THE GLOBAL BIODIVERSITY SCORE

GBS Review: Mining CommoTool

July 2020 - Corrected version

Content

CDC BIODIVERSITÉ

Note to the reader

GBS review reports are not completely independent from each other. Readers of this report are advised to first read the reports dedicated to **Core concepts of the GBS** (CDC Biodiversité 2020a), **Terrestrial pressures on biodiversity** (CDC Biodiversité 2020d) and **Aquatic pressures on biodiversity** (CDC Biodiversité 2019b) to ensure a good overall comprehension of the tool and the present report. In the reports dealing with pressures on biodiversity, the sections describing default assessment as well as the limitation sections are especially recommended.

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

- Assumptions
- Important sections
- Developments of the GBS planned in the future

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

[ERRATUM]: Following the review, the examples have been updated to reflect the changes that had been made in the tool during the review.

1 Mining CommoTool overview

1.1 Why assessing the biodiversity impacts of mining production?

Mining sector plays a key role in our economies as it provides materials essential to almost all industries and day-to-day lives. On top of that, the mining sector is expected to grow significantly over the next 30 years and is at the core of national economic development growth forecasts. “A global energy transition to address climate change will create new and vital markets for mined materials,” says UN Environment World Conservation Monitoring Centre expert Matt Jones. “If we want battery technology to support electric vehicles, we need lithium. Construction of solar panels and wind turbines are reliant on mined materials. While we continue to advocate for higher recycling rates of these metals, much will need to be mined to support a global shift.”

But mining operations generate significant impact on biodiversity. The impacts are direct through land occupation at the mine site level. They are also indirect through pollutants, associated infrastructures (roads, power lines, trains tracks…), greenhouse gas (GHG) emissions, water consumption, water management infrastructures, noise, etc. These impacts, both direct and indirect, occur at the different stages of the lifecycle of a mining project, including exploration, construction, operation, closure, and post closure and legacy. On top of these “business as usual” impacts, accidents may occur, causing significant impacts on the environment. Over the last 10 years, tailings dam failures occurred in average 3.3 times per year (‘Chronology of Major Tailings Dam Failures’ n.d.), with an upward trend. Considering a total number of dams of around 3500 (Davies 2002), this figure suggest a dam failures occurrence rate of 1‰.

Therefore, achieving a sustainable economy compatible with the preservation of a high level of biodiversity across the globe requires mining operations impacts to be assessed and mainstreamed at all levels of the economy: extractions industry but also manufacturers, retailers, investors…

1.2 Place of the Mining CommoTool in the GBS framework

The goal of the Mining CommoTool is to determine the **biodiversity impacts of mining related commodities: metals, minerals and solid fossil fuels**. This report explains how the **biodiversity impact factors databases for mining commodities** are constructed.

As a reminder, the evaluation of biodiversity impacts of economic activities with the GBS follows a stepwise approach according to the best data available at each step of the impact assessment (CDC Biodiversité 2020a).

In default assessments, the results of the Mining CommoTool feed the M matrix dedicated to mining commodities documented in EXIOBASE material account. The M matrices are the tables which gather biodiversity loss factors (in MSA.km²/t of commodity). They are combined to other matrixes which translate monetary data into inventories of raw materials and emissions in the Input-Output modelling (CDC Biodiversité 2019c).

In refined assessments, if "inventory" data, like purchased or produced quantities of mining commodities, are available, biodiversity impact factors linking tonnages of mining commodities to impacts on biodiversity in MSA.km² can be applied directly to the company's inventory.

