THE GLOBAL BIODIVERSITY SCORE

GBS Review: Livestock husbandry and Grass CommoTools

March 2020 – Revised version

CDC BIODIVERSITÉ | Caisse des Dépôts GROUPE

Content

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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 report dedicated to Core concepts (CDC Biodiversité 2020a) to ensure a good overall comprehension of the tool and the present report.

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 2019).

1 Livestock husbandry CommoTool and Grass CommoTool overview

1.1 Livestock sector context

A WHY ASSESS THE BIODIVERSITY IMPACTS OF THE LIVESTOCK SECTOR?

Livestock designates terrestrial and domesticated animals raised in an agricultural setting to produce labour and commodities such as meat, eggs, milk, wool. These livestock co-products play a major role in human nutrition today, and their production are **continuously growing worldwide:** meat production has reached at least 300 million tonnes in total in 2013 and has tripled since 1960.

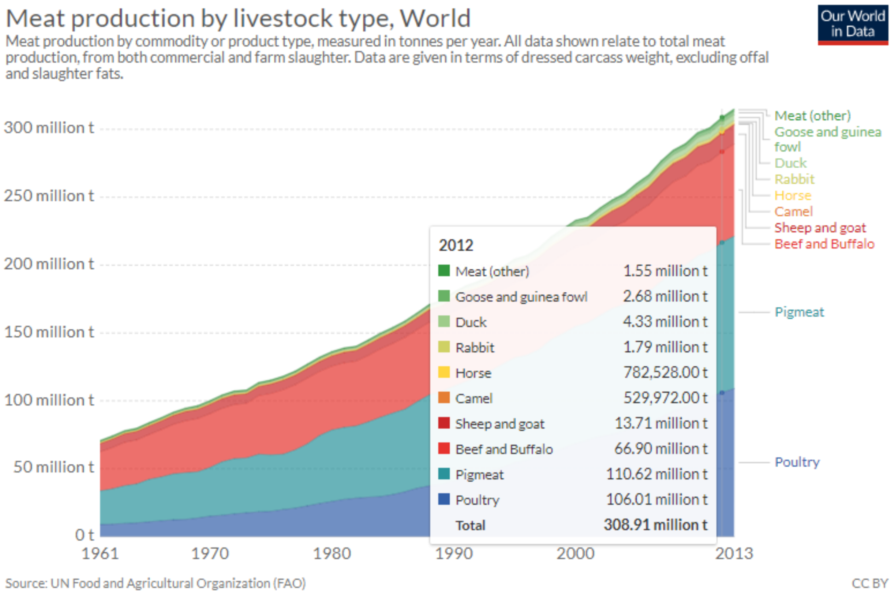

Figure 1: Meat production by livestock type, world, visualization by(Ritchie and Roser 2017) adapted from (FAOSTAT 2019b) data

This growing trend will continue over the next decades. According to FAO projections, meat demand will increase by over 200% by 2050 in a business as usual scenario (FAO 2018). This will **accentuate the five main pressures on biodiversity identified by the IPBES**, which are land use change, direct exploitation, climate change, pollution and invasive alien species (Díaz et al. 2019). The "Status and Trends – Drivers of Change" Chapter 2.1 of the IPBES Global Assessment (Balvanera et al. 2019) has notably identified in the literature that livestock production uses one third of world crop production for feed purposes and that agriculture in general responsible of 70-90% of withdrawals from rivers, lakes and aquifers. Depending on estimations, the amount of ice-free land mobilised by livestock production varies from 22% (Mottet et al. 2017) to 30% (Ramankutty et al. 2008; Monfreda, Ramankutty, and Foley 2008). The sector is also responsible for about 15% of global anthropogenic greenhouse gas emissions (FAO 2019; Gerber and FAO 2013). Yet, livestock husbandry can also positively contribute to nature and the ecosystems, notably through grazing, if it is well managed (without overgrazing nor under-grazing): it helps keeping open landscapes and can create favourable conditions to form habitat structures preferred by numerous species. Besides, manure left on well managed pastures fertilizes the soils and facilitates seeds transportation (Metera et al. 2010).

The large amount of resources dedicated to livestock is inter alia due to livestock **feeding and grazing**. Figure 2 gives an overview of the biodiversity losses attributed to economic sectors, among them, "Food production" including crop and livestock production is the largest contributor of actual and projected biodiversity loss. **Impacts of livestock and needed feed over the sector's whole value chain should be both assessed in order to have an exhaustive estimation of the impacts caused by livestock on biodiversity.**

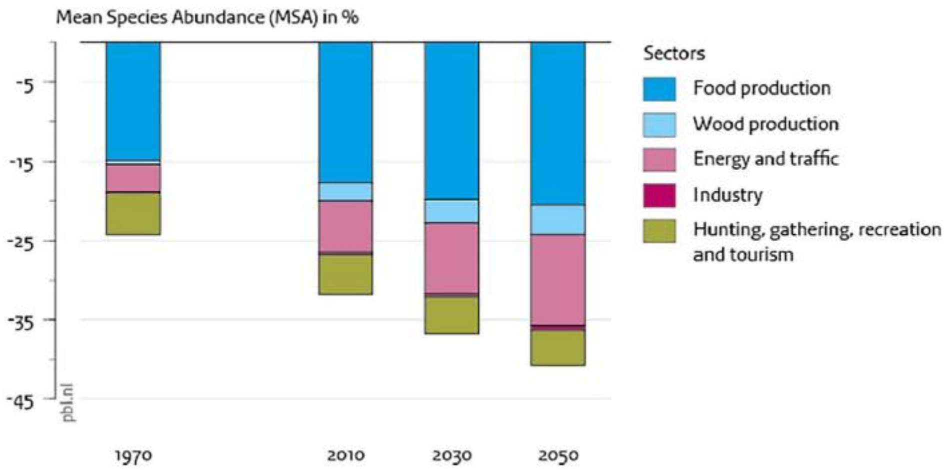

Figure 2: Attribution of terrestrial biodiversity impacts in MSA% to different production sectors under the Trend scenario (Kok et al. 2014)

B PLACE OF THE LIVESTOCK HUSBANDRY COMMOTOOL AND THE GRASS COMMOTOOL IN THE GBS STEPWISE APPROACH

As a reminder, the evaluation of the 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). Livestock direct impacts and feed impacts are assessed separately. The impacts of primary crops and fodder crops have already been assessed in the Crops CommoTool (CDC Biodiversité 2020b). The impacts of transformed feed can be assessed by breaking them down into their elementary primary and fodder crop components to be assessed with the Crops CommoTool. The only remaining feed component not already covered by the GBS is thus grazing. Two CommoTools are thus distinguished in this review document: one for livestock excluding feed, and one for grazing. They provide **biodiversity impact factors linking tonnages of livestock products or tonnages of grass to impacts on biodiversity in MSA.km²**. They fit in the stepwise framework in two ways, as illustrated by Figure 3.

The results of the CommoTools feed the M matrix dedicated to items documented in the EXIOBASE material account (CDC Biodiversité 2020d). These M matrix are used in default assessments.

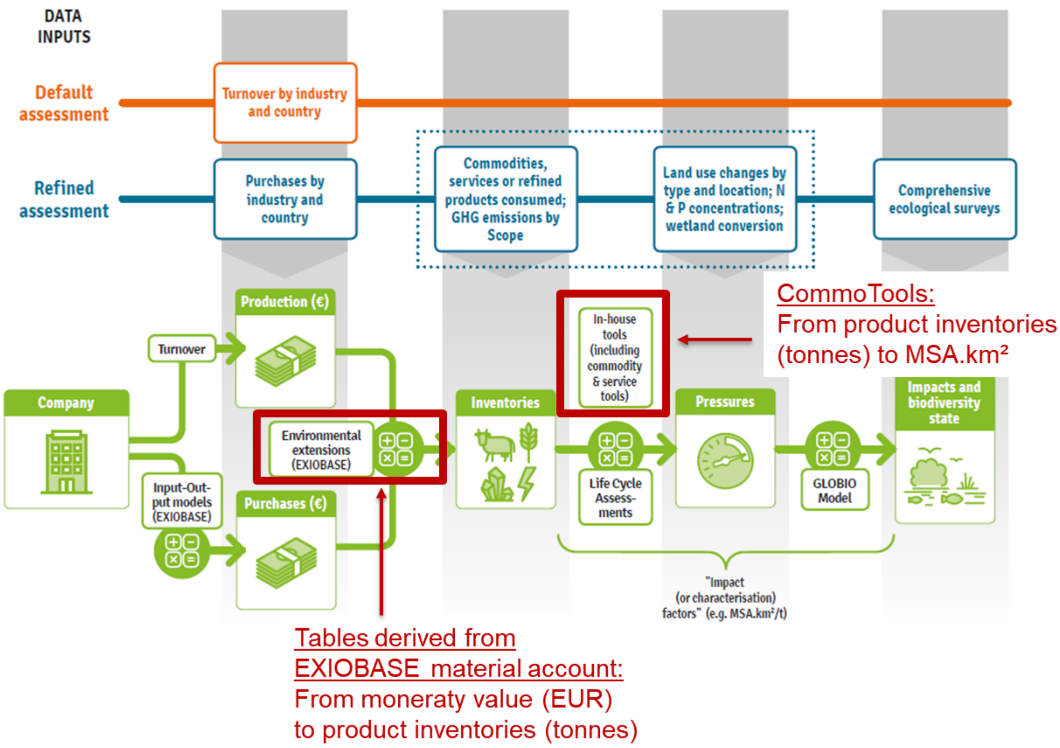

Figure 3: Livestock and Grass CommoTools in the GBS stepwise approach

The goal of the **livestock husbandry and grass CommoTools** is to determine the **Scope 1 biodiversity impacts of a given tonnage of respectively animal product and grazed grass**. This report explains how these **biodiversity impact factors databases** are constructed.

In the case where a biodiversity assessment is conducted on the husbandry part of a farm, Table 1 clarifies which GBS CommoTool should be used to assess each simplified stage through the livestock production activities. The Scope of each stage compared to the livestock husbandry part of the farm is also described.

Production stage	**Scope**[1]	**GBS tool(s) dealing with the stage**
Pasture exploitation	3 upstream	Grass CommoTool
Primary crops production for feed (w/o transformation)	3 upstream	Crops CommoTool
Fodder crops production for feed (w/o transformation)	3 upstream	Crops CommoTool
Crop residues	3 upstream	Crops CommoTool[2]

[1] The reference against which Scopes are defined is the livestock husbandry activity of an exploitation or company
[2] For now, economic allocation is used and no impacts are attributed to crop residues.

Processed feed transformation	3 upstream	Climate change impacts taken into account through a financial evaluation with the input-output (IO) modelling. Other pressures (e.g. Land use) are not yet covered. A dedicated "food processing ServiceTool" would have to be developed to cover them. If data on the underlying crop production required (as purchases) for the feed transformation is known (*e.g.* tonnes of soya purchased) thanks to LCI data for example, it can be taken into account through the Crops CommoTool (this is Scope 3 upstream of the feed processing step).
Purchased energy	2	Similar to feed processing: climate change impacts taken into account through a financial evaluation with the input-output (IO) modelling. Other pressures (e.g. Land use) are not yet covered and will be tackled by the future energy ServiceTool.
Animals direct water consumption	1	Livestock husbandry CommoTool
Buildings for livestock husbandry	1	Livestock husbandry CommoTool
Animal enteric fermentation	1	Livestock husbandry CommoTool
Manure treated (excluding application on pasture, crops)	1	Livestock husbandry CommoTool
Manure left on pasture	1	Livestock husbandry CommoTool[3]
Manure applied to soils	3 downstream	Crops CommoTool

Table 1: Articulation between different GBS tools to assess livestock husbandry stage

Table 2 shows how the GBS tools articulate between each other to assess the biodiversity impact of three fictive livestock husbandry systems. Here the Scopes are defined with a whole farm taken as reference (not just its husbandry part):

Exemple reference / Process stage	**Crop production (primary crops, fodder crops, crop residues)**[4]	**Pasture exploitation**	**Processed feed transformation**	**Purchased energy**	**Buildings and direct water use**	**Enteric fermentation**	**Manure treated**	**Manure left on pasture**	**Manure left on soil**
Ex 1: a landless pig farm importing 100% of feed	Upstream Scope 3 Crops CommoTool	NA	Upstream Scope 3 IO module for CC impacts	Scope 2 IO module for CC impacts[6]	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	NA	Downstream Scope 3 Crops CommoTool

[3] May be migrated to the grass CommoTool.
[4] Primary and fodder crops, crop residues.
[6] And energy ServiceTool for the other impacts in a future version of the GBS, see Table 1.

Ex 2: a grassland farm importing soybean cake from Brazil	Upstream Scope 3 Crops CommoTool	Scope 1 Grass CommoTool	Upstream Scope 3 IO module for CC impacts	Scope 2 IO module[6]	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool[3]	Downstream Scope 3 Crops CommoTool
Ex 3: a dairy farm with some temporary grassland for grazing, cultivating feed crops and importing concentrates	Upstream Scope 3 (concentrate imports) and Scope 1 (cultivated feed crops) Crops CommoTool	Scope 1 Grass CommoTool	Upstream Scope 3 IO module for CC impacts	Scope 2 IO module[6]	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool	Scope 1 Livestock husbandry CommoTool[3]	Downstream Scope 3 Crops CommoTool

Table 2: Livestock husbandry systems examples - Scopes and GBS tools to use along the production stages

C LIVESTOCK COMMOTOOL PERIMETER

1.1.C.1 Items considered

In the livestock husbandry CommoTool, we distinguish two levels of granularity of the impact factors.

Livestock category or species designates animal species or group of animal species having similar physiological properties. FAOSTAT reports some types of GHG emissions at this level of detail, and the covered livestock categories are listed in Table 3. Two broad categories of livestock animals can be distinguished: **ruminants** and **monogastric**, defined by their digestive system properties which notably impacts enteric fermentation emissions, and by the nature of their feed intakes (ruminants can digest grass unlike most of the monogastrics).

Livestock products designates the products "extracted" from the latter livestock species, essentially meat, milk, eggs, fibbers (*e.g.* wool), etc. FAOSTAT reports data at this level of detail and the covered livestock products are listed in Table 3, which also links the livestock categories to their products.

Depending on the pressure considered, the livestock biodiversity impact factors in the GBS are broken down at the livestock category or product level. In the GBS, the livestock products that are kept are those for which "Emission intensity" GHG data are available. More species are covered at the end of the dimensioning phase for emission-related pressures, they are not displayed here.

