rivers land use in catchment pressure for rivers (in MSA.km²/area of human land use type) are multiplied by the implicit area to obtain the corresponding impact factors.

For land use in catchment pressure for wetlands, intensities are expressed in MSA.km²/are of intensity weighted area. Therefore, to obtain impact factors for land use in catchment for wetlands, we multiply these intensities by the implicit area multiplied by the average national intensity for agricultural lands. As a reminder:

$$Intensity\% = 1 - MSA\%$$

```
    #STEP 7: Aquatic land use section
    mutate(
      msa_aquatic_land_use_river_static_wm = MSA_intensity_river_LU_static_wm /yield,
      msa_aquatic_land_use_river_static_cut = MSA_intensity_river_LU_static_cut / yield,
      msa_aquatic_land_use_river_dynamic_wm = MSA_intensity_river_LU_dynamic_wm / yield,
      msa_aquatic_land_use_river_dynamic_cut = MSA_intensity_river_LU_dynamic_cut / yield,

      msa_aquatic_land_use_wetland_static_wm = MSA_intensity_wetland_LU_static_wm * (1 -
average_msa) / yield,
      msa_aquatic_land_use_wetland_static_cut = MSA_intensity_wetland_LU_static_cut * (1 -
average_msa) / yield,
      msa_aquatic_land_use_wetland_dynamic_wm = MSA_intensity_wetland_LU_dynamic_wm * (1 -
average_msa) / yield,
      msa_aquatic_land_use_wetland_dynamic_cut = MSA_intensity_wetland_LU_dynamic_cut * (1
- average_msa) / yield)
```

The computed impact factors fall into data quality tier 2, because they rely national crop yields from FAOSTAT that are country specific linear factors. In this version, we have thus a **central or optimistic** impact factor, which is calculated under the **weighted mean scenario**, and a **pessimistic** impact factor calculated under the **cutoff scenario**.

2.2.A.3 About the use of implicit area

Figure 10 illustrates the cases of successive cropping, same stand crop and mixed crops with FAOSTAT data and shows the impacts in terms of computed implicit areas

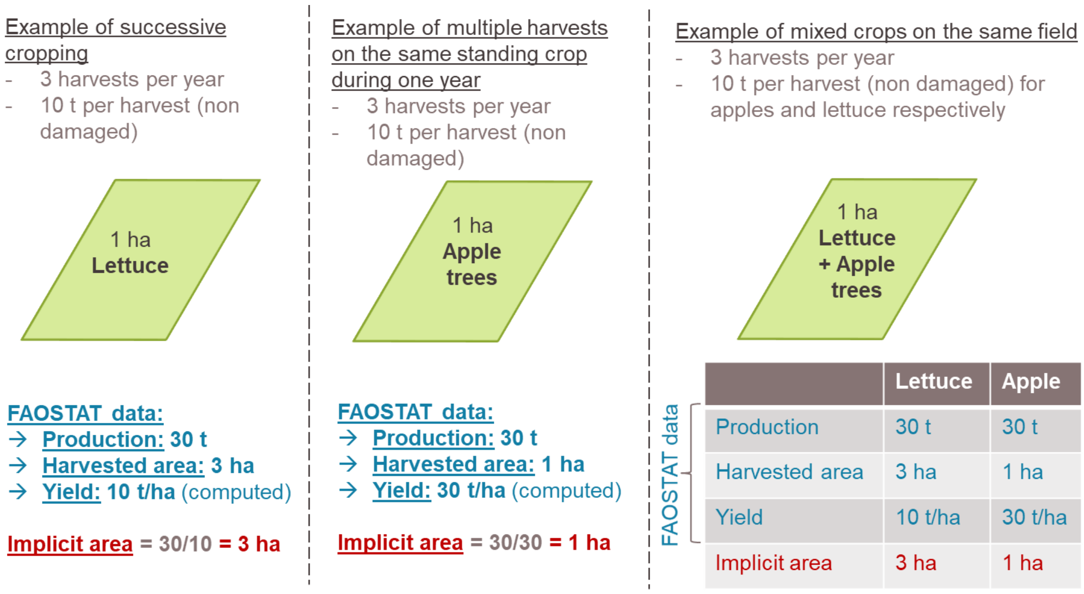


Figure 10: Illustration of the production data reporting method in FAOSTAT calculation and the implicit area[5] calculation, with three cases on 1 ha – successive cropping, same standing crop and mixed crops -

- For the **temporary crops with successive cropping** (example of lettuce in Figure 10), the implicit area calculated (3 ha) is much higher than the area physically occupied (1 ha). In the case where the temporary crop is harvested only once a year, it does not cause any problem.
- For **permanent crops with successive gatherings** (example of apple trees in Figure 10): the implicit area calculated (1 ha) reflects the real physical surface occupied by the crop during the year (without counting the damages and losses).

The default dimensioning of crop production's biodiversity impacts is based on the calculation of implicit areas from FAOSTAT data and the example of temporary crops with successive cropping demonstrates that the FAO methodology leads to double counting of agricultural lands. Consequently, the biodiversity impact factors related to land occupation (LU, E, F, LUR, LUW and WC pressures) are currently overestimated for crops with multiple harvests.

In order to retrieve the real physical land used for cropping and not double-count agricultural lands, one solution would be to get data on the **number of harvests per year for temporary crops** and to adjust the harvested areas / implicit areas with this information. For now, we have not yet found a comprehensive database on the topic for each crop and country.

[5]Conceptually, "harvested area" and "implicit area" are the same. However, in the GBS framework, implicit area designates a computed area whereas the harvested area data is reported by FAOSTAT. Moreover, the term "implicit area" is more generic and is used for other commodities which do not "harvest", for instance in the Mining CommoTool (CDC Biodiversité, 2020d).

B PRESSURES WITH IMPACT FACTORS EXPRESSED PER EMISSION OF NUTRIENTS

2.2.B.1 Terrestrial: atmospheric nitrogen deposition (N)

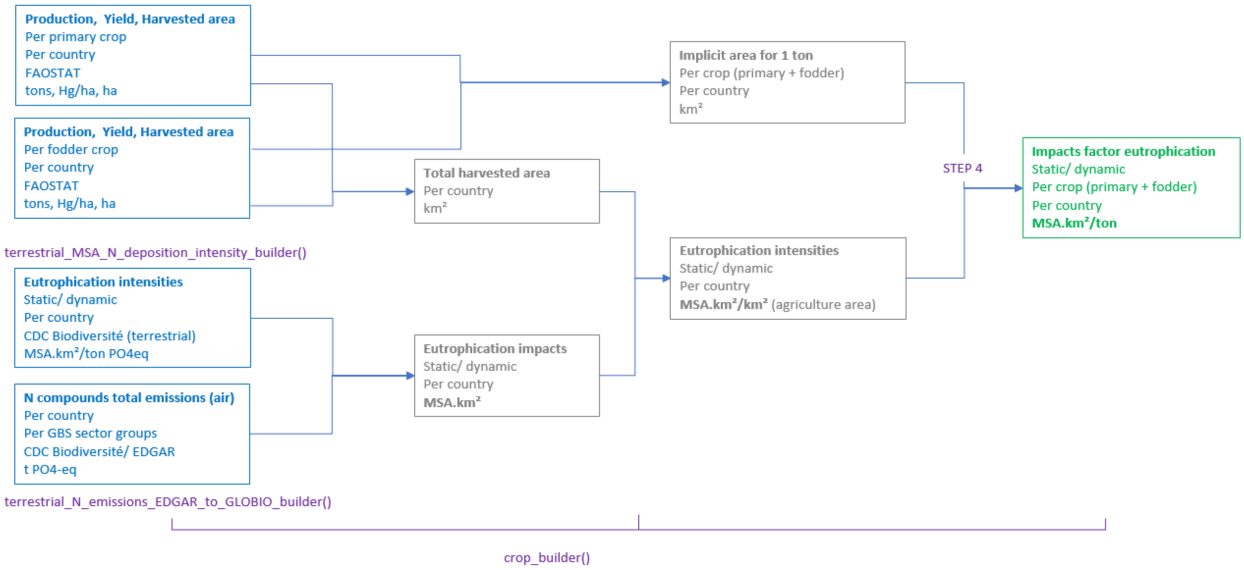


Figure 11: Overview of the construction of the terrestrial biodiversity impact factors of the crops CommoTool linked to atmospheric nitrogen deposition