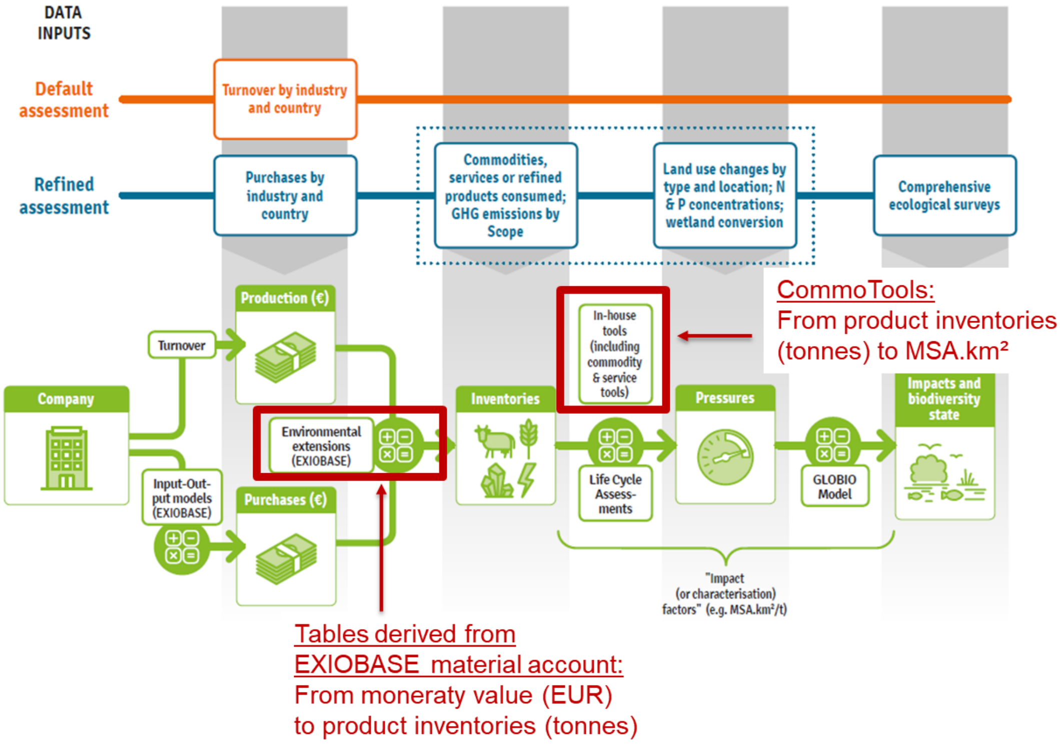

Figure 1: Mining CommoTool in the GBS stepwise approach

1.3 Mining: elements of context

A MINING TERMINOLOGY

The United-States Geological Survey (USGS)[1], a reference in the field of mining, does not provide a glossary of common mining terms. The definitions below were thus compiled by CDC Biodiversité from various

[1] The USGS (formerly simply Geological Survey) is a scientific agency of the United States government. The scientists of the USGS study the landscape of the United States, its natural resources, and the natural hazards that threaten it. The organization has four major science disciplines, concerning biology, geography, geology and hydrology.

sources and have only an illustrative purpose, to facilitate the understanding of what is meant by each word in this report.

Ore: rock, soil or sediment that contains economically recoverable levels of metals or minerals (Lottermoser 2003)

Mine wastes: solid, liquid or gaseous by-products of mining, mineral processing, and metallurgical mining. They are unwanted, have no current economic value and accumulate at mine sites (Lottermoser 2003)

Waste rock: wall rock material removed to access and mine ore (Lottermoser 2003)

Gangue minerals: valueless minerals that are intergrown on a microscopic or even sub-microscopic scale with ore minerals or industrial minerals (Lottermoser 2003)

Mining: process which results in the mining of ore/industrial minerals and gangue minerals (Lottermoser 2003)

Mineral processing: process which enriches the ore/industrial minerals and rejects unwanted gangue minerals (Lottermoser 2003)

Metallurgical mining: process which destroys the crystallographic bonds of minerals and rejects unwanted elements. It is largely based on hydrometallurgy (use of solvents, e. g. Au, U, Al, Cu, Zn, Ni, P) and pyrometallurgy (use of heat, *e.g.* Cu, Zn, Ni, Pb, Sn, Fe) and to a lesser degree electrometallurgy (use of electricity, e. g. Al, Zn) (Lottermoser 2003)

Processing wastes: wastes produced during the mineral processing phase, *i.e.* the portions of crushed, milled, ground, washed or treated resource deemed too poor to be treated further. The definition thereby includes tailings, sludges and waste water from mineral processing, coal washing and mineral fuel processing (Lottermoser 2003)

Tailings: processing waste from a mill, washery or concentrator that removed the economic metals, minerals, mineral fuels or coal from the mined resource (Lottermoser 2003)

Metallurgical wastes: wastes produced during metallurgical mining, defined as the residues of the leached or smelted resource deemed to poor to be treated further (Lottermoser 2003)

Acid mine drainage (AMD): refers to a particular process whereby low pH mine water is formed from the oxidation of sulphides minerals

Heap leaching: the process in which metals are dissolved from ores by leaching them with a solution. The ores are crushed and usually heaped onto an impermeable base known as a leach pad (Hudson-Edwards, Jamieson, and Lottermoser 2011).