ID_FAO_livestock_primary_products	FAO_livestock_primary_products	ID_FAO_emissions_species	FAO_emissions_species
1062	Eggs, hen, in shell	1052	Chickens, layers
947	Meat, buffalo	946	Buffaloes

867	Meat, cattle	961	Cattle, non-dairy
1058	Meat, chicken	1053	Chickens, broilers
1017	Meat, goat	1016	Goats
1035	Meat, pig	1048	Swine
977	Meat, sheep	976	Sheep
951	Milk, whole fresh buffalo	946	Buffaloes
1130	Milk, whole fresh camel	1126	Camels
882	Milk, whole fresh cow	960	Cattle, dairy
1020	Milk, whole fresh goat	1016	Goats
982	Milk, whole fresh sheep	976	Sheep

Table 3: Livestock products and related categories in the GBS

1.1.C.2 Definition of the perimeter under control and the impacts attributed to it

The assessed system is a **farm generating livestock products such as meat or milk without producing its own feeding items**. Its Scope 1 includes all the **natural resources directly used by animals, notably water and land**, and the direct outputs, which are **greenhouse gases and nutrients emissions.** Figure 4 clarifies the perimeter and the covered pressures within the livestock husbandry CommoTool. Soil biodiversity and breeding biodiversity are not assessed by the livestock husbandry CommoTool of the GBS.

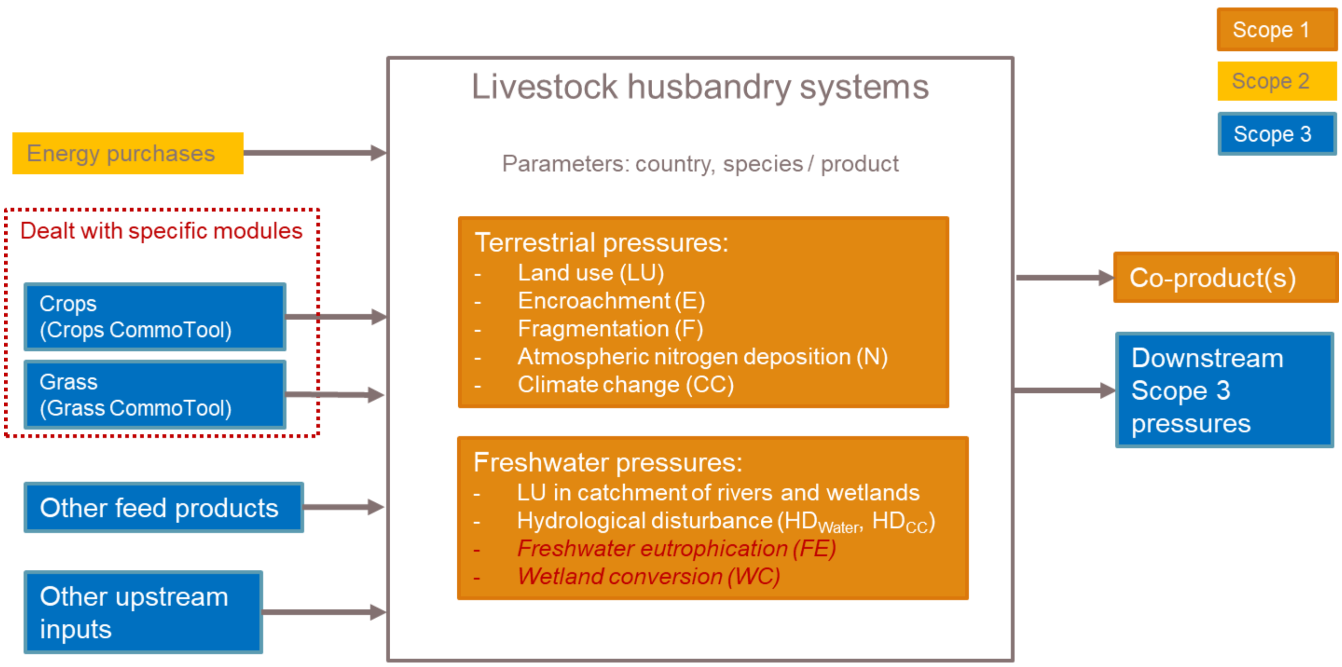

Figure 4: Perimeter of the Livestock husbandry CommoTool and covered pressures

The livestock husbandry CommoTool focuses only on these Scope 1 resources and outputs, and the engendered impacts on biodiversity. Please refer to the GBS review reports on terrestrial and freshwater modules for details about each pressure (CDC Biodiversité 2020g; 2020c). The attribution of impacts to the Scope 1 is conducted as follows:

Climate change and hydrological disturbance caused by climate change (CC, HD_{CC}): livestock herds are responsible of direct GHG emissions, namely **enteric fermentation** (CH_4 emission) produced by ruminants especially, and direct and indirect GHG emissions caused manure management. Such emissions (c.f. section 2.2A) cause impacts on terrestrial biodiversity (CC) and on aquatic biodiversity (HD_{CC}) that are 100% attributed to livestock systems.

Atmospheric nitrogen deposition (N) and freshwater eutrophication (FE): livestock herds emit nutrients through manure. Such nutrient emissions cause atmospheric nitrogen deposition (N) and freshwater eutrophication (FE), which are 100% attributed to livestock husbandry for now.

Land use (LU): livestock herds directly occupy areas with livestock buildings or feedlots for example (we exclude feed, which are tackled in dedicated CommoTools). Such land use cause impacts on biodiversity. 100% of the impacts (land occupation and conversion) caused by these areas are attributed to the livestock production sector.

Encroachment (E), fragmentation (F): the land directly used for livestock production (excluding feed) also cause encroachment and fragmentation pressures. 100% of the assessed impacts related to E and F are attributed to livestock production. However, these impacts may be overestimated as livestock installations are often close to other fragmenting and encroaching sources (such as roads, other anthropic installations) to which a share of the impacts can be attributed to.

Land use in catchment (LUR and LUW): The impact of upstream land use changes on river or wetland catchments are proxies for nutrients emissions leaching to the ecosystems (CDC Biodiversité 2020c). For **land use change impacting river catchments**, as areas directly used for livestock (excluding feed) are considered as "human" land-uses[7], the computed intensities in the freshwater module can be applied to those areas, and 100% of this LUR impact is attributed to the area directly exploited by livestock production. For impacts of upstream land use change impacting wetland catchments, as it is weighted by the land use intensity (100% - MSA%) and as areas used by livestock production are not at a natural state (MSA < 100%), they generate this pressure. 100% of the impact of the LUW impact is attributed to the area directly exploited by livestock production.

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[7] "Human" land-uses in this document designate land use types exerting specific pressures in the GLOBIO framework: LU, E, F, WC, LUC

Wetland conversion (WC): **in default assessments**, the impacts dimensioned are limited to those caused only by agricultural lands, understood here as cropland (CDC Biodiversité 2020c), so none is attributed to livestock production (feed excluded). Unfortunately, we have not been able to dimension (and thus attribute) impacts caused by conversion of wetlands into livestock-related buildings for livestock production in default assessments. **In refined assessments**, when company data reveal wetland conversion due to livestock production, 100% of the impacts is attributed to livestock production (feed excluded).

Hydrological disturbance (HD_{Water}): livestock herds directly consume water, namely blue water, which causes hydrological disturbance. Its impacts are 100% attributed to livestock systems.

D GRASS COMMOTOOL PERIMETER

1.1.D.1 Feeding products overview

According to the FAO, **grazed biomass** ("grassland and leaves") occupies an important place in the livestock feeding items in terms of dry matter tonnages with about 50% of the global feed intakes. Figure 5 displays the share of the feed sources categories for livestock worldwide.

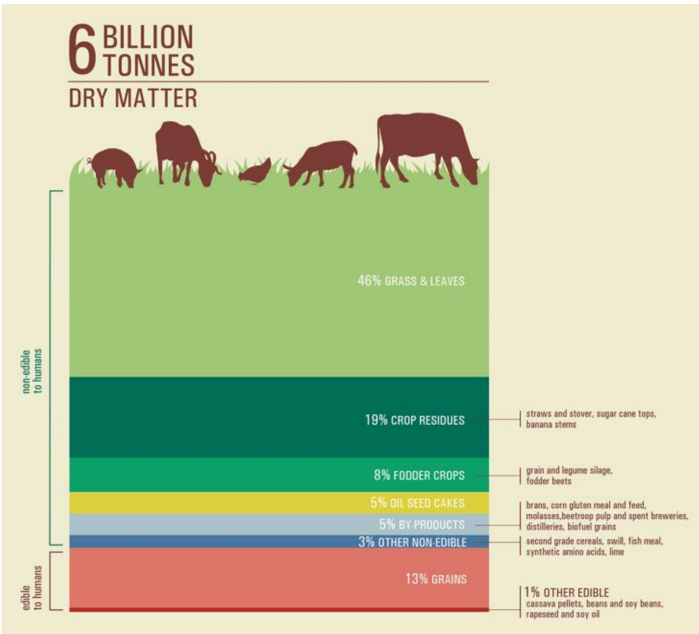
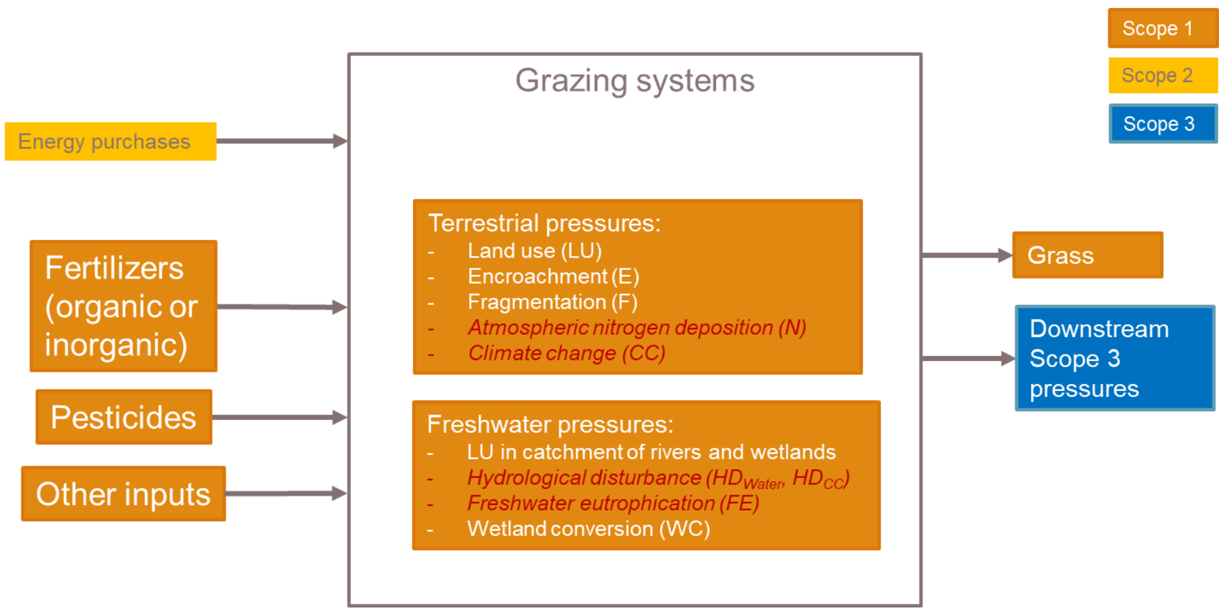


Figure 5: Share of the main feed types of feed consumed by livestock supply chains (both ruminants and monogastric species) in the global livestock feed intake in 2010 (FAO 2017a)

The other feed categories are **crop residues**[8]**, fodder crops and primary crops ("grains")**, which are already covered by the crops CommoTool (CDC Biodiversité 2020b). Feed products such as oil seed cakes, by-products (*e.g.* molasses, brans etc.) and other non-edible or edible feed are not directly treated in the first version of the GBS, but can be taken into account through the crops CommoTool if data on feed composition is available (for example with LCI data), as mentioned in Table 1. In the future, one option to integrate such products would be using LCI databases (cf. the methodology of section 4.1B. **To sum up, for the livestock Scope 3 impacts, this document focuses only on impacts of grass and not on other feed products.**

1.1.D.2 Definition of the perimeter under control and the impacts attributed to it

The assessed system is a **grassland.** Its Scope 1 includes all the direct natural resources inputs, notably water, land, fertilization (organic and inorganic), pesticides and chemical products. Figure 6 clarifies the perimeter and the covered pressures within the Grass CommoTool. Soil biodiversity and breeding biodiversity are not assessed by the grass CommoTool of the GBS.



[8] More specifically in the crops CommoTool, we use an economic allocation between the harvested grains or the desired product, and the crop residues. The latter have no impacts allocated to them for now.

Figure 6: Perimeter of the Grass CommoTool and covered pressures

The grass CommoTool focuses only on these Scope 1 resources and outputs, and the engendered impacts on biodiversity. Please refer to the GBS review reports on terrestrial and freshwater modules for details about each pressure (CDC Biodiversité 2020g; 2020c). The attribution of impacts to the Scope 1 is conducted as follow:

Climate change and hydrological disturbance caused by climate change (CC, HD_{CC}): Such emissions taking place on pastures cause impacts on terrestrial biodiversity (CC) and on aquatic biodiversity (HD_{CC}) that are 100% attributed to livestock husbandry for now.

Consistently with the crop CommoTool in which biogenic and land use change related carbon emissions are ignored, only "carbon dioxide (fossil)" is considered in the computation.

Atmospheric nitrogen deposition (N) and freshwater eutrophication (FE): Grasslands can be fertilized by inorganic or organic fertilisers. The former can be provided by livestock manures, which cause nutrient emissions responsible of atmospheric nitrogen deposition (N) and freshwater eutrophication (FE). They are 100% attributed to livestock husbandry for now. Impacts of inorganic fertilisers used for grasslands are not evaluated with this CommoTool.

Land use (LU): grasslands cause impact on biodiversity. The impacts (land use static occupation and dynamic change) caused by these areas are 100% attributed to the grasslands.

Encroachment (E), fragmentation (F): the grasslands cause encroachment and fragmentation pressures. 100% of the assessed impacts related to E and F are attributed to the grasslands. However, similar to the livestock husbandry CommoTool, these impacts may be overestimated as grassland and livestock installations may be close to other fragmenting and encroaching sources (such as roads, other anthropic installations) to which a share of the impacts can be attributed to.

Land use in catchment (LUC): as for livestock production, grasslands are considered as "human" land uses. For land use change impacting river and wetland in catchments, 100% of the impact is attributed to the grasslands.

Wetland conversion (WC): In GLOBIO, the land use class "cultivated grazing areas" are considered as agricultural lands, so that impacts of wetland conversion can be dimensioned for grazing areas. 100% of the impact is attributed to the grasslands.

Hydrological disturbance (HD_{Water}): grasslands mostly consume green water, blue water should be negligible. Currently, no hydrological disturbance impact is thus computed and there is none to attribute. In future versions of the tool, the impacts of blue water consumption, and thus biodiversity impact factors related to HD_{Water}, might be added.

1.2 Livestock husbandry and Grass CommoTools methodology overview

A DIMENSIONING BIODIVERSITY IMPACTS

In the livestock and grass CommoTools, the **dimensioning step determines the contribution of each commodity production to the biodiversity impact** in each selected geographical region. The general approach is that **biodiversity impact intensities** (expressed in MSA.km² per unit of pressure) calculated for terrestrial and freshwater biodiversity (CDC Biodiversité 2020g; 2020c) are combined to **relevant data related to livestock production and grassland** such as yields, land conversion or emission of P-eq. per tonne of commodity produced. At the end of the computation process, **the biodiversity impact factors** obtained (expressed in MSA.km² per tonne of commodity) can be declined at different geographical scales. In the **livestock husbandry CommoTool**, the obtained biodiversity impact factor's unit at the dimensioning stage is in **MSA.km² per livestock category, per country**. In the **grass CommoTool,** at the end of dimensioning, the impact factors are in **MSA.km² per tonne of grass, per country**.