In STEP 4, first, we compute national static and dynamic impacts for agriculture (in MSA.km²) by multiplying static and dynamic impact intensities (in MSA.km²/ t PO_4-eq) by national N-compound emissions (in t PO_4-eq). Then for a given crop, impact for 1 tonne is computed as the proportion of its implicit area (in km²) relatively to the national harvested area (in km²). National harvested area (in km²) is computed as the sum of all crops national production implicit areas based on FAOSTAT production data.

In practice, each impact factor (in MSA.km²/t) is therefore obtained by multiplying the corresponding impact intensity by national agriculture N-compound emissions then by multiplying by the implicit area and finally by diving by the national harvested area.

```
#STEP 4: Terrestrial: N deposition section
    mutate(
      msa_n_deposition_static = agriculture_crop_msa_intensity_static *
agriculture_crop_emissions / area_harvested_country /yield ,
      msa_n_deposition_dynamic = agriculture_crop_msa_intensity_dynamic *
agriculture_crop_emissions / area_harvested_country /yield) %>%
```

The computed impact factors fall into data quality tier 2, because they are based on national yields and production data (tier 2) combined with a tier 2 impact factor from the terrestrial module. In this version of the GBS, we only have an average estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

2.2.B.2 Freshwater eutrophication (lakes)

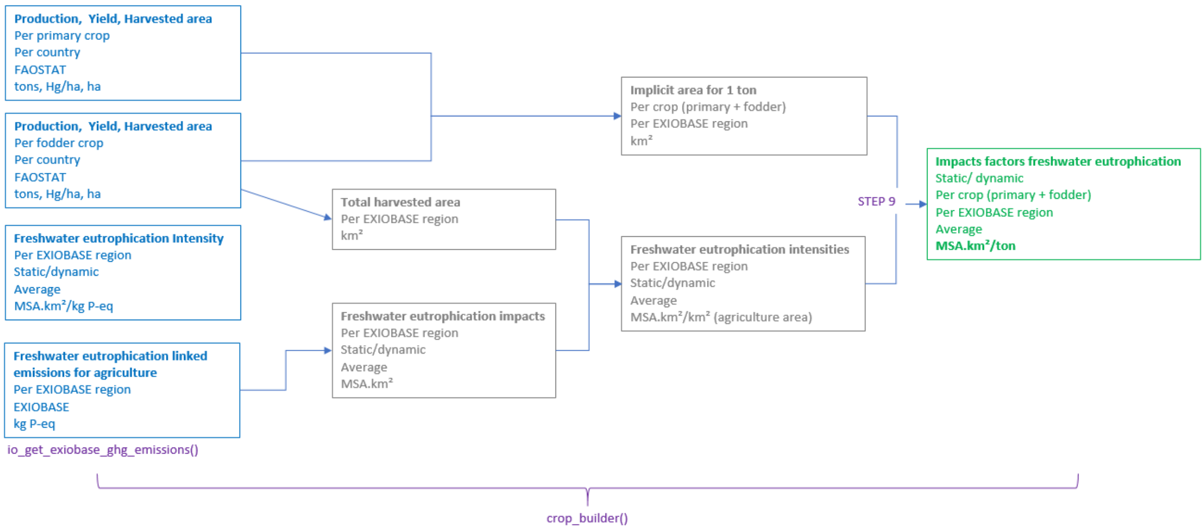


Figure 12: Overview of the construction of the terrestrial biodiversity impact factors of the crops CommoTool linked to freshwater eutrophication

Following the same principle than for atmospheric nitrogen deposition pressure, in STEP 9, first, we compute static and dynamic impacts for agriculture (in MSA.km²) at EXIOBASE region level by multiplying static and dynamic impact intensities (in MSA.km²/ t P-eq) by EXIOBASE region freshwater eutrophication linked emissions (in t P-eq Then for a given crop, impact for 1 tonne is computed as the proportion of its implicit area (in km²) relatively to the EXIOBASE region's harvested area (in km²). EXIOBASE region's harvested area (in km²) is computed as the sum of all crops implicit areas based on FAOSTAT annual production data.

In practice, each impact factor (in MSA.km²/ton) is therefore obtained by multiplying corresponding impact intensity by EXIOBASE freshwater eutrophication linked emissions then by multiplying by the implicit area and finally by diving by the EXIOBASE region's harvested area.

```
#STEP 9 Aquatic lake eutrophication section. Computation is done at the exiobase region
level
  mutate(
      msa_aquatic_lakes_eutrophication_static = MSA_intensity_lakes_eutrophication_static *
emission_P_equivalent_agriculture /
        area_harvested_exiobase_region /yield,
```

```
      msa_aquatic_lakes_eutrophication_dynamic = MSA_intensity_lakes_eutrophication_dynamic
* emission_P_equivalent_agriculture /
        area_harvested_exiobase_region /yield,
      join_code = paste(exiobase_region_id, item_code)
    )
```

The computed impact factors fall into data quality tier 2, because they are based on national yields and production data (tier 2) combined with a tier 2 impact factor from the aquatic module.

In this version of the GBS, we only have an average estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

C PRESSURES WITH IMPACT FACTORS EXPRESSED PER EMISSION OF GHG

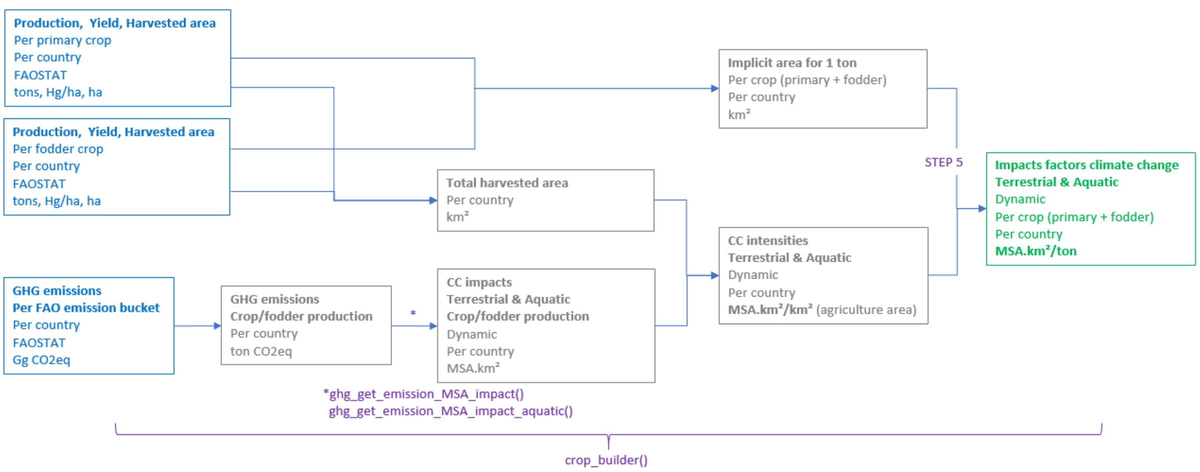


Figure 13: Overview of the construction of the biodiversity impact factors of the crops CommoTool related to climate change

Figure 13 describes the data treatment process used to compute the crops CommoTool factors in MSA.km²/tonne of crop for terrestrial and freshwater biodiversity impacts caused by **climate change.**

The contributions of a certain quantity of GHG emission to terrestrial Climate change (CC) and freshwater Hydrological disturbance due to climate change (HD_{CC}) pressures are assessed by specific functions explained in the terrestrial (CDC Biodiversité, 2020e) and freshwater module papers (CDC Biodiversité, 2020b), namely `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()`. Practically, both functions compute a **biodiversity impact in MSA.km² linked to a given GHG emission in tonnes CO_2-eq**.