To make a parallel with the LCA framework, the example of grass CommoTools use several types of data and characterisation factors, as described in Figure 7. Assessing the impact of grassland require data on land occupation in order to apply the biodiversity impact intensities computed in the terrestrial and freshwater modules (CDC Biodiversité 2020g; 2020c) with a similar approach to the crops CommoTool (CDC Biodiversité 2020b). For instance, for land use, a given tonnage of pasture plays the role of the **LCA inventory** data in the GBS. It is linked to an occupied area, which is a **midpoint**[9], through a **midpoint characterisation factor** based on the production yield. The midpoint is linked to an **endpoint**[10] **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 grassland area), computed in the terrestrial and aquatic modules of the GBS (CDC Biodiversité 2020g; 2020c). The impact factors in MSA.km²/t constituting the grass CommoTool are a combination of the midpoint and endpoint characterisation factors.

[9] "Midpoint" in LCA refers to an impact earlier in the cause-effect chain

[10] "Endpoint" in LCA designate an impact at the end of a cause-effect chain

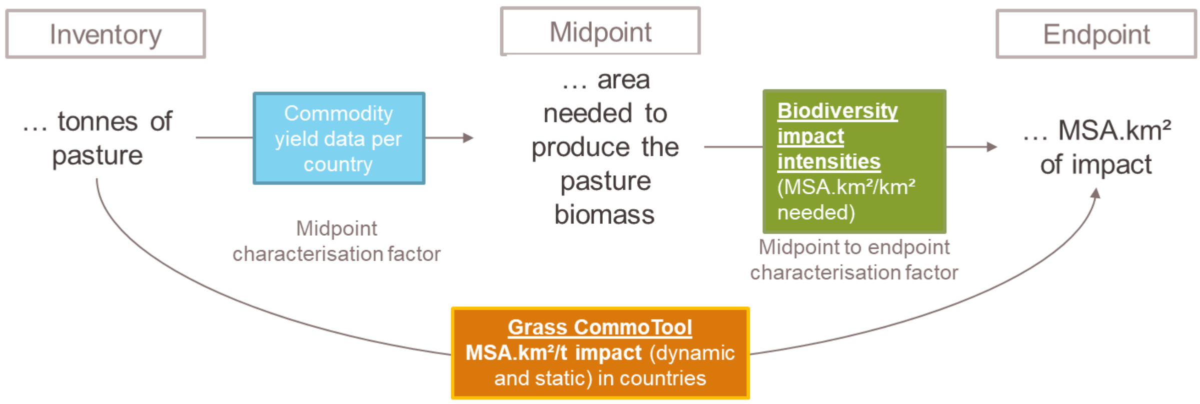


Figure 7: Impact factors used or constructed in the grass CommoTool within the LCA framework

B ATTRIBUTING BIODIVERSITY IMPACTS

Livestock production is a multifunctional process, meaning that the process delivers several goods and/or services. It has multiple unavoidable outputs (meat and milk for cattle herds). This notion of multifunctionality is important for our methodology, as the biodiversity impact needs to be attributed to the different outputs produced. Attributing[11] step shares the responsibility of the dimensioned impact, between the co-products of a same process. The repartition rules are further explained in section 4. At the end of this step, for the **livestock husbandry CommoTool**, the biodiversity impact factors units are expressed in **MSA.km² per tonne of livestock product, per country.** For the **grass CommoTool**, impacts of MSA.km² per tonne of grass (grazed by animals) are 100% attributed to grass.

[11] Here the term “attributing” is similar to “allocate” in the LCA framework. However, we used this term more broadly in the other GBS review documents: for example, in the terrestrial module of the GBS, notably for the pressure Atmospheric nitrogen deposition, the "attributing" step shares the global impacts caused by N volatilization between different economic sectors.

2 Dimensioning the impacts – Default assessments

2.1 Underlying data

A LIVESTOCK EMISSIONS DATA

2.1.A.1 Nutrients emissions

Nutrients emissions caused by livestock are originated from manure, which designates the dung and urine of the animals. Such data on nutrients emitted, especially **nitrogen**, are retrieved from FAOSTAT, more precisely in the section "Agri-Environmental Indicators", **"Livestock Manure"**. The section provides estimated nitrogen amounts (N content) excreted by the different animal cohorts in each country and the fractions linked to manure management and other losses, thanks to FAOSTAT statistics on animal stocks and IPCC methodologies. Table 4 synthesises the categories of nitrogen quantities and the associated computation method, for more details please refer to the FAOSTAT and IPCC documentation (FAOSTAT 2019f; IPCC 2006a; 2006b):

Livestock manure categories	Summary of the FAOSTAT estimation method
Amount excreted in manure (N content)	Application of an excretion coefficient to livestock number of heads and typical animal mass
Manure left on pasture (N content)	Application of a share of manure deposited on pasture to "Amount excreted in manure" & summing half of N excreted burnt for fuel (to consider N excreted in urine)
Manure left on pasture that volatilizes (N content)	Application of a volatilisation coefficient to the quantities of "manure left on pasture"
Manure left on pasture that leaches (N content)	Application of a leaching coefficient to the quantities of "manure left on pasture"
Manure treated (N content)	Considered manure management systems (MMS): "Lagoon, Slurry, Solid Storage, Drylot, Daily Spread, Digester, Other, Pit below 1 Month, Pit above 1 Month" For each MMS: application of a share of manure treated to the "Amount excreted in manure"

Losses from manure treated (N content)	For each MMS: application of a share of N lost from each system to the amount of "Manure treated"
Manure applied to soils (N content)	Difference between "Manure treated" and "Losses from manure treated"
Manure applied to soils that volatilizes (N content)	Application of a volatilisation coefficient to the quantities of "manure applied to soils"
Manure applied to soils that leaches (N content)	Application of a leaching coefficient to the quantities of "manure left applied to soils"

Table 4: Categories of nitrogen amount reported by FAOSTAT in "Livestock manure" and computation synthesis[12]

2.1.A.2 Greenhouse gas emissions

Data on GHG emissions on livestock production are needed to compute climate change related biodiversity impact factors. We use FAOSTAT data (FAOSTAT 2019a). The following datasets were retrieved from the database:

- In the section "Emissions – Agriculture": **"Agriculture Total"** (also used in the crops CommoTool (CDC Biodiversité 2020b)), **"Enteric Fermentation"** (reporting CH_4 emissions), **"Manure Management"** and **"Manure left on Pasture"** (reporting CH_4 emissions, direct N_2O and indirect N_2O emissions through volatilization and leaching) were collected

- The section "Agri-Environmental Indicators": **"Emissions intensities"** contains information about products GHG intensities (kg CO_2-eq/kg of product) and the products tonnage produced every year (milk, eggs, meat, etc.)

Table 5 synthetises how GHG emissions from "Enteric fermentation", "Manure management" and "Manure left on pasture" were estimated by FAOSTAT (FAOSTAT 2019h; 2019g; 2019e). Reported GHG emissions quantities caused by manure are based on reported livestock nitrogen amounts presented in the section above (2.1.A.1) and IPCC emission factors (IPCC 2006a; 2006b).

[12] The factors mentioned are derived from IPCC 2006 guidelines on National GHG inventories, especially the volume 4, chapters 10 and 11.

FAOSTAT GHG source / GHG type	Direct CH_4	Direct N_2O	Indirect N_2O
Enteric fermentation	Use a CH_4 rate per head number per livestock category (IPCC factor)	*NA*	*NA*
Manure management	Use a CH_4 rate per head number per livestock category (IPCC factor)	Application of N_2O-N / N content rates (IPCC factors per MMS[13]) to total amount of N in **"Manure treated"**	Application of N_2O-N / N content rate (IPCC factor) to the **"Manure treated" that volatilizes**
Manure left on pasture	*NA*	Application of N_2O-N / N content rate (IPCC factor) to the **"Manure left on pasture"**	Application of N_2O-N / N content rate (IPCC factor) to the **"Manure left on pasture that volatilizes"** and **"Manure left on pasture that leaches"**

Table 5: GHG emissions reported in FAOSTAT linked to livestock and computation synthesis

In each case, FAOSTAT reports emissions in mass of GHG (CH_4, N_2O…) and in CO_2-eq. The latter are used for the impacts factors computations within the GBS. FAOSTAT uses the GWP at 100 year-time horizon preconised by IPCC in 1996 (FAOSTAT 2019c), which are different than those used in the GBS. Table 6 compares the GWP factors used:

	100 year-time horizon GWP used in FAOSTAT	100 year-time horizon GWP used by the GBS (Stocker 2014)
CH_4	21	28
N_2O	310	265

Table 6: GWP used in FAOSTAT and GBS

[13] "Manure management system"

B DATA ON LAND AND WATER RESOURCES CONSUMED BY LIVESTOCK

As mentioned in the GBS review reports on wood logs and mining commodities (CDC Biodiversité 2020h; 2020e), LCI databases, especially the PEF (Product Environmental Footprint) developed by the European Commission's Joint Research Center provides data on resources consumptions (flows) needed to produce livestock commodities. In particular, occupied land area and water directly consumed by livestock all along their lifecycle are documented. Flow selection is detailed in sections 4.1B. We have chosen to keep using PEF (as in the wood logs and mining CommoTools) because it provides quite comprehensive water consumption and land occupation data for and a worldwide geographical coverage.

Agribalyse (Koch and Salou 2016) has also been identified as an important LCI data source, however, it is limited to French products. It could be useful for future developments exploring the differences in impacts according to farming practices.

Other data sources like agronomic studies, *e.g.* of dairy farms (FAO, International Dairy Federation, and International Farm Comparison Network 2014), or water footprint databases (Mekonnen and Hoekstra 2012) were used for comparison purposes to check the order of magnitudes of results.

C GRASS PRODUCTION YIELDS

Yield data are required for the conversion of tonnages into areas.

In a first instance, yield data from the FAO pasture country profiles based on agronomic experts' studies produced by the Plant protection division / AGP (FAO 2017b), with a coverage among about a hundred countries, were considered. However, such data are quite old and do not report yields in a harmonized way.

In practice for now, we use the EUROSTAT yield ranges distinguished by pasture intensity under continental European climates displayed in Table 7 (EUROSTAT 2013). These yield data refer uptakes grazed by animals per hectare.

	Yield range [t at 15%mc / ha]	Average yield [t at 15%mc / ha]
Rough grazing, alpine pasture	<1	0.5
Extensive pasture	1-5	2.5
Improved pasture	5-10	7.0

Source: The values are derived from data for Austrian grassland systems given in Buchgraber et al. (1994) and can be assumed typical for Central Europe.

Table 7: Typical yield of permanent pastures, (EUROSTAT 2013)

In a future version of the GBS, satellite data may be considered with more recent updates. The idea is to link biomass growth data from satellite observation such as NVDI (Normalized Difference Vegetation

Index) or net primary production data from MODIS (MODIS (Moderate Resolution Imaging Spectroradiometer) 2019) or GeoGLAM RAPP (GEOGLAM (Group on Earth Observations and its Global Agricultural Monitoring initiative) 2019), data from Copernicus program (Copernicus 2020) etc. with grassland yield data, thanks to mathematical models from the literature (*e.g.* linear regressions). It is not used in the GBS yet as we have not obtained reliable results for now.

2.2 Livestock husbandry (excluding feed) CommoTool

A PRESSURES WITH IMPACT FACTORS EXPRESSED PER GHG EMISSIONS (CC, HD_{CC})

After the dimensioning step, impact factors are in **MSA.km² per livestock categories / species**. We focus on emission-related pressures (climate change, atmospheric nitrogen deposition and freshwater eutrophication) at this stage. Pressures requiring LCI data (spatial pressures and hydrological disturbance) are directly treated in the attributing step in section 4.1B.

The goal of this section is to dimension climate change related biodiversity impacts caused by livestock husbandry direct operations. **GHG data detailed per sub-domain, per species**[14] **and per country** are available on FAOSTAT website and are directly used as inputs to construct the impact factors. As a reminder, Table 8 summarises FAOSTAT GHG emissions sub-domains that were considered for the computation of impact factors of GHG emission due to crop cultivation (for more details please refer to the crops CommoTool review report (CDC Biodiversité 2020b)).

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 8: Allocation of FAOSTAT GHG emissions to GBS assessed activities

[14] The impact factors are expressed per animal product in the attribution section.

We include the following GHG emissions data in the livestock husbandry Scope 1 CommoTool:

- "Enteric fermentation": this dataset gathers the direct methane (CH_4) emissions produced by digestive systems of ruminants and non-ruminants (FAOSTAT 2019e) that can be **imputed directly to the animal cohorts** and are taken into account in the livestock husbandry CommoTool

- "Manure management": manure designates the urine and dung produced by livestock. Manure management is the process of storage and treatment of manure after it is emitted. This dataset reports GHG emissions caused by this process, which are methane (CH_4) produced by anaerobic decomposition of manure stored and treated, and nitrous oxide (N_2O) from nitrification and de-nitrification processes in manure, and N volatilization and leaching (FAOSTAT 2019h). Such GHG are emitted especially if large number of animals are managed in a confined area (IPCC 2006a). Generally, this process is under the responsibility for the livestock farmer, therefore, **these emissions are taken into account in the livestock Scope 1 impact factors.**

- "Manure left on pasture"[15]: "manure left on pasture" is one specific type of manure management, and designated manure that remain on the pasture when livestock cohorts graze. This phenomenon causes nitrous oxide gas emissions on the deposition site and after volatilization/re-deposition and leaching processes, due to nitrification and de-nitrification of the manure (FAOSTAT 2019g). Imputing the responsibility of these GHG emissions to the Scope 1 livestock husbandry or to the Scope 1 of grass biomass is debatable[16]: these GHG are caused by the presence of livestock cohorts, but manure is also a source of organic fertilizer for pasture production. In practice, these GHG emission data due to manure left on pasture are available per livestock species and not per tonnage of grass biomass (required if we wanted to impute this responsibility to grasslands). Therefore, **for now, we consider that GHGs from "Manure left on pasture" are under the responsibility of livestock husbandry in the Scope 1** (which may be changed to grassland in a future version of the GBS).

"Burning – Savanna" data were excluded as the emissions were not attributed directly to species, rather to types of savanna burnt.

Two other options were also explored:

Option 1: it also follows the principle of choosing the relevant GHG emission categories in the FAOSTAT data, based on previous assumption. When constructing the crops CommoTool (CDC Biodiversité 2020b), we have built a table of GHG emissions caused by livestock husbandry per country, split between emissions caused by manure left on pasture and the remaining emissions. We could apply the biodiversity impact intensities (MSA.km²/t CO_2-eq) directly to these emissions, however the results would not be detailed per species. As a reminder, Table 8 summarises FAOSTAT GHG emissions sub-domains that were considered in this computation, the relevant columns are `cattle_grazing` (including "Manure left on pasture" and a part of "Burning – Savannah") and `cattle_cattle` (including "Manure management" and "Enteric fermentation").