CDC BIODIVERSITÉ

We use GHG emissions data for agriculture from FAOSTAT. It is available **at country level for ten emission source categories**. Definition for each category can be found on FAOSTAT website (FAOSTAT, 2019a). The emissions of FAOSTAT category sources are allocated between the different agricultural activities assessed by the GBS following the rules in described in Table 5 (table `gbs_GHG_FAO_allocation`):

FAO_emission_category	allocation_type	agriculture_extensive	agriculture_irrigated	agriculture_intensive	agriculture_biofuels	agriculture_rice	agriculture_organic	cattle_grazing	cattle_cattle
Enteric Fermentation									X
Manure management									X
Rice cultivation						X			
Synthetic Fertilizers	surface		X	X					
Manure applied to soils	surface	X	X	X					
Manure left on pasture								X	
Crop residues	surface	X	X	X					
Cultivation of organic soils							X		
Burning - Savanna	surface	X	X	X	X			X	
Burning - Crop residues	surface	X	X	X					

Table 5: Allocation of FAOSTAT GHG emissions to GBS assessed activities[6]

When the emission source category is shared by multiple agricultural activities, allocation is done based on the surface area. For example, if in a fictive country, 10 000 Gg CO_2-eq are emitted due to "Synthetic fertilizers", and the country has 20 000 km² of irrigated crops, and 80 000 km² of intensive crops, then $\frac{20\,000}{20\,000+80\,000} \times 10\,000$ Gg CO_2-eq, 2 000 Gg CO2-eq would be attributed to irrigated crops and the rest to the intensive crops. Impact factors for organic agriculture are not available for GBS 1.0 but we isolated this practice in the perspective of further developments. The description and allocation rules for the 2 livestock categories, cattle and grazing, are further explained in the review report on livestock CommoTool (CDC Biodiversité, 2020c).

In STEP 5, based on those allocation rules we compute national GHG emissions for agriculture excluding rice production (sum of all agriculture activities: extensive, irrigated, intensive, biofuels and organic). Then we use the functions `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()` to compute the **national terrestrial and aquatic biodiversity impacts in MSA.km²**. Then for a given crop, impact for 1 tonne is computed as the proportion of its implicit area (in km²) relatively to the national harvested area (in km²). National harvested area (in km²) is computed as the sum of all crops implicit areas based on FAOSTAT annual production data.

In practice, each impact factor (in MSA.km²/t) is therefore obtained by applying corresponding impact function (terrestrial or aquatic) to national agriculture GHG emissions then by multiplying by the implicit area and finally by dividing by the national harvested area.

```
#Terrestrial climate change
#for each combination of (crop, country)
ghg_get_emission_MSA_impact("CO2", "formula", emission_agri_ex_rice *10^3,  "tons", 100) /
harvested_area_country/ yield

#Hydrological disturbance due to climate change
#for each combination of (crop, country)
ghg_get_emission_MSA_impact_aquatic("CO2", "formula", emission_agri_ex_rice *10^3,  "tons",
100) / harvested_area_country / yield
```

If the considered crop is <u>rice</u> then specific additional emissions are accounted for on top of the agriculture general ones described above. Indeed, rice production implies specific methane gas emissions from the anaerobic decomposition of organic matter in paddy fields accounted in FAOSTAT emission category “Rice Cultivation” (Table 5).

To compute this additional impact factor, we apply the functions `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()` to national GHG emissions due to rice production to compute the **national terrestrial and aquatic biodiversity impacts in MSA.km²**. Then impact for 1 tonne of rice is obtained by dividing national impact by the national rice production (FAOSTAT).

```
#Additional terrestrial climate change for rice production
#applied to each country
ghg_get_emission_MSA_impact("CO2", "formula", emission_rice *10^3,  "tons", 100) /
production

#Additional Hydrological disturbance due to climate change for rice production
#applied to each country
ghg_get_emission_MSA_impact_aquatic("CO2", "formula", emission_rice *10^3,  "tons", 100) /
production
```

These computations yield to dynamic impact factors at the country level. Static impacts of climate change are not attributed as explained in section 4.3. The computed impact factors fall into data quality tier 1, because they are based on tier 1 impact factors (MSA.km^2/kg CO_2-eq). In this version of the GBS we only have an average estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

D PRESSURE WITH IMPACT FACTOR EXPRESSED PER M^3

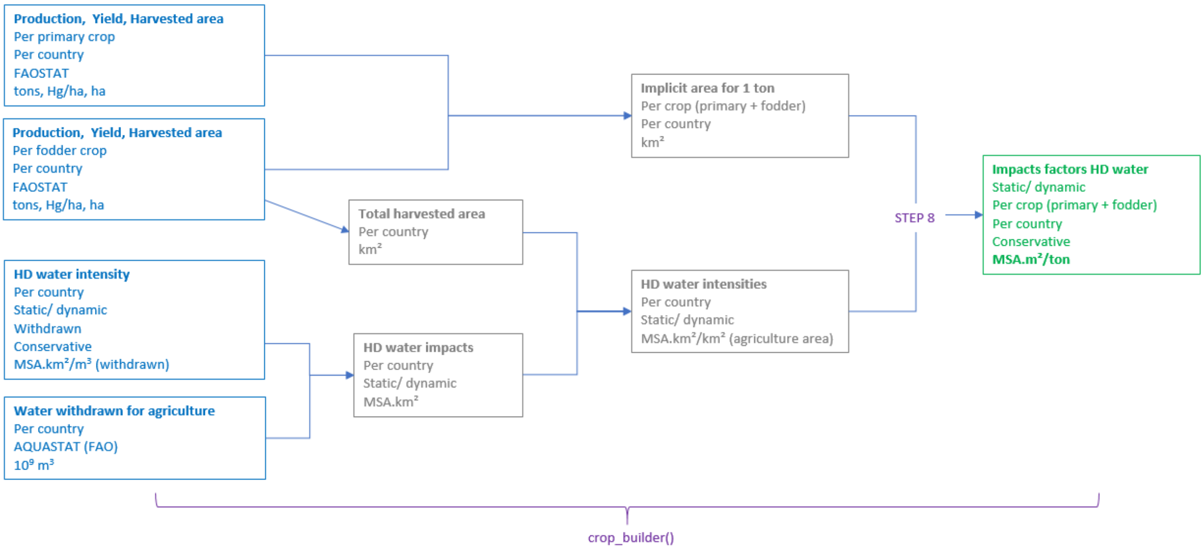


Figure 14: Overview of the construction of the biodiversity impact factors of the crops CommoTool linked to hydrological disturbance

In STEP 8, for **hydrological disturbance from direct water use** pressure, we use intensities for **withdrawn water (MSA.km² per m³)**. Two intensity calculations modes are used: **central** ("wm" for weighted-mean in the code) and **conservative** ("cut" for cut-off in the code).These are combined to data on **national water withdrawal for crop agriculture from AQUASTAT** to compute total associated national impacts (in MSA.km²) for crop agriculture. Then for a given crop, impact for 1 tonne is computed as the proportion of its implicit area (in km²) relatively to the national harvested area (in km²). National harvested area (in km²) is computed as the sum of all crops implicit areas based on FAOSTAT annual production data.