Option 2: FAOSTAT also directly reports GHG Emissions intensities in kg CO_2-eq per kg of product (fresh cow milk, eggs etc.) to which we can directly apply climate change impact intensities (MSA.km²/t CO_2-eq)

[15] This approach is a kind of "source attribution", attributing the responsibility of emissions to livestock husbandry or other activities.

[16] Expert opinion on this attribution choice of impacts caused by manure left on pasture to Scope 1 livestock husbandry or grass would be very instructive

and thus obtain impact factors in **MSA.km² per quantities of animal product**. However, FAOSTAT attributes more emission categories (than our approach) to livestock husbandry: it also includes **"Manure left on soils"** in addition to "Enteric fermentation", "Manure management" and "Manure left on pasture".

Option 1 is dropped because it does not allow to assess impacts per species, and the choice of GHG emission sources differs for the case of "Burning – Savanna". Option 2 is only applicable to climate change impacts, whereas the methodology chosen could be replicated for other emissions' impacts (such as atmospheric nitrogen deposition or freshwater eutrophication in section 2.2B, and also more consistent with the methodology used to account for climate change impacts caused by crop production (CDC Biodiversité 2020b). The second option will be used nonetheless in the attributing step in section 4.1A. Figure 8 gives an overview of the methodology chosen, both at the dimensioning and attributing steps, only **dimensioning** (STEP 1) is detailed in this section. Section 4.1A provides further explanations on the attributing phase to the corresponding animal products during STEP 2.

Figure 8: Methodology overview to construct the biodiversity impact factors of climate change caused by livestock

The three data sets regarding "**Enteric fermentation", "Manure management" and "Manure left on pasture"** are first cleaned by matching FAO countries with GLOBIO countries, removing NA values (similar data treatment as for crop yields in the Crops CommoTool). For now, we keep the most recent record per {country, species} (in general in 2017), in a future version we could consider using an average over several years. Then, in STEP 1, the functions `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()` are both applied to each dataset to obtain factors in MSA.km² for each combination of {country; species}. Species granularity can be found in the Table 3. These functions were further explained in the terrestrial and freshwater aquatic review reports (CDC Biodiversité 2020g; 2020c). The chosen time horizon is 100 years, and the GWP values used can be found in the terrestrial and crop CommoTool review reports (CDC Biodiversité 2020g; 2020b). Here are how the functions are called in the function `livestock_builder_scope1_CC_impacts_country()`:

```
    mutate(MSA_CC_terrestrial_dynamic_MSA_km2 =
GBStoolbox::ghg_get_emission_MSA_impact("CO2", "formula",total_GHG_gigagrams_co2eq * 10^3,
"tons", 100),
           MSA_CC_aquatic_dynamic_MSA_km2 =
GBStoolbox::ghg_get_emission_MSA_impact_aquatic("CO2", "formula", total_GHG_gigagrams_co2eq
* 10^3, "tons", 100))
```

As explained earlier, the impact factors obtained are in **MSA.km² per {country; species}**, and fall into the data quality tier 1, as they are based on tier 1 biodiversity intensities computed in the terrestrial and freshwater modules (MSA.km^2/kg CO_2-eq). In this version of the GBS, we only provide a central estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

B PRESSURES WITH IMPACT FACTORS EXPRESSED PER NUTRIENTS EMISSIONS (N, FE)

The goal of this section is to **dimension terrestrial and freshwater eutrophication impacts** on biodiversity caused by livestock husbandry direct operations. The methodology used to compute an impact factor in **MSA.km² per emitted nutrient per {country; species} pair** is described below.

As mentioned in paragraph 2.1.A.1, the section **"Livestock Manure" from FAOSTAT** estimates amounts excreted in manure per country based on livestock production data, and distributes these amounts to manure left on pasture, treated manure and manure applied to soils. Losses caused by each manure treatments are also reported (caused by volatilisation or leaching). In the GLOBIO-IMAGE framework, the pressure **atmospheric nitrogen deposition (N)** is related to the quantity of nitrogen depositions originated from emissions to air exceeding the critical load of ecosystems (Schipper et al. 2016) so that FAOSTAT data on volatilized manure (left on pasture and applied to soils) could be considered.

For **atmospheric nitrogen deposition (N)**, we convert the biodiversity intensities expressed in MSA.km²/ton PO_4-eq into MSA.km²/ton N-eq thanks to eutrophication potentials. The intensities are then applied to the **volatilized emissions of manure or losses reported per species and countries in FAOSTAT (N content)**[17].

To be consistent with the GHG methodology choices in 2.2A, losses from manure management and manure left on pasture are considered. Thus, the relevant categories of manure to which the impact

[17] Applying eutrophication potentials to N content may not be completely satisfying but used as a first approach with the available data, expert opinion on this point would be much appreciated.

factors are applied are **"manure left on pasture that volatilizes"** and "**losses from manure treated**". "Manure applied to soils" and associated losses are considered as under the "responsibility" of crop production, similar to what is done for GHGs.

The pressure **freshwater eutrophication (FE)** in lakes is assessed with the accumulated total nitrogen and phosphorus concentrations as proxies of intensity of human land use in the catchments in the GLOBIO-IMAGE framework (Janse et al. 2015). This total nutrient concentration sums up the nutrients from leaching or runoff from agricultural areas and manure and the urban nutrient emissions. In the first version of the GBS, we assume that only phosphorus compounds were responsible for this pressure freshwater eutrophication (in lakes), as phosphorus is often considered as the limiting factor of eutrophication in freshwater ecosystems. The GBS review reports about freshwater pressures (CDC Biodiversité 2020g; 2020c) describes how the biodiversity impacts intensities are computed in **MSA.km² per emitted ton of P-eq**. **FAOSTAT "Livestock Manure"** disseminates data on manure that leaches in nitrogen content, unfortunately direct phosphorus emissions due to livestock husbandry is not available in a systematic way for each country and livestock species.

As data on phosphorus emitted by livestock husbandry is limited, no impact factor is computed for the pressure **freshwater eutrophication (FE).** More research for such data is needed.

Figure 9 gives an overview of the impact dimensioning methodology described above (STEP 1). Section 4.1A provides further explanations regarding impacts attribution to the corresponding animal products during STEP 2.

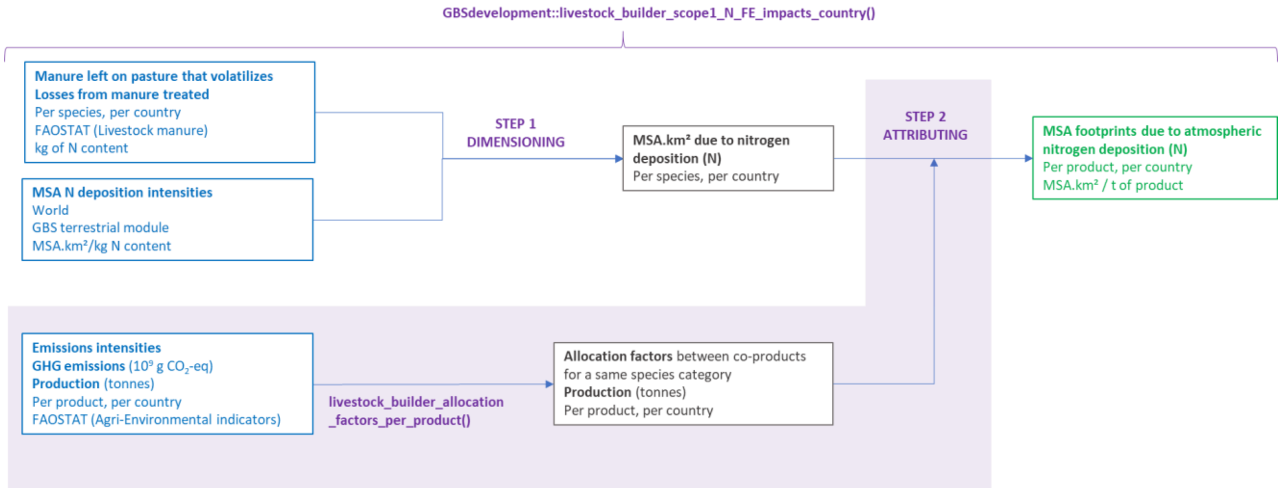


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Figure 9: Methodology overview to construct the biodiversity impact factors of atmospheric nitrogen deposition (N) caused by livestock (Scope 1). Dimensioning and attributing steps are both mentioned here.

Here is the formula used in the GBS to dimension the biodiversity impacts related to Atmospheric Nitrogen deposition (N) due to livestock husbandry per combination of {species; country} (in MSA.km²) `total_N_content_kg` designates the sum of the N contents of the selected nutrient emission sources:

```
#For Atmospheric Nitrogen deposition:
[…]
   mutate(msa_N_terrestrial_dynamic_MSAkm2 = total_N_content_kg *
MSA_terrestrial_N_dynamic_MSAkm2_per_kg_Ncontent,
           msa_N_terrestrial_static_MSAkm2 = total_N_content_kg *
MSA_terrestrial_N_static_MSA_km2_per_kg_Ncontent)
```

The computed impact factors fall into data quality tier 2, because they are based on national livestock manure data (tier 2) combined with a tier 2 impact factor from the terrestrial module.

Future development

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

C PRESSURES WITH IMPACT FACTORS DERIVED FROM LCI DATA

This concerns the **spatial pressures and the hydrological disturbance due to water consumption**. The **dimensioning and attributing steps are merged** as these biodiversity impact factors have been assessed with LCI data which have been inventoried directly for a functional unit corresponding to livestock products, for example 1 kg of cattle meat, or 1 kg of eggs from chicken layers. Please refer to section 4.1B for more details about these pressures.

2.3 Grass CommoTool

The goal of this section is to dimension a biodiversity impact factor in **MSA.km²/tonne of grass at the country level**.

Grasslands cover about 30% of the global land (Ali et al. 2016) and is an important source of feed for livestock, especially ruminants. Livestock grazing can have adverse effects on rangeland biodiversity such as removal of biomass, trampling or destruction of the root systems and replacement of wild grazing animals by livestock (Alkemade et al. 2013). However, when grazing activities are well managed, they can be a tool to maintain or restore biodiversity of open landscape (Metera et al. 2010). Grasslands can be classified according to their intensity of human exploitation. We will refer to the classification presented in Table 10, used in GLOBIO and mentioned in the terrestrial module (CDC Biodiversité 2020g). Cause-effect relationships between pasture land use classes more or less intensively managed and impacts on biodiversity are defined by (Alkemade et al. 2013) based on the meta-analysis of biodiversity in pastures. The analysis is based on 24 studies providing information on species composition in grazed systems and natural rangelands and pasture management practices. The variables used to determine grazing intensity are presented in Table 9: for each variable/criteria, a note is defined and column "Rules of assignment" aggregating the notes of each variable in Table 10 defines the grazing intensity.

Criteria / note	0	1	2	3
reported intensity	un-grazed or abandoned	natural grazing	moderate grazing intensity	high grazing intensity
visual alteration of the vegetation structure	not or slightly altered	significantly altered in height or species composition, including exotics	/	/
rangeland management	no management	presence of management such as soil disturbance, clearance of vegetation and application of fertilizers, planting or sowing grass or forage crops	/	/
seasonal variation	only seasonal grazing corresponding to natural grazing pattern	continuous grazing regardless of the season	/	/

Table 9: Variables determining the grazing intensity in the meta-analysis of (Alkemade et al. 2013)

Grazing intensity	Description	Rule of assignment	MSA	Example threshold stocking rates in the studies extracted in the meta-analysis of (Alkemade et al. 2013)[18]

[18] For more details please refer to the Supplement 1, table S1.2 of (Alkemade et al. 2013). These are only examples of stocking rates and vary depending on the context and grassland capacity. According to livestock expert's opinion, these figures are lower than expected.

Un-grazed, abandoned rangeland (0)	“Original grasslands no longer in use, lacking wildlife grazing and no forests developed”	“If the reported intensity of rangeland management equals 0, and the description is clear on the absence of wildlife grazing then grazing is assigned as un-grazed, abandoned rangeland”	70 % [19]	“removing 20% of herbage annually” (Hart 2001)
Natural (1)	“Rangeland ecosystems determined by climatic and geographical circumstances and grazed by wildlife or domestic animals at rates similar to those of free-roaming wildlife”	“If the sum of reported intensity, visual alteration of the vegetation structure and seasonal variation equals 1 than grazing is ‘natural’”	100 % [20]	“0.07 animal units per ha (Unit = a 455 kg steer)” (O’connor 2005)
Moderately used grazing lands (2) or "cultivated grazing area"	“Rangelands with higher stocking rates: grazing has different seasonal patterns or vegetation structure is different compared with natural rangelands”	“If this sum [of all criteria] is 2 or 3 then it moderately used grazing lands”	60 % [20]	“by 1 cow on 12-17 ha and limited rotation to less then 45 days a year” (Bock, Jones, and Bock 2006; 2008), “0.4 AU. Mown 2-4 times a year” (O’connor 2005)
Intensively used rangeland (3)	“Rangelands with very high stocking rates: grazing has different seasonal patterns and vegetation structure is different compared with natural rangelands”	“and if the sum [of all criteria] is 4 or 5 then the intensity class is intensively used rangeland”	50 % [19]	“stocking rate of 0.25-0.5 cows / ha” (Cagnolo, Molina, and Valladares 2002), "> 0.8 AU” (O’connor 2005), "0.88 livestock units per ha" (Smart, Whiting, and Twine 2005), "0.1 adult equivalent per ha" (J. Woinarski et al. 2002; J. C. Z. Woinarski and Ash 2002)
Man-made grasslands (4)	“Rangeland with high degree of human management, including converted forests”	“if the rangeland management equals 1, then the intensity class is man-made grasslands”	30 % [21]	NA

Table 10: MSA values for different grazing intensities, adapted from (Alkemade et al. 2013)

[19] Not used in the land-use pressure-impact relationships of GLOBIO
[20] This MSA value is used in the land-use pressure-impact relationships of GLOBIO 3.6 and GLOBIO 3 (used for GBO4 assessment)
[21] This MSA value is used in the land-use pressure-impact relationships of GLOBIO 3.6 only

We seek to build **impact factors per tonne for default assessments**. We need to associate an average land use to an average tonne grazed. The "**Natural grassland**" land use class in GLOBIO cause-effect relationships (MSA = 100%) is based on data extracted from papers of the meta-analysis and include for instance undisturbed savanna, natural reserves, without grazing or with very little grazing (wildlife grazing). Some grazing intensity figures were given, such as 0.07 animal units per hectare (1 unit = a 455 kg steer). The higher MSA value of “Natural grasslands” is not an assumption but a result from the meta-analysis (Alkemade et al. 2013).