In practice, each impact factor (in MSA.km²/m³) is therefore obtained by multiplying corresponding impact intensity by national water withdrawals volumes for agriculture (in m³) then by multiplying by the implicit area (in km²) and finally by diving by the national harvested area (in km²).

```
#STEP 8 Aquatic hydrological disturbance (water usage part) section
left_join(agriculture_water_withdrawals,  by = "globio_country_code") %>%
mutate(
  msa_aquatic_HD_water_withdrawn_static_wm = MSA_intensity_HD_water_withdrawn_static_wm *
agriculture_water_withdrawal_country / area_harvested_country / yield,
  msa_aquatic_HD_water_withdrawn_static_cut = MSA_intensity_HD_water_withdrawn_static_cut *
agriculture_water_withdrawal_country / area_harvested_country / yield,
  msa_aquatic_HD_water_withdrawn_dynamic_wm = MSA_intensity_HD_water_withdrawn_dynamic_wm *
agriculture_water_withdrawal_country / area_harvested_country / yield,
  msa_aquatic_HD_water_withdrawn_dynamic_cut = MSA_intensity_HD_water_withdrawn_dynamic_cut
* agriculture_water_withdrawal_country / area_harvested_country / yield
)
```

The computed impact factors fall into data quality tier 2, because they involve national crop yields from FAOSTAT, and regionalized water extraction data that are country specific linear factors and combine them with tier 2 intensities from the aquatic module (CDC Biodiversité, 2020b).

E SYNTHESIS OF THE DIMENSIONING METHODOLOGY

Table 6 and Table 7 provide an overview of the outputs of this dimensioning methodology.

Terrestrial Pressure		Land Use (LU)	Encroachment (E)	Fragmentation (F)	Atmospheric Nitrogen deposition (N)	Climate change (CC)
Biodiversity impact intensity unit		MSA.km^2/km^2 of land use type (agricultural land)	MSA.km^2/km^2 of encroaching land use type	MSA.km^2/km^2 of fragmenting land use type	MSA.km^2 / tonne of PO_4-eq emitted	MSA.km^2 / kg CO_2-eq emitted
CommoTool	Crops CommoTool impact unit	MSA.km^2 / tonne of crop				
CommoTool	Detail level (geographic, items)	FAOSTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops
CommoTool	Data quality tier	2	2	2	2	1

Table 6: Synthesis of the methodology and tool coverage for each terrestrial pressure

Freshwater pressure		Hydrological disturbance due to direct water use (HD_{water})	Land Use in catchment for rivers (LUR) and wetlands (LUW)	Wetland conversion (WC)	Freshwater eutrophication (FE)	Hydrological disturbance due to climate change (HD_{CC})
Biodiversity impact intensity unit		MSA.km^2/m^3 withdrawn (for agriculture)	Rivers: MSA.km^2/km^2 of human land use Wetlands: MSA.km^2/km^2 intensity weighted	MSA.km^2/km^2 of agricultural land	MSA.km^2/kg P-eq emitted linked to agriculture	MSA.km^2 / kg CO_2-eq emitted
CommoTool	Crops CommoTool impact unit	MSA.km^2 / tonne of crop				
CommoTool	Detail level (geographic, items)	AQUASTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops	FAOSTAT countries FAOSTAT crops	EXIOBASE regions	FAOSTAT countries FAOSTAT crops
CommoTool	Data quality tier	2	2	2	2	1

Table 7: Synthesis of the methodology and tool coverage for each aquatic freshwater pressure

2.3 Example

A INPUT DATA

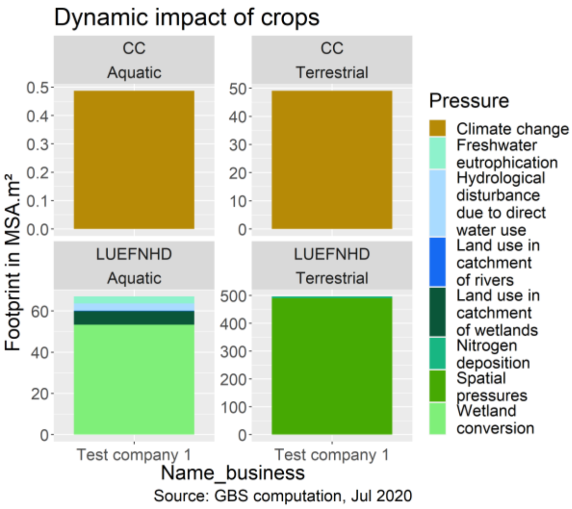
We illustrate the methodology using a fictive sourcing for 2 crops, one primary crop (Soybeans[7]) and one fodder crop (Forage and silage, maize[8]) among 10 countries, accounting for 20 sourced items of 1 tonne each, 20 tonnes in total. The chosen countries are among the biggest producers of soybeans in 2017 according to FAOSTAT primary crops data, and are the same as in the first GBS publication (CDC Biodiversité, 2017b). The type of agriculture (*i.e.*, intensive, low-input or irrigation-based) is not specified here as global national output data from FAO does not present this level of granularity. Therefore, impact results for 1 tonne of commodity (in MSA.km²) show average national impacts representative of average national mixes of agriculture types.

B **THE BIODIVERSITY IMPACT FACTOR (IN MSA.KM²/T) OF THE CROP AND COUNTRY OF INTEREST IS APPLIED TO EACH OBSERVATION**. THE CALCULATION PROCESS IS CARRIED OUT IN `TEST-CROP.RMD` USING BIODIVERSITY IMPACT FACTORS COMPUTED BY THE CROPS COMMOTOOL AND GATHERED IN `GBSTOOLBOX::CROP_MSA_COUNTRY`. THE `GBSTOOLBOX` PACKAGE CONTAINS THE EXAMPLE FILE `EXAMPLE_COMMODITY_CROPS_INPUT.RDA`. THE SUCCESSIVE APPLICATION OF `COMMODITY_PRE_TREATMENT()` AND `COMMODITY_EVALUATOR()` LEADS TO THE RESULTS DISPLAYED BELOW.MAIN RESULTS

Figure 15 and Figure 16 display the total dynamic and static impacts for the full sourcing (20t of crop commodities in 10 countries). As a reminder, a positive figure represents a biodiversity loss, whereas a negative figure is a biodiversity gain. Results are expressed in MSA.m². The conservative impact factors are used for impacts on aquatic biodiversity (CDC Biodiversité, 2020b). Results related to climate change, whether terrestrial or aquatic, are reported separately.

---

[7] FAO name
[8] FAO name



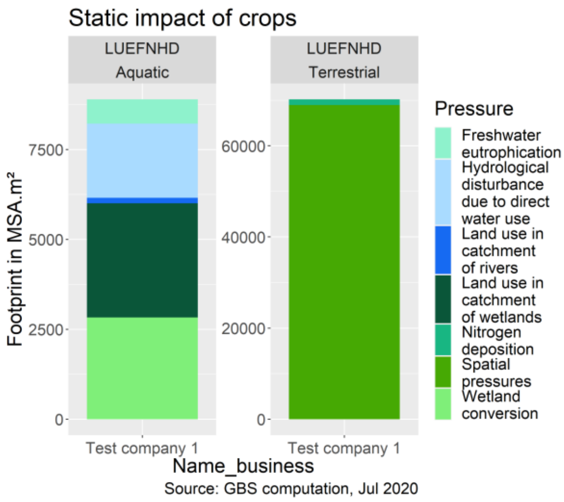


Figure 15: Total dynamic impacts of the example crop inventory

Figure 16: Total static impacts of the example crop inventory

Dynamic impacts: the most impacting dynamic aquatic pressure is wetland conversion, followed by land use in catchment for wetlands. "Spatial pressures" displayed in the terrestrial pressures is the aggregation of "Land use", "Encroachment" and "Fragmentation", which are intertwined. They are predominant for dynamic terrestrial impacts.

Static impacts: the range of static impacts is about 100 to 200 times greater. The terrestrial biodiversity losses caused by the example crop inventory amount to 70 175 MSA.m² with a major responsibility of spatial pressures, and total losses due to aquatic pressures reach up to 8 892 MSA.m², with a major contribution of "land use in catchment for wetlands" (36%), followed by "wetland conversion". Static aggregated terrestrial impacts are also around 8 times greater than the static aquatic impacts.

Table 8 focuses on the dynamic terrestrial impacts assessed for the commodity "Soybeans" with the latest version of the crops CommoTool. These results are compared with the results of the same sourcing in the

GBS first publication (CDC Biodiversité, 2017a) in order to track the evolution of the crops CommoTool methodology.

				Dynamic biodiversity impact in MSA.m²					
Country	Commodity	Tonnes	Yield[9] (t/ha)	LU	N	F	E	Terrestrial CC	Total
Paraguay	Soybeans	1	2.82	35.7	0.16	0	0	1.42	**37.32**
China	Soybeans	1	1.79	15.9	1.08	0	0	8.93	**25.94**
Brazil	Soybeans	1	3.02	11.0	0.37	0	0	2.08	**13.41**
Argentina	Soybeans	1	2.93	29.1	0.22	0	2.09	1.36	**32.73**
United States	Soybeans	1	3.23	0.4	0.26	0	0	3.62	**4.29**
India	Soybeans	1	0.97	13.1	0.87	0	0	9.11	**23.06**
Uruguay	Soybeans	1	2.10	57.2	0.87	0	0	3.11	**61.17**
Ukraine	Soybeans	1	2.07	16.6	0.10	0	0	2.66	**19.37**
Bolivia	Soybeans	1	2.33	80.0	0.25	0	12.6	1.65	**94.48**
Canada	Soybeans	1	2.89	41.2	0.18	0	2.30	3.24	**46.94**

Table 8: Extract of the assessment results - dynamic terrestrial impacts of soybeans

The differences with the same example in our first publication can be explained by the following factors: firstly, since the last publication, **the FAO yield data used to build crop impact factors have been updated**. For example, the impact of 1 t of Soybeans in Uruguay have roughly doubled compared to the results in the last publication, and at the same time, it has become less efficient: its yield has been divided per 2, from 2.4 t/ha to 1.2 t/ha.

Differences in the **atmospheric nitrogen deposition** impacts can be explained by changes in the methodology since the last publication, especially concerning the introduction of **eutrophication potentials.** Indeed, N-equivalent used to be computed based on molecular masses, while the eutrophication potentials from the CML database (CML - Department of Industrial Ecology, 2019) is now used.

For **fragmentation** and **encroachment**, the gains of biodiversity have been capped at 0 MSA.km^2: most impacts are now null. Gains due to fragmentation and encroachment can be explained as follows: when human activities increase, more natural spaces are fragmented and encroached. This leads to a decrease of the surface areas of such natural spaces so that the fragmenting and encroaching pressures are applied to smaller surfaces. For instance if an area of 10 km² is fragmented with a 45% MSA loss, then the MSA loss due to fragmentation is 4.5 MSA.km² and when this area shrinks to 1 km² with a 65% MSA loss, the loss due to fragmentation dwindles to only 0.65 MSA.km² even if the area is more fragmented. -0.65-(-4.5) = +3.85 MSA.km2: it generates gains. An error in previous figures (CDC Biodiversité, 2017a) for Argentina, Bolivia and Canada has also been corrected and impacts are now biodiversity losses (were gains).

[9] In this example, the computations are done with yield data of 2017 from FAOSTAT. However, yield data will soon be changed to a five-year average of FAOSTAT annual yield data.

For terrestrial **climate change**, differences can be explained by **changes in the characterisation factor** between the first publication and the most recent methodology. It is now $4.37.10^{-9}$ MSA.km²/kg CO_2-eq, for more details please refer to the terrestrial review report (CDC Biodiversité, 2020e). The agricultural sectors GHG emissions data reported by FAOSTAT have also been updated, but they are quite stable and are not the main factor explaining results difference.

2.4 Tests

A FODDER CROPS YIELDS

We test that:

- The **needed input data to build the fodder yield data table** (in .rda) **are available in the package**, which are the correspondence table between the fodder crops and primary crops in FAO, EXIOBASE nomenclature; different datasets of fodder crop production and yield data provided by FAOSTAT; the country correspondence tables, with the nomenclature provided by FAOSTAT directly; and the primary crop yields.
- The generated fodder crops yield table is not null
- The evolution of fodder crop yield data after multiple runs meaning that if we run the function that builds the fodder crops yield table (`crop_fodder_yield_builder()`), the characteristics of the new generated fodder crops yield table are equal to the existing ones, and display the eventual differences.
- In the existing fodder crops yield table, the yield directly retrieved from FAOSTAT for fodder crops are not replaced by proxies from primary crops.

B PRIMARY CROPS TESTS

Various tests are performed to check that impact factors for crops commodities are consistent with GLOBIO-IMAGE outputs, meaning that total impacts obtained by applying impact factors to FAOSTAT world production are in-line with total impacts from GLOBIO-IMAGE outputs. Those tests are summarized in Figure 17 and Figure 18. Those tests also allow us to check if there are mistakes in the code. Green lines show impacts factors category where the test on global figures is acceptable, yellow lines where the test is not fully acceptable. Red lines would show absurd values which we do not have here.