The land use class "**Pasture - man-made**" (MSA = 30%) cannot be used as no land use intensity factors are available in the GBS (cf. GBS terrestrial module review document for more details).

Therefore, we have chosen "**Pasture - moderately to intensively used**" (MSA = 60%, also called “**cultivated grazing area**” in the terrestrial module of the GBS) as the default land use for grazing. It is described as "rangelands with higher stocking rates [than natural rangelands], grazing has different seasonal patterns or vegetation structure is different compared with natural rangelands" (Alkemade et al. 2013). In refined assessments, the two other land uses cited could also be considered.

Cultivated grazing areas are classified as a **human land-use**, meaning that they exert the following spatial pressures on biodiversity: **land use (LU), encroachment (E), fragmentation (F), wetland conversion (WC) and land use change in catchment (LUR and LUW)**.

Regarding the use of water resources, for now we assume that mostly green water is requested and the blue water used (*e.g.* for irrigation) should be negligible: therefore, **cultivated grazing areas do not contribute to the pressure hydrological disturbance (HD_{water})**[22].

Figure 10 gives an overview of the methodology used to compute biodiversity impact factors related to grasslands. Only pressures with intensities (from the terrestrial and aquatic GBS modules) expressed in MSA.km²/km² are taken into account as explained above. Yield data are issued from (EUROSTAT 2013) as explained in section 2.1C. We apply an average yield of 2.5 t/ha to all countries, corresponding to the intermediary range of “Extensive pasture” in (EUROSTAT 2013).

[22] For atmospheric nitrogen deposition (N) and climate change impacts (CC and HD_{CC}), impacts directly generated by the livestock herds are already accounted for in the livestock section with data from FAOSTAT about “manure left on pasture” and attributed to Scope 1 for now (c.f. sections 0 and 2.2B). There may be other impacts linked to fertilizers, machines (and fuels) used for managed grasslands (Scope 3 for grasslands), which are not accounted for now in the GBS.

Figure 10: Overview of the computation methodology for grass impacts factors on biodiversity

The formula used to compute the biodiversity impact factors of grass in MSA.km²/t of pasture are similar to those used in the crops CommoTool based on yield data, please refer to the review document for more details (CDC Biodiversité 2020b).

The computed impact factors fall into data quality tier 1, because they are based on a world average grassland yield (tier 1) combined with tier 2 biodiversity intensities from the terrestrial module. In this version of the GBS, we only provide a central estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced[23].

3 Dimensioning the livestock husbandry & grass impacts – Refined assessments

The principle is that, if **custom consumption and emissions data can be provided by the companies (consumed water, land, emitted GHG, emitted nutrient for example), we can inject them in the default methodologies presented in the previous sections and compute refined impact factors.** This applies both to the Livestock (feed excluded) and the Grass CommoTools.

[23] For the case of some freshwater pressures, there are different impact factors with conservative or optimistic scenarios (cut or weighted mean), which are taken for conservative and optimistic assessment assessments.

4 Attributing the impact of the livestock sector to its products

4.1 Attributing livestock husbandry (excluding feed) impacts per animal product

A IMPACTS DUE TO EMISSIONS (CC, HD_{CC}, FE, N)

For livestock (feed excluded) impacts, especially emission-related, the attributing step consists in allocating the obtained impact at the end of dimensioning phase in **MSA.km² per combination of {country; species}** to corresponding animal products (meat, milk, eggs etc.), and thus obtaining factors in **MSA.km² per tonne of livestock product per country**.

This section deals with STEP 2 on Figure 8 and Figure 9. The approach is applicable to **climate change and eutrophication** impact factors. For the other pressures using LCI data (land use and water-related pressures), this approach cannot be implemented as dimensioning and attributing phases are merged.

The approach is based on FAOSTAT emission intensities and its underlying allocation factors. As mentioned in the section 2.1.A.2, these emission intensities data are in kg CO_2-eq per kg of animal product and computed by dividing the sum of GHG emissions reported by FAOSTAT in the categories "**Enteric fermentation", "Manure management", "Manure left on pasture" and "Manure left on soils"** by the **corresponding production tonnage of animal product**.

Table 3 summarises the **matching between species and products for which GHG emission intensities data are available.**

For **Cattle, Poultry, and Swine**, the correspondence is quite straightforward, as species GHG emissions ("Enteric fermentation", "Manure management", "Manure left on pasture" and "Manure left on soils") are directly reported by FAOSTAT separately for the population dedicated to meat production and the population dedicated to milk or eggs production[24].

For **Buffaloes, Sheeps, Goats and Camels**, the reported GHG emissions per species ("Enteric fermentation", "Manure management", "Manure left on pasture" and "Manure left on soils") are not split between the population dedicated to each co-product. FAOSTAT computes the part of GHG linked to each co-product livestock population and then the co-products emission intensity (kg CO_2-eq/kg of co-product), by estimating **an allocation factor** which is the **fraction of animals involved in the production of each co-product (milk or meat, …)**[25]**. The latter is obtained by dividing the number of heads of animals dedicated to this co-product** (in FAOSTAT, in "Production/Livestock primary", "Producing animals", for each livestock co-product, the number of "Producing Animals/Slaughtered [animals]" are detailed) **by the total number of heads of the species** (available in "Production/Live animals"). **For each species, the sum of allocation factors of the co-products equals 1**. For more details, please refer to the FAOSTAT documentation (FAOSTAT 2019d). FAOSTAT can then deduce the GHG emissions linked to each co-product C produced by the species S, in a specific country CN with the formula below:

GHG emission(C, S, CN) = GHG emission(S, CN) * allocation factor(C, S, CN)

GHG emission data per species and country (GHG emission (S, CN)) are reported in each dataset "Manure management", "Enteric fermentation" etc. The computed GHG emission data per co-product and country (GHG emission (C, S, CN)) are reported in the "Emission intensities" page alongside the co-product's emission intensities. The allocation factors described above are not directly reported in the "Emission intensities" data page of FAOSTAT. In order to retrieve them, in the function `livestock_builder_allocation_factors_per_product()`, we group GHG emissions and production data per species, and calculate the **allocation factor which is the ratio of GHG emission(C, S, CN) / GHG emission(S, CN):**

```
group_by(FAO_country_name, FAO_country_code, ID_FAO_emissions_species,
FAO_emissions_species) %>%
    mutate(allocation_factor = total_GHG_gigagrams_co2eq/sum(total_GHG_gigagrams_co2eq))
```

Then, in the specific functions for **each emissions pressure (CC, HD_{CC}, N, FE)**, *i.e.* `livestock_builder_scope1_CC_impacts_country()` and `livestock_builder_scope1_N_FE_impacts_country()`, the total impact in MSA.km² per {country; species} assessed during the dimensioning step is multiplied by the allocation factor and divided by the production

[24] We are aware that this distinction between the cohorts producing each type of commodity is artificial. We may consider multi-products cases in a future version of the GBS. For now, the allocation between animal products is based on FAOSTAT data about livestock cohort's population data, which separate meat and dairy cohorts.

[25] For the case of camels, no GHG emission intensities are reported in FAOSTAT for camel meat, so that all impacts dimensioned for the species "Camels" are attributed to camel milk.

of the co-product in the given country to obtain a factor in MSA.km²/tonne of co-product. This is the code for climate change:

```
mutate(MSA_terrestrial_CC_dynamic_MSAkm2_per_tonne = msa_CC_terrestrial_dynamic_MSAkm2 *
allocation_factor / total_production_t,
       MSA_aquatic_HDCC_dynamic_MSAkm2_per_tonne = msa_CC_aquatic_dynamic_MSAkm2 *
allocation_factor / total_production_t,
[…])
```

The impact factor falls into the data quality tier 1, as they are based on tier 1 impact factors computed previously. In this version of the GBS we only provide a central estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.

In future versions of the GBS, **other allocation options could be used**. For example, the methodology used in the GLEAM model developed by the FAO consists in allocating first the impacts to fibber (*e.g.* wool) based on economic values, and then allocate the remaining impacts between meat and other co-products such as milk and eggs using physical allocation rules (mass or according to protein content). The advantage would be to add other animal products (such as wool) and to have a more refined allocation. However, it requires more extensive data, especially on prices and protein contents to compute the allocation factors. Besides, GLEAM allocation rules follow partially the LEAP principles (FAO 2016). A full biophysical allocation method is also advised by livestock experts.

B IMPACT FACTORS DERIVED FROM LIFE-CYCLE INVENTORIES DATA (LCI)

4.1.B.1 Principle

As mentioned in section 2.1B, the LCI database PEF used for the mining and wood logs CommoTools also contains livestock products processes, which gathers input and output flows needed to produce a given unit of the final livestock products (for example 1 kg of cattle meat in France). For this section, we are interested into first quantifying the resources (land, water) needed for livestock (excluding grazing), especially the needed area for livestock buildings on the farm, and the water directly consumed by the animals. PEF inventory data usually seeks to be comprehensive all over the lifecycle of the product and each flow is not always decomposable in the source processes. Hence, there could be flows that originates from an upstream or downstream process generating the product. We selected flows that should mostly fit in the Scope 1 of the livestock product generation process in sections 4.1.B.2 and 4.1.B.3. To simplify, we consider for now that the quantities are within the Scope 1 of livestock husbandry systems.

Besides, it should be kept in mind that for these pressures, unlike for emissions-related pressures (CC, HD_{CC}, N, FE) in the previous sections, **the steps of dimensioning the impacts of animal species and attributing the impacts to the livestock products are merged**, as retrieved LCI data already have functional units in tonnages or kilograms of livestock products (1 kg of cattle meat, or 1 kg of fresh cow milk etc.).

Figure 11 gives an overview of the computation procedure for biodiversity impact factors derived from LCI data. The principle is to use functions already used for the mining and wood logs commodities in order to retrieve the **needed quantities of flows of interest** (used land or water) from LCI data, *inter alia* the function `lca_get_input_item_quantity()`. Such retrieved quantities correspond to **midpoint impacts**. Then, the **biodiversity impacts intensities calculated in the terrestrial and freshwater modules** (CDC Biodiversité 2020g; 2020c) are applied to the quantified flows to obtain **endpoint impacts**. Computations are explained in more details in the next sections.

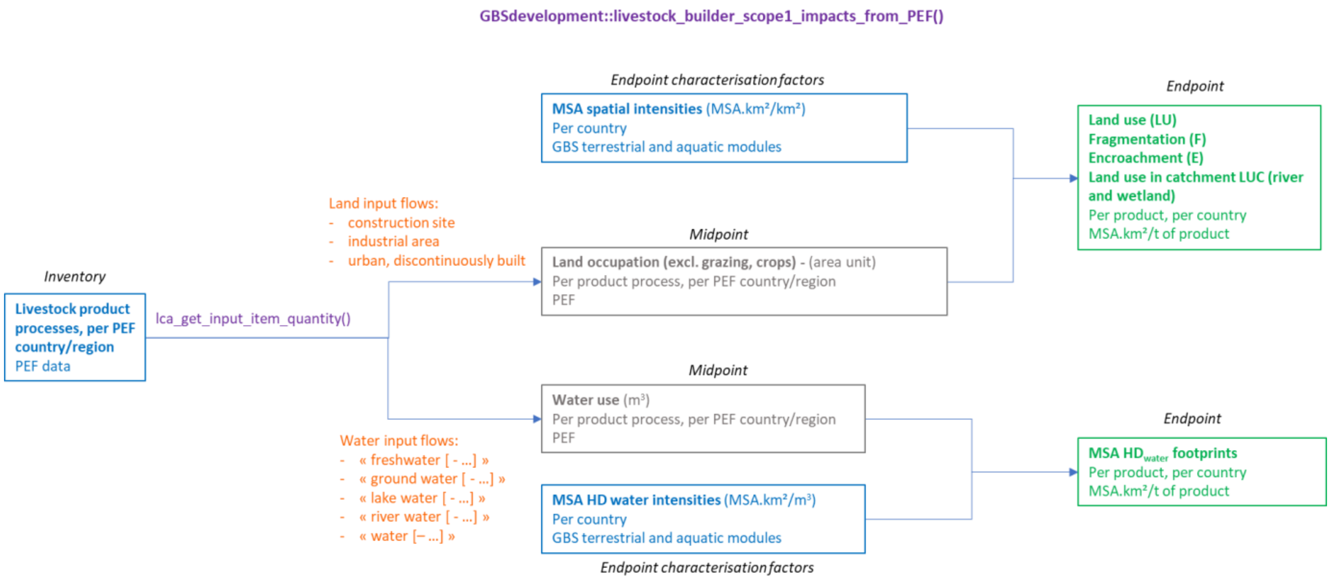

Figure 11: Methodology overview to construct the biodiversity impact factors of pressures caused by livestock (excluding feed) based on LCI data. Dimensioning and attributing steps are merged.

Table 11 presents the correspondence between the livestock products assessed and PEF processes from which land use and water data are retrieved. For the geographical correspondence between PEF process and GLOBIO country biodiversity intensities, all the GLOBIO countries within EU28+3 are associated to the average EU PEF process in Table 11, except if more refined process is available for a specific country. Other countries outside EU28+3 are associated to the GLO process if no refined process per country is available.

ID FAO livestock products	FAO livestock products	Loca -tion	LCA Process from PEF
1062	Eggs, hen, in shell	DE	Eggs__at_farm__production_mix__per_kg___EU_28_3
1062	Eggs, hen, in shell	ES	Eggs__at_farm__production_mix__per_kg___EU_28_3

1062	Eggs, hen, in shell	EU	Eggs__at_farm__production_mix__per_kg___EU_28_3
1062	Eggs, hen, in shell	FR	Eggs__at_farm__production_mix__per_kg___EU_28_3
947	Meat, buffalo	NA	NA
867	Meat, cattle	DE	Beef_cattle__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
867	Meat, cattle	ES	Beef_cattle__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
867	Meat, cattle	EU	Beef_cattle__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
867	Meat, cattle	FR	Beef_cattle__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
867	Meat, cattle	GLO	Beef_cattle__at_farm__for_slaughter__per_kg_live_weight___GLO
1058	Meat, chicken	DE	Broiler__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
1058	Meat, chicken	ES	Broiler__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
1058	Meat, chicken	EU	Broiler__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
1058	Meat, chicken	FR	Broiler__at_farm__for_slaughter__per_kg_live_weight___FR
1058	Meat, chicken	NL	Broiler__at_farm__for_slaughter__per_kg_live_weight___NL
1017	Meat, goat	NA	NA
1035	Meat, pig	DE	Swine__at_farm__for_slaughter__per_kg_live_weight___DE
1035	Meat, pig	ES	Swine__at_farm__for_slaughter__per_kg_live_weight___ES
1035	Meat, pig	EU	Swine__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
1035	Meat, pig	FR	Swine__at_farm__for_slaughter__per_kg_live_weight___FR
1035	Meat, pig	NL	Swine__at_farm__for_slaughter__per_kg_live_weight___NL
977	Meat, sheep	AU	Sheep__at_farm__for_slaughter__per_kg_live_weight___AU
977	Meat, sheep	DE	Sheep__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
977	Meat, sheep	ES	Sheep__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
977	Meat, sheep	EU	Sheep__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
977	Meat, sheep	FR	Sheep__at_farm__for_slaughter__per_kg_live_weight___EU_28_3
977	Meat, sheep	NZ	Sheep__at_farm__for_slaughter__per_kg_live_weight___NZ
951	Milk, whole fresh buffalo	NA	NA
1130	Milk, whole fresh camel	NA	NA
882	Milk, whole fresh cow	DE	Cow_milk__at_farm__production_mix__per_kg_FPCM___EU_28_3
882	Milk, whole fresh cow	ES	Cow_milk__at_farm__production_mix__per_kg_FPCM___EU_28_3
882	Milk, whole fresh cow	EU	Cow_milk__at_farm__production_mix__per_kg_FPCM___EU_28_3
882	Milk, whole fresh cow	FR	Cow_milk__at_farm__production_mix__per_kg_FPCM___FR
882	Milk, whole fresh cow	GLO	Cow_milk__at_farm__production_mix__per_kg_FPCM___GLO
1020	Milk, whole fresh goat	NA	NA
982	Milk, whole fresh sheep	NA	NA

Table 11: correspondence between FAO livestock products and PEF processes

4.1.B.2 Biodiversity impact factors of pressures expressed in unit of area: LU, E, F, WC, LUR, LUW

As mentioned earlier, we first select the following **input land resources flows** assumed to be **relevant for livestock husbandry (excluding feed) impacts**: among the category “Land use/Land occupation” in the input table of the livestock production processes, we assume that the flows **"construction site", "industrial area",** and **"urban, discontinuously built"** are representative of the buildings and areas directly used for livestock husbandry. Flows referring to agricultural areas such as arable lands, crops and grasslands are assumed to be covered by the Crops and Grass CommoTools.