Check item name	Unit	Value	Computation	Benchmark ratio	Validation
World harvested area - FAO	km²	14 540 828			
World harvested area - FAO implicit - benchmark	km²	14 498 616			
World harvested area - GLOBIO	km²	16 514 073	GLOBIO/ FAO implicit	113,9%	too high
LU dynamic impact - benchmark	MSA.km²	70 773	GLOBIO world agriculture land use dynamic impacts		
LU dynamic impact - total	MSA.km²	66 970	production * impact factors	94,6%	
LU static impact - total	MSA.km²	12 419 246	production * impact factors		
LU static impact - hybrid benchmark	%	85,5%	1 - Word average MSA% for agriculture		
LU static impact - total	%	85,7%	production * impact factors / FAO world implicit harvested area	100,1%	
GLOBIO world human land use type area	km²	39 035 982			
E dynamic impact - benchmark	MSA.km²	-7 208	GLOBIO world harvested area/ GLOBIO world human LU area * GLOBIO world encroachement dynamic impacts		
E dynamic impact - total	MSA.km²	1 098	production * impact factors	-15,2%	difference due to gains cap
E static impact - benchmark	MSA.km²	2 688 145	GLOBIO world harvested area/ GLOBIO world human LU area * GLOBIO world encroachement static impacts		
E static impact - total	MSA.km²	2 405 784	production * impact factors	89,5%	within acceptable range given that spatial configuration not accounted in benchmark
F dynamic impact - benchmark	MSA.km²	-2 238	GLOBIO world harvested area/ GLOBIO world human LU area * GLOBIO world fragmentation dynamic impacts		
F dynamic impact - total	MSA.km²	2	production * impact factors	-0,1%	difference due to gains cap
F static impact - benchmark	MSA.km²	1 004 886	GLOBIO world harvested area/ GLOBIO world human LU area * GLOBIO world fragmentation dynamic impacts		
F static impact - total	MSA.km²	526 565	production * impact factors	52,4%	inline with average split ratio with infrastructures
Total N-compounds emissions for agriculture - EDGAR	kg PO4-eq	39 036 282			
Total N-compounds emissions for agriculture - EDGAR	kg PO4-eq	180 112 925			
N dynamic impact - benchmark	MSA.km²	869	Agriculture N emissions/ Total N emissions * GLOBIO world N-deposition dynamic impacts		
N dynamic impact - total	MSA.km²	2 231	production * impact factors	256,9%	difference due to gains cap
N static impact - benchmark	MSA.km²	183 059	Agriculture N emissions/ Total N emissions * GLOBIO world N-deposition static impacts		
N static impact - total	MSA.km²	265 642	production * impact factors	145,1%	too high
FAO total GHG emission for crop	t CO2eq	3 688 819 035 091			
CC dynamic impact - benchmark	MSA.km²	16 120	FAO total crop GHG emission/ total emissions * GLOBIO world CC dynamic impacts		
CC dynamic impact - total	MSA.km²	16 082	production * impact factors	99,8%	

Figure 17: Tests for primary crops - terrestrial pressures part

Check item name	Unit	Value	Computation	Benchmark ratio	Validation
HD_{cc} dynamic impact - benchmark	MSA.km²	157	FAO total crop GHG emission/ total emissions * GLOBIO world HD_{cc} dynamic impacts		
HD_{cc} dynamic impact - total	MSA.km²	157	production * impact factors	99,8%	inline with HD split ratio for HD
WC static impact - benchmark	MSA.km²	561 363	GLOBIO world WC static impacts		
WC static impact - total	MSA.km²	471 558	production * impact factors	84,0%	too low
WC dynamic impact - benchmark	MSA.km²	999	GLOBIO world WC dynamic impacts		
WC dynamic impact - total	MSA.km²	3 142	production * impact factors	314,5%	difference due to gains cap
GLOBIO world intensity weighted area	km²	27 160 806			
GLOBIO world agriculture intensity weighted area	km²	14 124 905			
LUW static impact - benchmark	MSA.km²	668 693	Agriculture intensity weighted area/ total intensity weighted area * GLOBIO world LUW static impact		
LUW static impact - total average	MSA.km²	612 405	production * impact factors	91,6%	
LUW static impact - total conservative	MSA.km²	1 441 482	production * impact factors	215,6%	
LUW dynamic impact - benchmark	MSA.km²	1 543	Agriculture intensity weighted area/ total intensity weighted area * GLOBIO world LUW dynamic impact		
LUW dynamic impact - total average	MSA.km²	1 645	production * impact factors	106,6%	ok
LUW dynamic impact - total conservative	MSA.km²	4 954	production * impact factors	321,0%	
LUR static impact - benchmark	MSA.km²	18 004	Agriculture area/ total human LU area * GLOBIO world LUR static impact		
LUR static impact - total average	MSA.km²	22 129	production * impact factors	122,9%	ok
LUR static impact - total conservative	MSA.km²	49 766	production * impact factors	276,4%	
LUR dynamic impact - benchmark	MSA.km²	67	Agriculture area/ total human LU area * GLOBIO world LUR dynamic impact		
LUR dynamic impact - total average	MSA.km²	81	production * impact factors	120,5%	difference due to gains cap
LUR dynamic impact - total conservative	MSA.km²	231	production * impact factors	344,3%	difference due to gains cap
AQUEDUCT total water withdrawal	m³	11 911 580 537 641			
AQUASTAT water withdrawal for agriculture	m³	6 966 587 300 000			
AQUASTAT total water withdrawal	m³	21 700 212 802 000			
HDwater static impact - benchmark	MSA.km²	348 041	AQUASTAT water withdrawal agriculture/ AQUEDUCT water withdrawal total * GLOBIO world HDwater static impact		
HDwater static impact - total average	MSA.km²	148 851	production * impact factors	42,8%	inline with split ratio with infra & CC
HDwater static impact - total conservative	MSA.km²	401 952	production * impact factors	115,5%	
HDwater dynamic impact - benchmark	MSA.km²	-119	AQUASTAT water withdrawal agriculture/ AQUEDUCT water withdrawal total * GLOBIO world HDwater dynamic impact		
HDwater dynamic impact - total average	MSA.km²	140	production * impact factors	-117,5%	difference due to gains cap
HDwater dynamic impact - total conservative	MSA.km²	621	production * impact factors	-521,4%	difference due to gains cap
EXIOBASE freshwater eutrophication emissions for agricultur	kg P-eq	2 943 575 059			
EXIOBASE freshwater eutrophication emissions total	kg P-eq	3 006 595 406			
FE static impact - benchmark	MSA.km²	157 849	EXIOBASE emissions agriculture/ Exiobase emissions total * GLOBIO world FE static impact		
FE static impact - total	MSA.km²	153 649	production * impact factors	97,3%	
FE dynamic impact - benchmark	MSA.km²	419	EXIOBASE emissions agriculture/ Exiobase emissions total * GLOBIO world FE dynamic impact		
FE dynamic impact - total	MSA.km²	445	production * impact factors	106,2%	
FAO total GHG emission for agriculture	t CO2eq	10 575 506 422 100			
EXIOBASE total GHG emission for agriculture	t CO2eq	5 909 730 025 891		55,9%	too low

Figure 18: Tests for primary crops - aquatic pressures part

3 Dimensioning the crop production impacts – Refined assessments

The previous sections build crops biodiversity impact factors based on national average crops yields from FAOSTAT. If the assessed entity can provide **custom and more precise yield data**, average yield data can be replaced by the custom ones to obtain more consistent biodiversity impact factors in the CommoTool.

4 Attributing the crop production impacts to different crop types

4.1 Crop production, a multifunctional process

In the Life-Cycle Assessment framework, **co-products** are defined as "any of two or more products coming from the same unit process or system" according to [ISO 14044:2006] and ILCD handbook (European Commission & Joint Research Centre, 2010). They are generated by **multifunctional processes**, which deliver several goods and/or services. Figure 19 illustrates the multifunctional aspect of crop production using the vocabulary based on the nomenclature of EXIOBASE.

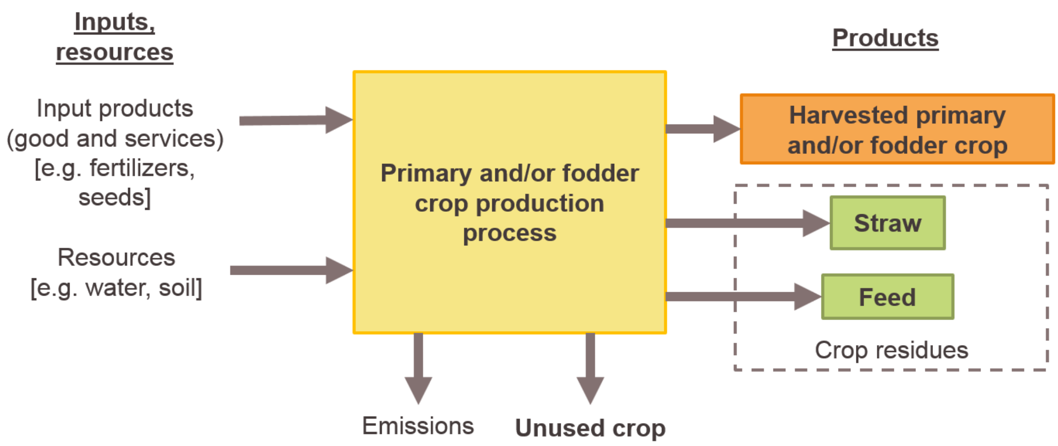


Figure 19: Simplified flowchart of primary and/or fodder crop production to illustrate the multifunctional aspect of the process. Arrow thickness is not representative of the flow importance

Here are defined each types of material flows mentioned in the Figure 19, primary crops and fodder crops were defined in 2.1A:

<u>Used extraction</u> is an input entering any economy, namely that the used extracted material acquires the status of a product. Here the used extraction is the **harvested primary or fodder crop**.

<u>Unused extraction</u> are materials extracted from the environment without the intention of being used, therefore remaining outside of the economy on purpose (EUROSTAT, 2013).

<u>Crop residues:</u> primary crop harvest is commonly just a fraction of the actual cultivated total plant biomass. The **residual biomass**, called crop residues, such as straw, leaves, etc. are often subject to **further economic use**, such as feed and bedding for livestock husbandry, or input for energy production etc. Residues left in the field and ploughed in the soil or burnt are **not considered as used extraction**. Crop residues can be divided into two sub-categories:

- **<u>feed:</u>** crop residue intended to be fed directly to food producing animals,
- **<u>straw</u>** crop residue that comes from dry stems and leaves left after the harvest of cereals, legumes and other crops (Feedipedia, n.d.). It is highly fibrous and covers diverse uses other than human food (as it is not digestible by humans), such as fuel and biofuel, construction, paper etc. In agriculture, it could be used as fertilizer for the successive crop if it is left on the field, protection against erosion and feed or bedding for animals. Straws can be used for animal feeding purposes, however, they **are considered as low-value roughage** according to the French Livestock Institute (IDELE, n.d.) and interesting only for animals with low nutritional needs.

In this module, both crop residues and the source primary and/or fodder crops can be considered as **co-products** because the production of the crop residues is unavoidable and simultaneous to the production of the primary crops and fodder crops.

4.2 Allocation rules choices

As crop residues production is indissociable from the production of primary crop and fodder crop products, **allocation is needed**. In the GBS 1.0 version we use economic allocation.

As a reminder economic allocation is based on the market value of each output product when they leave the common process. If the prices vary over the reporting period, averages can be used.

$$\begin{aligned} &Biodiversity\ impact\ of\ output\ i \\ &\qquad = \frac{Output\ i\ market\ value}{Total\ market\ value\ of\ the\ process\ outputs} \times Process\ biodiversity\ impact \end{aligned}$$

Concerning the economic value of cereal straw, we apply the same rule than AGRIBALYSE (Koch & Salou, 2016), a Life Cycle Inventory (LCI) database specialized in agriculture launched by ADEME, the French environment and energy agency. In AGRIBALYSE, for cereal and legume straw, the authors choose an economic allocation between grains and straw and attribute **100% of the impact to the grains and no impact**

to the straw, except for the biogenic CO_2 (*i.e.* carbon stocked or emitted by natural sources in short-time perspectives).

Concerning the economic value of feed: the use of crop residues for animal feeding purposes is highly variable depending on the localisation and the agricultural system (whether it is intensive or extensive livestock husbandry). Usually, crop residues (part of roughages) are not digestible for monogastric animals (hens, pigs) and only ruminants are concerned by this item. They are considered as low-quality feed and should not be used for high producing animals such as lactating cows or meat-producing animals according so some agronomic studies (Agriculture & rural development department, Province of Kwazulu-Natal (South Africa), n.d.). They have quite a low protein-content, are highly fibrous and not easily digestible, but play an important part in developing countries' animal feeding rations. Moreover, chemical treatments can also be applied to the crop residues to enhance their digestibility and N-value, as explained above for the straws.

Concerning the economic value of unused extractions: by definition, unused extractions are outside of the economy so in the context of an economic allocation no impact should be attributed to them.

In GBS 1.0, we use an **economic allocation** and we consider that crop residues have a low economical value and that unused products are outside of the economy so considered as wastes. Therefore, for now, the dimensioned biodiversity impacts in described in section 2 are fully allocated to the main products (primary and fodder crops).

Further research on the use of crop residues and their economic value in the livestock husbandry module could improve the chosen allocation rules. Indeed, crop residues represent a great share of the global vegetal biomass production (5 bn tonnes of dry matter in the EXIOBASE Environmental Extension material account, in Figure 20). Furthermore, we know that there are possible environmental impacts specific to straw management according to (Feedipedia, n.d.): for example, some chemical treatments (with alkali which break down lignin-carbohydrate linkages) are necessary to make straw easier to digest but can be source of hazard for the health of workers and for the environment. Besides, when crop residues are treated with ammonia and urea (which increases digestibility and N content), large amount of water is needed which can lead to NH_3 leaching.

Concerning unused extraction, economic allocation can pose problem for the cases where huge exceptional harvest losses happen. In FAOSTAT, the lost production and associated occupied areas occupied are not reported. Even though no commodity nor economic product is indeed commercialized due to the loss, resources (water, land etc.) are used and emissions occur leading to unallocated impacts.

4.3 Case of the static impacts of climate change

Past GHG emissions generated static impacts. They are not attributed to any economic activity due to the lack of data on the sources of all past emissions.

When they are known, past emissions of an assessed entity can however be considered as contributing to its static impacts.

5 Linkage with the input-output modelling

5.1 M Matrix

The output of the crops CommoTool is concretely a **table of characterisation factors for each pressure on biodiversity** with the units of **MSA.km²/t of crop, with one line per couple of {FAOSTAT crop; FAOSTAT country}**.

The **M matrix** in the Input-Output modelling framework (CDC Biodiversité, 2019b) is also a matrix of **characterisation factors, in MSA.km² per tonne of raw material or commodity**. As for both primary crops and fodder crops, we used EXIOBASE items in the CommoTool, therefore the only difference is the **geographical aggregation.** It does not always go down to country level, as some countries are grouped in macro regions. To have this aggregated level, weighting computation is done.

First, the **weight of the production of a given crop in a given country over the total production of the same crop in the EXIOBASE region containing the country of interest** is computed by **grouping all the countries within the same EXIOBASE region**, and using the following formula for each country:

```
mutate(Weight_of_crop_country_in_region = production/sum(production))
```

Then, for all the pressures except terrestrial climate change, **impact factor in MSA.km²/t at the EXIOBASE regional level for each combination of {crop; EXIOBASE region}** is calculated by **averaging each national impact factor for the crop of interest, weighted by the production share calculated above** (here only the example of terrestrial dynamic land use pressure is displayed to simplify):

```
Regional_MSA_loss_per_ton_LU_dynamic = weighted.mean(msa_land_use_dynamic,
Weight_of_crop_country_in_region)
```

For the case of terrestrial climate change, as explained in the Input-Output framework document, the emissions from EXIOBASE are used instead of the ones calculated in the crops CommoTool.