The function `lca_get_input_item_quantity()` is applied to the selected flows above and to each of the livestock processes linked to products identified in Table 11, so that a matrix of land directly used by the process (generally a 1kg of the product) is obtained, in m^2.yr, a time-integrated result. In the descriptions of the selected processes from the PEF inventory database, it is mentioned that the temporal boundaries are generally set to 1 year of production, so that the reported time-integrated area in m^2.yr is equal to the used area in m^2 during 1 year to produce the given mass of the product.

As mentioned earlier, areas directly occupied by livestock husbandry (excluding pastures), especially buildings for livestock, can be considered more than 80% built up areas, *i.e.* "urban areas" in terms of GLOBIO land use category. Thus, we assume that their MSA is the same as that of urban areas, *i.e.* 5%. Therefore, the intensities related to urban areas (in MSA.km^2/km^2) computed in the terrestrial module review report and the intensities in MSA.km^2/km^2 computed in the freshwater module (CDC Biodiversité 2020g; 2020c) are applied to the selected areas, with the same principles than in the Crops CommoTool review document (CDC Biodiversité 2020b).

Newly calculated impact factors are in MSA.km^2/t of animal product. The computed impact factors fall into data quality tier 2, because they are based on LCI data per countries or regions (tier 2) combined with a tier 2 biodiversity intensity from the terrestrial and freshwater modules. Besides, in this version of the GBS, we only provide a central estimation of the impact factor. In later versions, conservative and optimistic assessments will be introduced.[26]

4.1.B.3 Biodiversity impact factors of pressures expressed in volume of water: HD_{water}

As mentioned earlier, we first select the following **input water resources flows** assumed to be **relevant for livestock husbandry impacts (feed excluded)** beginning with these terms: "freshwater", "ground water", "lake water", "river water", "water -"

This pressure assessment follows the same principle as in section 4.1.B.2: the function `lca_get_input_item_quantity()` is applied to the selected flows above and to each of the livestock processes linked to products identified in Table 11, so we obtain a matrix of volumes of water resources directly used by the process (generally 1kg of the product). Then, we apply intensities in MSA.km^2/m^3 from

[26] For the case of some freshwater pressures, there are different impact factors with conservative or optimistic scenarios (cut or weighted mean), which are taken for conservative and optimistic assessment assessments.

the aquatic freshwater module for water withdrawal (CDC Biodiversité 2020c) to the water volumes quantified for each process.

```
[…]  #HD water intensity unit: per m3 withdrawn or consumed; wm or cut scenarios
    mutate(msa_aquatic_HD_water_withdrawn_dynamic_wm_MSAkm2_per_t =
MSA_intensity_HD_water_withdrawn_dynamic_wm * total_selected_water_flow_m3,
           msa_aquatic_HD_water_withdrawn_static_wm_MSAkm2_per_t =
MSA_intensity_HD_water_withdrawn_static_wm * total_selected_water_flow_m3,
           msa_aquatic_HD_water_withdrawn_dynamic_cut_MSAkm2_per_t =
MSA_intensity_HD_water_withdrawn_dynamic_cut * total_selected_water_flow_m3,
           msa_aquatic_HD_water_withdrawn_static_cut_MSAkm2_per_t =
MSA_intensity_HD_water_withdrawn_static_cut * total_selected_water_flow_m3)
```

Newly calculated impacts factors are in MSA.km²/t of animal product, with the same characteristics as in section 4.1.B.2.

4.2 Attributing grass impacts

For now, we would attribute 100% of the dimensioned impacts to tonnages of grass.

In future versions of the GBS, we would like to link the upstream feed impacts to livestock products. To do so, data on **animal intakes** (tonnages in dry matter of feed needed to produce 1 tonne of a given animal product) and **animal rations** (decomposition of the intake in % of ingredients) are needed. For now, we don't have implemented any default methodology to link quantities of feed to livestock products. We have identified that in the GLEAM model, some data may be retrieved about tonnages of dry matter consumed by cohorts per countries (FAO n.d.), and defaults animal rations in % (FAO 2010) may also be available to be used in a future version of GBS.

It is however possible to **compute refined Scope 3 impacts at the level of livestock products** if the assessed **entity can provide custom data about the feed rations taken by the animals in absolute tonnages**, so that we can apply to them the CommoTools impact factors.

Figure 12 and Figure 13 summarise the pressures assessed, the characterisation factors used (biodiversity impact intensity), the units in the CommoTool databases, the geographic scale and the quality tiers of the factors computed.

	Pressure	LU	E	F	N	CC	HD_{CC}	HD_{water}	LUW	LUR
	Biodiversity impact intensity unit	MSA.km²/ km² of land use type	MSA.km²/ km² of "human" land-use (encroaching LU)	MSA.km²/ km² of "human" land-use (fragmenting LU)	MSA.km²/ t PO_4-eq emitted	MSA.km² / kg CO_2-eq emitted		MSA.km²/ m^3 withdrawn or consumed	MSA.km²/ km² of intensity weighted area	MSA.km²/ km² of "human" land-use
CommoTool	**Livestock CommoTool impact unit**	**MSA.km² / tonne of livestock product**								
CommoTool	**Detail level (geographic, items)**	GLOBIO countries FAOSTAT items								
CommoTool	**Data quality tier**	2	2	2	2	1	1	2	2	2

Figure 12: Summary of livestock husbandry Scope 1 CommoTool

	Pressure	LU	E	F	WC	LUW	LUR
	Biodiversity impact intensity unit	MSA.km²/ km² of land use type	MSA.km²/km² of "human" land-use (encroaching LU)	MSA.km²/km² of "human" land-use (fragmenting LU)	MSA.km²/ km² of agricultural area (including grazing)	MSA.km²/ km² of intensity weighted area	MSA.km² / km² of "human" land-use
CommoTool	**Grazing CommoTool impact unit**	**MSA.km² / tonne of grass**					
CommoTool	**Detail level (geographic, items)**	GLOBIO countries					
CommoTool	**Data quality tier**	1	1	1	1	1	1

Figure 13: Summary of the grass CommoTool

5 Linkage with the input-output modelling

The previous sections explained how **biodiversity impact factors in MSA.km²/tonnes of livestock products per countries** had been computed. These impact factors are useful when the assessed entity can provide inventories of the consumed or purchased quantities of commodities (livestock product, grazed areas etc.). When the assessed entity only has **financial data** on purchases or production, other impact factors in **MSA.km²/financial value** are used. The goal of this section is to explain how such factors are computed in the GBS.

5.1 Livestock husbandry (feed excluded)

Figure 14 describes the data processing workflow in order to link the livestock husbandry CommoTool and the IO framework.

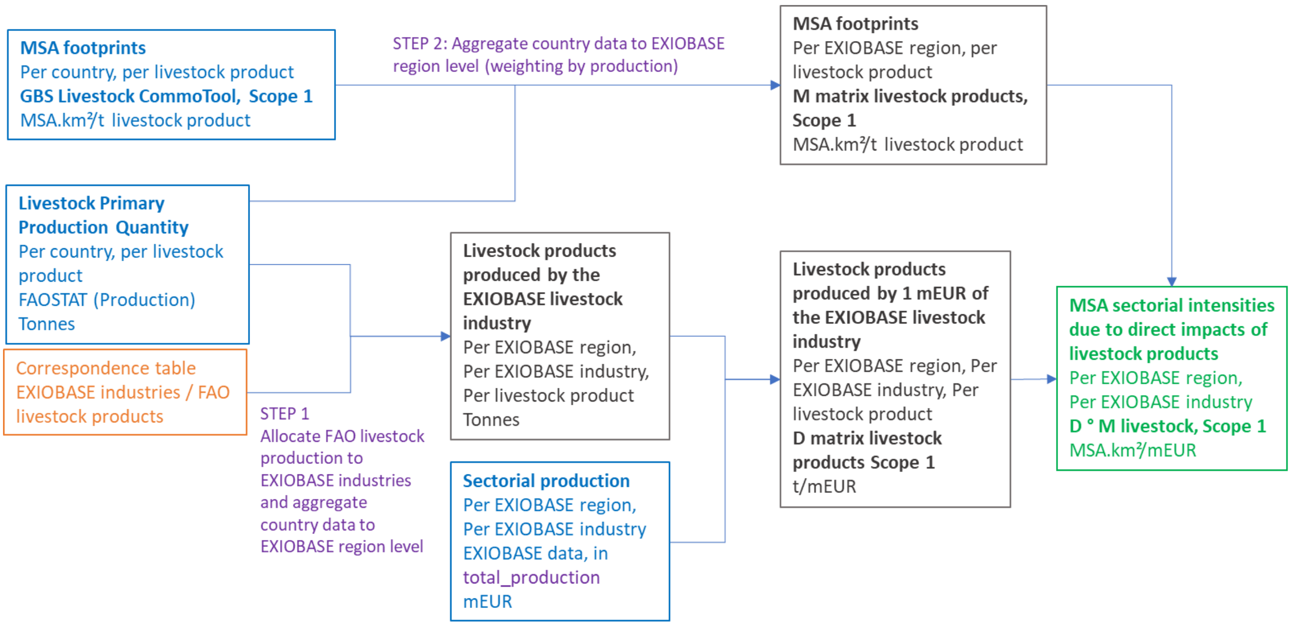

Figure 14: Overview of the integration of livestock direct impact factors in the IO framework

A SCOPE 1 D MATRIX OF LIVESTOCK INDUSTRIES: RAW MATERIALS DIRECTLY PRODUCED

The EXIOBASE input-output economic table contains industries related to livestock products which extracts notably crop and grass commodities and related to other resources uses. However, in the **material account of the environmental extension of EXIOBASE 3, there are no production data reported for livestock products** (tonnages of cattle meat or eggs per industry and country) as the EXIOBASE material accounts report only materials directly extracted from soils (such as crops, forestry, mining commodities) and related emissions and resources consumptions. Moreover, not all the related resources use and emissions are considered, such as Scope 1 land occupation for livestock buildings. We would like to have sectorial default impact factors of EXIOBASE livestock industries in MSA.km² per million EUR: a database linking livestock products tonnages and biodiversity impacts can be built using the CommoTool databases (M matrix, c.f. section 5.1B), and a database linking the livestock industries financial value and produced tonnages should be constructed (D matrix). This involves another method than the one presented in the Input-Output framework (CDC Biodiversité 2020d) to compute the **D matrix,** a matrix which provides the amount of raw materials related to the production of one million euros of each {region; industry} in **tonne per EUR 1 million**. We assume that each livestock industry produces only a limited number of the FAO livestock products identified in Table 12 and in **STEP 1** of Figure 14. In order to construct the D matrix, we divide FAOSTAT production data in a given year (tonnages of livestock products from (FAOSTAT 2019b)) by the `total_production` (output in MEUR of an industry) of the relevant EXIOBASE industry in the same year, following the correspondence table displayed in Table 12. One FAO product appears in maximum one industry, if it appeared in multiple EXIOBASE industries, we would have split the production tonnage between the industries following other assumptions.

FAO_ID _product	FAO_product	EXIOBASE_ID _industry	EXIOBASE_industry
867	Meat, cattle	9	Cattle farming
1035	Meat, pig	10	Pigs farming
1058	Meat, chicken	11	Poultry farming
1062	Eggs, hen, in shell	11	Poultry farming
947	Meat, buffalo	12	Meat animals nec
1017	Meat, goat	12	Meat animals nec
977	Meat, sheep	12	Meat animals nec
951	Milk, whole fresh buffalo	14	Raw milk
1130	Milk, whole fresh camel	14	Raw milk
882	Milk, whole fresh cow	14	Raw milk
1020	Milk, whole fresh goat	14	Raw milk
982	Milk, whole fresh sheep	14	Raw milk

Table 12: Correspondence between animal EXIOBASE industries and FAO livestock products

In the case of the EXIOBASE industry “Raw milk”, “Poultry farming” and “Meat animals nec”, multiple FAOSTAT products are associated to these industries. In this case, we attribute the financial value of the industry to the sum of all the products’ tonnages.

Table 13 shows the example of cattle meat and cow milk in France where tonnages per EUR 1 million of the industries of “Cattle farming” and “Raw milk”.

<table>
<tr><th>FAO product</th><th>FAO production in France (tonnes)</th><th>EXIOBASE industry</th><th>EXIOBASE industry production 2011 in France (EUR 1 million MEUR)</th><th>Intensity in tonne per EUR 1 million in France</th></tr>
<tr><td>Meat, cattle</td><td>1 566 806</td><td>Cattle farming (ID 9)</td><td>8 192.92</td><td>191.24</td></tr>
<tr><td>Milk, whole fresh cow</td><td>24 361 094</td><td>Raw milk (ID 14)</td><td rowspan="3">10 840.97</td><td rowspan="3">2332.77</td></tr>
<tr><td>Milk, whole fresh goat</td><td>655 252</td><td>Raw milk (ID 14)</td></tr>
<tr><td>Milk, whole fresh sheep</td><td>273 089</td><td>Raw milk (ID 14)</td></tr>
</table>

Table 13: D matrix factor computation example for “Cattle farming” and “Raw milk” industries in France

B SCOPE 1 M MATRIX OF LIVESTOCK INDUSTRIES: DIRECT ENVIRONMENTAL IMPACTS OF A GIVEN QUANTITY OF LIVESTOCK PRODUCTS

The **M matrix** contains characterisation factors in **MSA.km^2 per tonne of raw material or commodity per EXIOBASE region and per pressure.** The principle is to adapt the livestock husbandry CommoTool Scope 1 output at the end of the attributing phase (section 4), which gives impact factors in MSA.km^2/tonne of livestock product per country, and to calculate it by EXIOBASE region. This is done by applying a **production weight to the impact factors calculated for each country and pressures (except for climate change which is computed separately thanks to GHG emission data directly reported in EXIOBASE environmental extensions)**, *i.e.* by grouping all the countries within the same EXIOBASE region and applying the formula below to the impact factors (STEP 2 of Figure 14):

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

The granularity of the livestock products is less precise than the CommoTool, some items are aggregated to obtain the same level of detail than the factors in t/MEUR of the D matrix (e.g. Raw milk of the previous example in Table 13). Impact factors of the aggregated items are computed with a weighted mean of the impact factor of each product, weighted by the share of each item within the total tonnage of the products at the EXIOBASE region level.