5.2 Coverage of biomass products listed in EXIOBASE

Figure 20 presents the proportions of the different biomass categories in the EXIOBASE materials account in terms of tonnages:

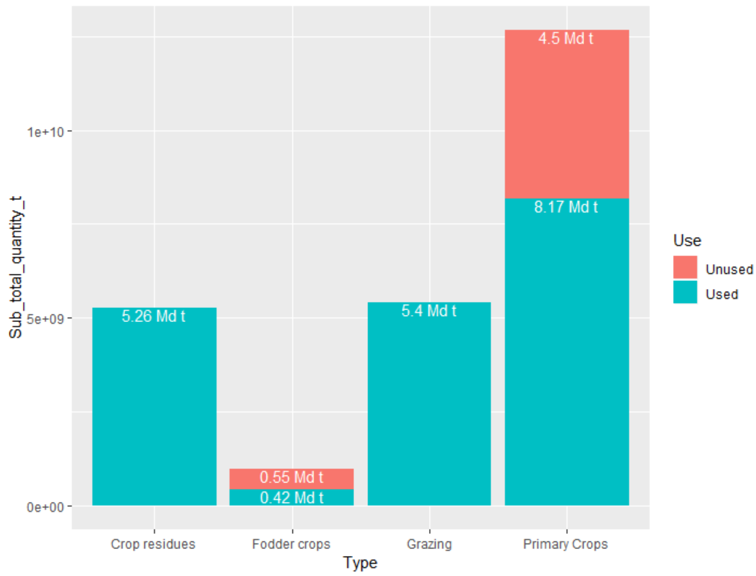


Figure 20: Global biomass tonnages extracted in EXIOBASE materials account

The biomass categories represented in Figure 20 are primary crops, fodder crops, crop residues and grazing (which will be treated in the livestock husbandry module). We can observe that there are no unused crop residues nor unused grazing. Both primary crops and fodder crops are shared between used and unused extractions. In 2011, crop residues and unused production represented a non-negligible part of the world's vegetal biomass production, with 5.3 billion of tonnes of crop residues (with 15% of moisture content), including 3.3 billion tonnes of straw and 2 billion tonnes of feed. Furthermore, about 5 billion tonnes of the production are unused, (primary crops and fodder crops, with variable moisture content). In comparison, global used primary crops and fodder crops represents about 8.5 billion tonnes (with variable moisture content depending on the crop). This emphasizes the further developments needed around allocation options as discussed in section 4.2.

5.3 Comparison of EXIOBASE and FAO production data

FAO yield, production and harvested area data per crop in every country are used to evaluate the biodiversity impacts per tonne of crop commodities in the CommoTool. These national impact factors are used to compute impact factors at EXIOBASE regions level so that they can be applied to **EXIOBASE production data** in default assessments. Therefore, FAOSTAT and EXIOBASE production data have to be in line so that global impact computed in default assessment matches the global agriculture impact as we dimensioned it (see section 2). EXIOBASE production data comes from FAOSTAT – year 2015 – according to the supplementary material about the material account data (SI5) in the EXIOBASE 3 paper (Stadler et al., 2018). It would be interesting to compare harvested area from FAOSTAT and EXIOBASE as well but as EXIOBASE does not provide yield and provides area only for aggregated crop types, therefore, we only compare the **production data**.

In total, there are 3621 {EXIOBASE region; Crop item production} pairs for which the computed production of the crop item is not null (166 primary crops and 49 regions are covered) and 4513 pairs for which the production of the crop of interest is null in the EXIOBASE region considered. For the 3621 pairs for which production is not null, we compare EXIOBASE production – computed based on the IO table and the material account – with the crop production documented in FAOSTAT for the year 2015. For **3129 observations (86.4%), the difference between FAOSTAT production and the computed production in EXIOBASE is inferior to 5%, revealing very limited inconsistencies. Moreover, the observations with a production difference superior to 5% represent a limited share of the total tonnage of crops (3.8%).**

We thus consider that the production data is consistent between FAO and EXIOBASE.

6 Limits and perspectives

The crops CommoTool is an essential component of the GBS for default assessments when data on material flows is available (tonnage of crop commodities). It should be noted that the results of such assessments with the crops CommoTool will suffer from uncertainties explained by the following identified limitations.

6.1 Underlying data limitations

For FAOSTAT crops yield data (yield, production and harvested area) we pick the **most recent input available** but yield data can be volatile from one year to another, especially in the coming years if climate conditions become more unstable. Therefore, resulting CommoTool impact factors can be volatile too. On way to improve this would be to use a smoothed average of yield over 5 years for example.

Sensitivity tests should be set to monitor suspicious variations of the impact factors when they are updated. Tracking the results of one unique example and explain the differences would be a first safeguard.

For **fodder crops**, production data used is less robust and not as regularly updated than for primary crops. For the impacts' **attribution** phase, **economic data on crop co-products**, especially crop residues, were needed to estimate whether they should bare a part of the impact responsibility, and these data were quite limited. A continuous monitoring of the best available data for primary crops, fodder crop and their co-products covering both production and economic value is required to keep improving the GBS.

6.2 Methodology and assumptions limitations

In the impacts dimensioning section, the methodology is mainly based on applying the impacts intensities computed in the terrestrial and aquatic sections to an implicit area occupied by the production of 1 tonne of crop, which is equivalent to the inverse of its yield. However, this means **that we apply the same impact intensity for every crop.** There is thus no distinction between the different agronomic choices linked to each crop specificity. For example, maize and lentils do not require the same amount of nitrogen fertilization, thus causing different quantities of atmospheric nitrogen deposition. Land use dynamic can also be very different among crops. For instance, in a given country, coffee crops and palm oil crops might not the same responsibility regarding deforestation. No distinction is made neither between agricultural, between conventional and organic farming for instance. The methodology to distinguish the impacts of different agricultural practices is being considered and will be integrated in future version of the GBS.

Impacts dimensioning is based on an **annual MSA loss calculation** in each GLOBIO cell. The annual loss is a linear interpolation of GLOBIO-IMAGE outputs in 2010 and 2050. It would be interesting to have more computation intermediaries to better take into account non-linear patterns.

When yield data is lacking, especially for several **fodder crops** in different countries, **proxy yield choices** are made based on the resembling crop species, which could cause uncertainties in the assessed results. It can be avoided if better production data on fodder crop production can be retrieved.

In the **attributing** step, the choice was made to use an economic allocation and **leave 100% of the impact on the primary and fodder crop, leading crop residues to get zero impact.** The economic value of the crop residues may also be correlated to their nutritional value and their use for the livestock husbandry sector, further bibliography on the topic is needed.

Moreover, the **case of attributing biodiversity impacts to different crops occupying the same field** is not treated for now in the GBS as explained in section 2.1.

6.3 Uncertainties

Uncertainties should be tackled by including the possibility to use multiple calculation modes, with central, pessimistic and optimistic values of both collected corporate data and characterization factors, that have quantified uncertainties.

Sensitivity tests mentioned earlier (section 6.1) about tracking the evolution one unique examples results should also feed the reflexion about uncertainties embedded in the GBS.

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