For the case of terrestrial climate change, as explained in the Input-Output framework document (CDC Biodiversité 2020d), the emissions from EXIOBASE are used instead of the ones calculated in the livestock husbandry Scope 1 CommoTool.

The impact factors from both the D and M matrixes are then combined with a Hadamard product, the process is described more in depth in the review report on the Input-Output framework. The obtained factors are MSA sectorial intensities in **MSA.km² per EUR 1 million per EXIOBASE industry and EXIOBASE region linked to direct impacts of the livestock production, gathered in a `D_x_M` matrix.**

5.2 Grass

Grass items have tonnages reported by the environmental extension of EXIOBASE, so that a similar methodology to link with the IO framework as in the crop CommoTools can be applied (CDC Biodiversité 2020b).

D matrix for grass is an extract of the D matrix already constructed as explained in the Input-Output framework document (CDC Biodiversité 2020d). The goal here is to construct the **M matrix of characterisation factors in MSA.km² per tonne of raw material or commodity per EXIOBASE region**. For **land use (LU), encroachment (E), fragmentation (F)**, the methodology to do so consists in applying land use intensities in MSA.km²/km² of pasture at the EXIOBASE regions level ("cultivated grazing area" in GLOBIO) computed in the terrestrial module (CDC Biodiversité 2020g) to the grassland yield presented in section 2.1C.

For the case of terrestrial climate change, as explained in the Input-Output framework document (CDC Biodiversité 2020d), the emissions from EXIOBASE are used instead of the ones calculated in the grass CommoTool.

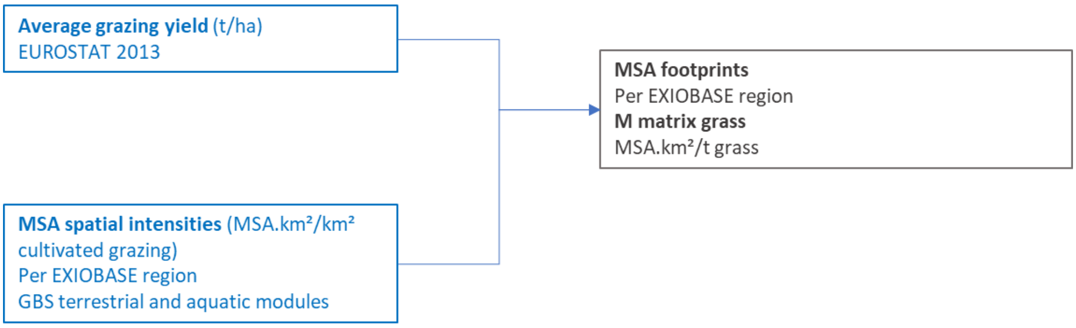

Figure 15: Computation of the MSA footprints of grass in the IO framework

6 Tests and orders of magnitude

6.1 Underlying data checks

Several systematic data checks were first conducted before verifying the consistency of the CommoTool impact factors with GLOBIO-IMAGE outputs.

FAOSTAT livestock manure data have been used to assess atmospheric nitrogen deposition (N) and freshwater eutrophication (FE) pressures. We have tested whether it was in line with EDGAR data about agricultural livestock nutrient emissions, as it is the major data source on which the N impact intensities are based. For more details please refer to the GBS terrestrial and freshwater review reports (CDC Biodiversité 2020g; 2020c). We have used the same eutrophication potentials as mentioned in section 2.2B to convert t N content to t PO_4-eq.

Table 14 presents the results. The manure left on pasture that volatilises and losses from manure treated after conversion represent roughly 2/3 of the total EDGAR nitrogen emissions related to livestock, meaning that not all the N pressure caused by livestock in Scope 1 is covered. However, the conversion with eutrophication potentials may add uncertainty to this result. More research is needed on which nitrogen data to take into account and how to apply the biodiversity loss intensities.

Reference	**Emission quantity**	**Ratio FAOSTAT N content / reference** (after eutrophication potentials conversion)
FAOSTAT N content (from "manure left on pasture that volatilises" and "losses from manure treated")	**17 764 686** t N content	1
Total EDGAR N emissions from livestock	**11 288 377** t PO_4-eq	0.66

Table 14: Nutrient emission data checks results

About the **GHG data**, we have compared FAOSTAT data with global GHG emission data to verify whether it is in line with the general orders of magnitude that livestock is responsible about **10-20% of the global GHG emissions**. GHG data from "enteric fermentation", "manure left on pasture" and "manure management" from FAOSTAT were considered as explained in section 2.1.A.2. The reference global GHG data (without land use change) is issued from the IPCC report in 2012 and also used as reference in the mining review document (CDC Biodiversité 2020e), and amounts to **32 Gt CO_2-eq**. Table 15 summarises the results, and the computed ratios seem to be in range with order of magnitudes available in the literature:

GHG emission data to check	**Emitted quantity**	**Ratio of comparison with reference**
Total GHG emitted by the livestock products	3,23 Gt CO_2-eq	**10.1%**
Total GHG emitted by the livestock species	3,92 Gt CO_2-eq	**10.4%**

Table 15: GHG data checks results

For the order of magnitudes of **grazing land areas**, we have compared the total **EXIOBASE grazss tonnage production (item "Grazing") multiplied by an average yield of grass** (at 2.5 t/ha for extensive pastures from (EUROSTAT 2013)), with the **total cultivated grazing areas in GLOBIO** during the current year. These **two areas match at roughly 97%, so that in terms of areas the GLOBIO cultivated areas should be well covered**, provided that grazing production tonnages and the average yield are in a correct range of values. The same data check will be conducted on the detailed grass yields per country (from FAO pasture profiles data as mentioned in section 2.1C, they are not all retrieved yet due to lack of time) to refine the coverage overview of the Grass CommoTool.

6.2 Code computation procedure tests

A IMPACT FACTORS GENERATION PROCESS

Several tests were conducted on the function `livestock_builder()` which calls the sub-functions building the impact factors per pressure and assemble them into the final .rda datasets of livestock Scope 1 and grass impact factors:

- The input datasets needed to build the impact factors are available in the package folders

- When running `livestock_builder()` from scratch, the newly generated impact factors .rda are not null, and the comparison of the newly run impact factors datasets with the ones in use in the package `GBStoolbox` is possible.

B ATTRIBUTING STEP

These tests are specific to pressures having impact factors at both species and products levels, namely **emission pressures climate change (CC, HD_{CC}), atmospheric nitrogen deposition (N), and freshwater eutrophication (FE)**. Allocation factors to attribute impacts dimensioned at the species levels to the corresponding livestock products are constructed both at the country level and at the EXIOBASE region level as explained in the section 4.1A.

The first test verifies that, **within each livestock species, the sum of the allocation factors of the co-products equals 100%**, at both country and EXIOBASE region levels.

The second test verifies that **all the impacts attributed to the livestock products using such allocation factors actually cover the impacts dimensioned in the first place at the species level**.

6.3 Impact factors order of magnitudes

A COMPARISON OF THE IMPACTS ASSESSED IN THE COMMOTOOLS WITH THE GLOBIO-IMAGE FRAMEWORK

For both livestock (excluding feed) and grass, we could **compare the global impacts dimensioned in the CommoTool with biodiversity losses documented in GLOBIO-IMAGE outputs** (globally or attributed to cultivated grazing areas specifically). To do so, we would apply the CommoTool impact factors per country to the national production data if needed (livestock products or grass), in the case of species the biodiversity loss is already dimensioned for the whole livestock category.

B IO LINKAGE

These tests were not implemented yet but will be when the linkage with the input-output framework is effective.

7 Limits and perspectives

7.1 Underlying data limitations

Both livestock husbandry Scope 1 and grass CommoTools encounter several limitations due to the underlying data used.

FAOSTAT is a database largely used to assess emissions pressures for livestock Scope 1. We have picked the **most recent available input**, as for the Crops CommoTool but the production data could be volatile depending on the years. In a future version of the GBS, five-year averaged production data can be considered. Another limitation of FAOSTAT data, especially regarding GHG emission and manure data, is that such statistics are based on **values computed with IPCC tier 1 methodology**, meaning that these factors are driven by animal population data, which is not refined enough to take into account better management practices. Tier 2 methods shall be checked for future versions of the GBS. However, they are comprehensive, cover most countries and a large panel of species. Therefore they are used as a first approach to exhaustively assess the emission-related pressures that livestock husbandry exerts on biodiversity. Some of FAOSTAT methodological choices also differ from those used in the GBS, such as **GWP values**, or the **GHG emission sources attributed to livestock and crop production**. For the pressure **freshwater eutrophication**, as the biodiversity impact intensities computed in the GBS freshwater module (CDC Biodiversité 2020c) apply to phosphorus, we could not use manure data expressed in N content to assess this pressure.

The **PEF database LCI data aggregates flows over the whole value chain. Thus, Scope 1 flows could not be easily isolated** to feed the livestock husbandry Scope 1 CommoTool. Moreover, the land occupation flow data used are time integrated, in m^2.year, but we have assumed that the time integrated area is equal to the area occupied over one year. Other data sources (LCI database or not) could be considered in future versions of the GBS regarding land and water use, such as the water footprint (Mekonnen and Hoekstra 2012).

Grass yield data is retrieved from (EUROSTAT 2013) which is more specific to Europe and comes from an old study. In future versions of the GBS, using satellite data (linking produced biomass and satellite observations) could be considered.

The environmentally extended IO model EXIOBASE is used in the GBS for default assessments and linked to all the CommoTools. Though, its application to livestock impacts has shortcomings. Indeed, in the case of livestock Scope 1, no livestock products are directly registered in the material account of EXIOBASE, which required some methodological assumptions for linkage with livestock industries. Concerning grass data, it should be also noted that data on estimated grass biomass tonnages directly taken up by animals reported in the material account of the Environmental Extension of EXIOBASE were computed based on the difference between the feed demand and the supply of the feed (market and non-market such as fodder crops and crop residues - (Giljum, Lutter, and Bruckner 2018)). These obtained "**grazing gap**" values may not entirely reflect the real economy as these are computed figures and not originating from databases such as FAOSTAT.

A continuous monitoring of the best available data for livestock emissions and resources use is required to keep improving the GBS.

7.2 Methodology and assumptions limitations

Some methodological choices made in the **livestock husbandry Scope 1 CommoTool** may be discussed.

In the **dimensioning phase**, for both climate change and atmospheric nitrogen deposition, it was decided to count the impacts of **manure left on pasture** within the Scope 1 of livestock husbandry, rather than in the Scope 1 of grassland. This choice may be reconsidered in the future. Regarding **atmospheric nitrogen deposition**, defining **which FAOSTAT N content data** (total deposited content, volatilised fraction, etc.) **should be considered** is key. The choice made to consider the volatilised fraction can be discussed. **Freshwater eutrophication is not taken into account for now**, as it should be mainly caused by phosphorus for which comprehensive data is not available. It could be an important biodiversity impact gap to fill. At first, we tested to assess impacts of freshwater eutrophication with FAOSTAT database on manure, but it led to inconsistent results in the global tests. More research is needed on the underlying data and the methodology used for this pressure.

In the **attributing phase of the livestock husbandry Scope 1 CommoTool**, for the emission-related pressures, the methodology is based on the use of allocation choices from FAOSTAT based on the number of animals dedicated to each co-product. Other allocation choices based on physical (mass, protein) or economical values can be considered in a future version of the GBS. **The case of multiple species occupying the same area is not treated, and the case of multiple layers of animals (such as poultry) is not directly integrated either (potentially partially through the LCI database used)**.

In terms of **Scope 3 impacts of livestock husbandry**, only **grass** is treated through the **grass CommoTool**. The impact factors are based on yield data which not completely exhaustive nor recent, which may lead to uncertainties. The choice to assess impacts per **tonnage or per area** may also impact the quality of the assessment and may also evolve with future versions of the GBS. Among the other Scope 3 impacts of livestock husbandry, **other feed (forage crops, primary crops)** are assessed within the Crops CommoTool. **Compound feed** is not assessed for now, and the **automatic linkage between 1 tonnage of livestock product**

and the required feed quantity is not made yet. Other impacts due to chemicals or energy uses are not considered.

The livestock Scope 1 and the grass CommoTools also **provide an average impact factor for grass and one for each animal co-product, depending on the geographical region**. In the GBS 1.0, there is no further distinction between different production techniques within one country for grass or animal co-product (*i.e.* only one type of grass). Breaking down impact factors by agricultural practices (organic vs conventional, etc.) may be considered in a future version of the GBS, as for the impacts assessment of crops. However, it does not mean that biodiversity footprint assessment for companies will only reflect negative impacts. For example, if the assessed company transforms a plot of land with limited biodiversity (for example an intensive cropland with a MSA of 10%) to a grazed pasture ("cultivated grazing area",MSA = 60%), a biodiversity gain would be assessed (*cf.* refined assessments using the terrestrial module of the GBS (CDC Biodiversité 2020g)). In this simplified example taking only into account the land use pressure, grazing can thus indeed reflect gains of biodiversity compared to a given reference which is not natural or undisturbed. In the case where the reference state is undisturbed (MSA at 100% with natural grassland for example), biodiversity gains with MSA temporarily superior to 100% cannot be accounted for with the MSA (c.f. further paragraphs).

Besides, as mentioned earlier in the document, the GBS does **not take into account soil biodiversity** so that more refined practices cannot be reflected in this regard. Also, the focus of the GBS is **on wild biodiversity and not breeding biodiversity**. Genetic diversity and cultivated biodiversity are thus not included in the GBS (including in modules such as the Crops CommoTool for plant cultivation). Regarding **landscape**, the GBS deals with Fragmentation and Encroachment pressures, which are an aspect of landscape biodiversity. Yet overall, pressure interactions in a landscape are not taken into account by GLOBIO cause-effect relationships.

More broadly, the question of whether **gaining or losing biodiversity with livestock farming** on a land plot, especially with grazing practices, can have different answers depending on **which type of biodiversity** is considered. If we focus on biodiversity in terms of ecosystem intactness, notably with the MSA metric[27], this question depends on which undisturbed state is considered as a reference for the plot. Let's take an example of pasture for livestock grazing (without overgrazing) being converted into a forest. When the plot is not grazed anymore, most of the grassland-type ecosystem reference species will progressively disappear in favour of forestry-type ones. In terms of number of species and species population sizes, a biodiversity loss may be registered. However in terms of MSA, this trend may not be observed. A forest can have an MSA of 85%, (against 60% for pastures), even though the number of species identified may be lower in the forest. Yet, these species are specific to a forest-type ecosystem and the reference used to compute its MSA are forest-type species. The **undisturbed state** against which grassland's MSA is assessed can be debated. In agroecosystems where grazing has a long history and where wild herbivores are extinct,

[27] As a reminder, the MSA (mean species abundance) is the ratio between the mean abundance of original species in disturbed conditions and their abundance in undisturbed habitat and is an indicator of the degree to which an ecosystem is intact (Schipper et al. 2016).

grassland grazed by wild herbivores should be theoretically the "reference" undisturbed state. If livestock grazing is maintained (provided that there is no overgrazing), an overall good MSA would characterize this agroecosystem. Grazing will however not lead to situations where MSA exceeds 100% as there will not be more species or more abundant populations of native species than in the undisturbed ecosystem. Degradation can be registered in case of overgrazing, and thus other more intensive pasture types exist in the GLOBIO pressure-impact relationships.

Both CommoTools may also embed limitations related to the intermediate characterisation factors used, such as the biodiversity loss intensities from terrestrial and freshwater modules (CDC Biodiversité 2020g; 2020c).

Guidelines for biodiversity assessment of livestock systems exist, such as the LEAP principles (FAO 2016) advocated by the FAO. The LEAP principles mention other biodiversity impact factors sources than GLOBIO cause-effect relationships (Chaudhary and Brooks 2018). Those impact factors are also recommended by the UNEP-SETAC Life Cycle Initiative. The impact factors tackle with species richness rather than abundance, account for endemism and threat status, however, they only cover the land use pressure, which are some reasons why GLOBIO cause-effect relationships were preferred to them (CDC Biodiversité 2020a). More generally speaking, the LEAP guidelines apply to the way a Biodiversity Footprint Assessment (BFA) should be conducted, described in the GBS review document "Quality Assurance" (CDC Biodiversité 2020f), and not just to how the CommoTool is built. The livestock husbandry CommoTool and the grass CommoTool are only part of the biodiversity assessment, as they only build the impact factors linking commodities and biodiversity impacts. someone of the points raised by these principles, the choice of a reference, is briefly addressed in the review document on Core concepts (CDC Biodiversité 2020a).

7.3 Uncertainties

As mentioned throughout the text, uncertainties should be tackled by including the possibility to use multiple calculation modes, with central, pessimistic and optimistic values of both collected corporate data inputs and characterization factors.

Sensitivity tests comparing the results of several versions of the livestock Scope 1 and grass CommoTool, as was done for the crops CommoTool (CDC Biodiversité 2020b) should also feed the reflexion about uncertainties embedded in the GBS.

8 References

Ali, Iftikhar, Fiona Cawkwell, Edward Dwyer, Brian Barrett, and Stuart Green. 2016. 'Satellite Remote Sensing of Grasslands: From Observation to Management'. *Journal of Plant Ecology* 9 (6): 649–71. https://doi.org/10.1093/jpe/rtw005.

Alkemade, R., R. S. Reid, M. van den Berg, J. de Leeuw, and M. Jeuken. 2013. 'Assessing the Impacts of Livestock Production on Biodiversity in Rangeland Ecosystems'. *Proceedings of the National Academy of Sciences* 110 (52): 20900–905. https://doi.org/10.1073/pnas.1011013108.

Balvanera, Patricia, Alexander Pfaff, Andrés Viña, Eduardo García Frapolli, Syed Ainul Hussain, and Leticia Merino. 2019. 'IPBES Global Assessment on Biodiversity and Ecosystem Services. Chapter 2. Status and Trends; Indirect and Direct Drivers of Change. 2.1 Chapter 2.1. Status and Trends – Drivers of Change'.

Bock, Carl E., Zach F. Jones, and Jane H. Bock. 2006. 'Rodent Communities in an Exurbanizing Southwestern Landscape (U.S.A.)'. *Conservation Biology* 20 (4): 1242–50. https://doi.org/10.1111/j.1523-1739.2006.00419.x.

———. 2008. 'The Oasis Effect: Response of Birds to Exurban Development in a Southwestern Savanna'. *Ecological Applications* 18 (5): 1093–1106. https://doi.org/10.1890/07-1689.1.

Cagnolo, L., S.I. Molina, and G.R. Valladares. 2002. 'Diversity and Guild Structure of Insect Assemblages under Grazing and Exclusion Regimes in a Montane Grassland from Central Argentina'. *Biodiversity & Conservation* 11 (3): 407–20. https://doi.org/10.1023/A:1014861906082.

CDC Biodiversité. 2017. 'Global Biodiversity Score: Measuring a Company's Biodiversity Footprint'. 11. Biodiv'2050 Outlook.

———. 2019. 'Global Biodiversity Score: A Tool to Establish and Measure Corporate and Financial Commitments for Biodiversity'. 14. Biodiv'2050 Outlook. CDC Biodiversité.

———. 2020a. 'GBS Review: Core Concepts'.

———. 2020b. 'GBS Review: Crops CommoTool'.

———. 2020c. 'GBS Review: Freshwater Pressures on Biodiversity'.

———. 2020d. 'GBS Review: Input Output Modelling'.

———. 2020e. 'GBS Review: Mining CommoTool'.

———. 2020f. 'GBS Review: Quality Assurance'.

———. 2020g. 'GBS Review: Terrestrial Pressures on Biodiversity'.

———. 2020h. 'GBS Review: Wood Logs CommoTool'.

CDC Biodiversité, ASN Bank, and ACTIAM. 2018. 'Common Ground in Biodiversity Footprint Methodologies for the Financial Sector'. Paris: ACTIAM, ASN Bank, CDC Biodiversité. Supported by Finance in Motion. https://www.asnbank.nl/web/file?uuid=b71cf717-b0a6-47b0-8b96-47b6aefd2a07&owner=6916ad14-918d-4ea8-80ac-f71f0ff1928e&contentid=2412.

Chaudhary, Abhishek, and Thomas M. Brooks. 2018. 'Land Use Intensity-Specific Global Characterization Factors to Assess Product Biodiversity Footprints'. *Environmental Science & Technology*, April. https://doi.org/10.1021/acs.est.7b05570.

Copernicus. 2020. 'Vegetation | Copernicus Global Land Service'. 2020. https://land.copernicus.eu/global/themes/vegetation.

Díaz, S., J. Settele, E. Brondízio, H. Ngo, M. Guèze, J. Agard, A. Arneth, P. Balvanera, K. Brauman, and S. Butchart. 2019. 'Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)'. IPBES.

EUROSTAT. 2013. 'Economy-Wide Material Flow Accounts (EW-MFA). Compilation Guide 2013.' Luxembourg: Statistical Office of the European Communities.

FAO. 2010. 'Global Livestock Environmental Assessment Model 2.0', 121.

———. 2016. 'Principles for the Assessment of Livestock Impacts on Biodiversity. Livestock Environmental Assessment and Performance (LEAP) Partnership.' Rome, Italy: FAO. http://www.fao.org/3/a-i6492e.pdf.

———. 2017a. *Global Feed Intake in 2010*. http://www.fao.org/ag/againfo/home/en/news_archive/photo/2017_Infografica_6billion.jpg.

———. 2017b. 'Plant Production and Protection Division: Grasslands, Rangelands and Forage Crops'. 2017. https://web.archive.org/web/20170831035632/http://www.fao.org/ag/AGP/AGPC/doc/Counprof/regions/index.htm.

———. 2018. 'Shaping the Future of Livestock Sustainably, Reponsibly, Efficiently. The 10th Global Forum for Food and Agriculture (GFFA)'. Berlin. http://www.fao.org/3/i8384en/I8384EN.pdf.

———. 2019. 'Five Practical Actions towards Low-Carbon Livestock'.

———. n.d. 'Gleam-I'. Accessed 6 January 2020. http://gleami.org/.

FAO, International Dairy Federation, and International Farm Comparison Network. 2014. *World Mapping of Animal Feeding Systems in the Dairy Sector*.

FAOSTAT. 2019a. 'Data, Emissions - Agriculture, Agriculure Total'. FAOSTAT. 2019. http://www.fao.org/faostat/en/#data/GT.

———. 2019b. 'Data, Production, Livestock Primary'. 2019. http://www.fao.org/faostat/en/#data/QL.

———. 2019c. 'Methodological Note, Agriculture Total'. FAOSTAT. 2019. http://fenixservices.fao.org/faostat/static/documents/GT/GT_e_2019.pdf.

———. 2019d. 'Methodological Note, Emissions Intensities'. FAOSTAT. 2019. http://fenixservices.fao.org/faostat/static/documents/EI/EI_e_2019_final.pdf.

———. 2019e. 'Methodological Note, Enteric Fermentation'. http://fenixservices.fao.org/faostat/static/documents/GE/GE_e_2019_final.pdf.

———. 2019f. 'Methodological Note, Livestock Manure'. 2019. http://fenixservices.fao.org/faostat/static/documents/EMN/EMN_e_2019.pdf.

———. 2019g. 'Methodological Note, Manure Left on Pastures'. http://fenixservices.fao.org/faostat/static/documents/GP/GP_e_2019_final.pdf.

———. 2019h. 'Methodological Note, Manure Management'. http://fenixservices.fao.org/faostat/static/documents/GM/GM_e_2019_final.pdf.

GEOGLAM (Group on Earth Observations and its Global Agricultural Monitoring initiative). 2019. 'GEOGLAM RAPP | Rangeland and Pasture Productivity'. Rangeland and Pasture Productivity. 2019. https://www.geo-rapp.org/.

Gerber, Pierre J., and FAO, eds. 2013. *Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*. Rome: Food and Agriculture Organization of the United Nations.

Giljum, Stefan, Stephan Lutter, and Martin Bruckner. 2018. 'SI_materials Supporting Information for Material Accounts - EXIOBASE 3.5'. *Journal of Industrial Ecology*, 9.

Hart, Richard H. 2001. 'Plant Biodiversity on Shortgrass Steppe after 55 Years of Zero, Light, Moderate, or Heavy Cattle Grazing', 2.

IPCC. 2006a. '2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 10: Emissions from Livestock and Manure Management.' https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf.

———. 2006b. '2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use. Chapter 11: N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application'. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf.

Janse, J. H., J. J. Kuiper, M. J. Weijters, E. P. Westerbeek, MHJL Jeuken, M. Bakkenes, R. Alkemade, W. M. Mooij, and J. T. A. Verhoeven. 2015. 'GLOBIO-Aquatic, a Global Model of Human Impact on the Biodiversity of Inland Aquatic Ecosystems'. *Environmental Science & Policy* 48: 99–114.

Koch, P., and T. Salou. 2016. 'AGRIBALYSE®: Rapport Méthodologique – Version 1.3'. ADEME.

Kok, Marcel T.J., Rob Alkemade, Michel Bakkenes, Eline Boelee, Villy Christensen, M. Van Eerdt, Stefan van der Esch, Jan Janse, SISE Karlsson-Vinkhuyzen, and Tom Kram. 2014. *How Sectors Can Contribute to Sustainable Use and Conservation of Biodiversity*. 79. PBL.

Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2012. 'A Global Assessment of the Water Footprint of Farm Animal Products'. *Ecosystems* 15 (3): 401–15. https://doi.org/10.1007/s10021-011-9517-8.

Metera, Ewa, Tomasz Sakowski, Krzysztof Sloniewski, and Barbara Romanowicz. 2010. 'Grazing as a Tool to Maintain Biodiversity of Grassland - a Review'. *Animal Science Papers and Reports* 28 (January): 315–34.

MODIS (Moderate Resolution Imaging Spectroradiometer). 2019. 'MODIS Gross Primary Production (GPP)/Net Primary Production (NPP)'. 2019. https://modis.gsfc.nasa.gov/data/dataprod/mod17.php.

Monfreda, Chad, Navin Ramankutty, and Jonathan A. Foley. 2008. 'Farming the Planet: 2. Geographic Distribution of Crop Areas, Yields, Physiological Types, and Net Primary Production in the Year 2000: GLOBAL CROP AREAS AND YIELDS IN 2000'. *Global Biogeochemical Cycles* 22 (1): n/a-n/a. https://doi.org/10.1029/2007GB002947.

Mottet, Anne, Cees de Haan, Alessandra Falcucci, Giuseppe Tempio, Carolyn Opio, and Pierre Gerber. 2017. 'Livestock: On Our Plates or Eating at Our Table? A New Analysis of the Feed/Food Debate'. *Global Food Security* 14 (September): 1–8. https://doi.org/10.1016/j.gfs.2017.01.001.

O'connor, T. G. 2005. 'Influence of Land Use on Plant Community Composition and Diversity in Highland Sourveld Grassland in the Southern Drakensberg, South Africa'. *Journal of Applied Ecology* 42 (5): 975–88. https://doi.org/10.1111/j.1365-2664.2005.01065.x.

Ramankutty, Navin, Amato T. Evan, Chad Monfreda, and Jonathan A. Foley. 2008. 'Farming the Planet: 1. Geographic Distribution of Global Agricultural Lands in the Year 2000: GLOBAL AGRICULTURAL LANDS IN 2000'. *Global Biogeochemical Cycles* 22 (1): n/a-n/a. https://doi.org/10.1029/2007GB002952.

Ritchie, Hannah, and Max Roser. 2017. 'Meat and Dairy Production'. *Our World in Data*, August. https://ourworldindata.org/meat-production.

Schipper, Aafke M., Johan R. Meijer, Rob Alkemade, and Mark A. J. Huijbregts. 2016. 'The GLOBIO Model: A Technical Description of Version 3.5'. The Hague: Netherlands Environmental Agency (PBL). http://www.pbl.nl/sites/default/files/cms/publicaties/pbl_publication_2369.pdf.

Smart, Rhett, Martin J. Whiting, and Wayne Twine. 2005. 'Lizards and Landscapes: Integrating Field Surveys and Interviews to Assess the Impact of Human Disturbance on Lizard Assemblages and Selected Reptiles in a Savanna in South Africa'. *Biological Conservation* 122 (1): 23–31. https://doi.org/10.1016/j.biocon.2004.06.016.

Stocker, Thomas. 2014. *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Woinarski, J. C. Z., and A. J. Ash. 2002. 'Responses of Vertebrates to Pastoralism, Military Land Use and Landscape Position in an Australian Tropical Savanna'. *Austral Ecology* 27 (3): 311–23. https://doi.org/10.1046/j.1442-9993.2002.01182.x.

Woinarski, John, Alan Andersen, Tracey Churchill, and Andrew Ash. 2002. 'Response of Ant and Terrestrial Spider Assemblages to Pastoral and Military Land Use, and to Landscape Position, in a Tropical Savanna Woodland in Northern Australia'. *Austral Ecology* 27 (June): 324–33. https://doi.org/10.1046/j.1442-9993.2002.01183.x.

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