Grade is the relative quantity or the mass percentage of desirable mineral or metal content in an ore.

Overburden is the waste rock or other material that overlies an ore or mineral body and is displaced during mining without being processed.

Mine capacity: maximum annual production of a mine for a given commodity. By default, mine capacity refers to refined commodity production.

Surface mining, including strip mining and open-pit mining is a broad category of mining in which soil and rock overlying the mineral deposit (the overburden) are removed.

Strip mining is a surface mining technique of extracting rock or minerals from the earth by removing the top layer of soil instead of digging deep holes.

Figure 2: Illustration of strip mining in Hambach, Germany (© Raimond Spekking / [CC BY-SA 4.0](CC BY-SA 4.0) via Wikimedia Commons)

Open pit mining is a surface mining technique of extracting rock or minerals from the earth by their removal from an open pit or borrow.

Figure 3: Illustration of open pit mining in Chuquicamata, Chile (©Reinhard Jahn / Creative Commons Attribution-Share Alike 2.0 Generic)

Underground mining is a broad category of mining in which the overlying rock is left in place, and the mineral is removed through shafts or tunnels.

B MINING MATERIALS CATEGORIES

Mining materials is split into 3 categories: **metal ores, mineral resources** (non-metallic), also referred to as minerals, and **solid fossil fuels**, referred to as coal. Definitions from EUROSTAT (Eurostat 2019) and USGS are reminded below.

"Metal ores are mineral aggregates that contain metals. Most metal ores are polymetallic, *i.e.* the metal ore contains more than one metal. The different metals are separated during the production process. Examples of metal ores are iron, copper, nickel, lead, zinc, tin, aluminium, gold, silver, platinum, uranium or cobalt. Metals are essential for a wide range of industries like mechanical engineering, transport, aerospace, construction, packaging, electricity and energy, consumer electronics, medical devices, etc"[2].

"A '**Mineral Resource**' [(non metallic)] is a concentration or occurrence of material of economic interest in or on the earth's crust in such form, quality and quantity that there are reasonable prospects for eventual economic mining. Examples of mineral resources are marble, granite, sandstone, chalk, limestone, slate, chemical and fertilizer minerals, salt, clays or sand. Minerals are essential raw materials for modern society, contributing significantly to its social and technological progress. They are used for the production of

[2] https://ec.europa.eu/eurostat/web/environmental-data-centre-on-natural-resources-old/natural-resources/raw-materials/metal-ores

infrastructure such as roads, homes, schools and hospitals and of many industrial and consumer products such as cars, computers, medicines, and household appliances."[3]

Solid fossil fuels, also known as coal, "are divided into four major types (or "ranks") of coal. Rank refers to steps in a slow, natural process called "coalification," during which buried plant matter changes into an ever denser, drier, more carbon rich, and harder material. The four ranks are:

- **Anthracite**: The highest rank of coal. It is a hard, brittle, and black lustrous coal, often referred to as hard coal, containing a high percentage of fixed carbon and a low percentage of volatile matter.
- **Bituminous**: Bituminous coal is a middle rank coal between subbituminous and anthracite. Bituminous usually has a high heating value and is the most common type of coal used in electricity generation in the United States. Bituminous coal appears shiny and smooth when you first see it but look closer and you may see it has layers.
- **Subbituminous**: Subbituminous coal is black, dull and has a higher heating value than lignite.
- **Lignite**: Lignite coal is the lowest grade coal with the least mineral processing of carbon.

Also, there is peat. Peat is not actually coal, but rather may be considered a precursor to coal. Peat is a soft organic material consisting of partly decayed plant and, in some cases, deposited mineral matter. When peat is placed under high pressure and heat, it becomes coal."[4]

Sometimes "black" or "brown" can be used to categorize coal but the definition varies depending on the location. For instance, in Australia, sub-bituminous, bituminous and anthracite are collectively referred to as black coal, whilst lignite is referred to as brown coal but in Europe, sub-bituminous coal is also considered to be brown coal. To avoid any confusion, we never refer to black or brown coal in the Mining CommoTool.

C EXTRACTIVE COMMODITIES PRODUCTION PROCESSES

Production of metals, industrial minerals and extractive fuels (coal) uses different processes. Mining and mineral processing are common to all commodities. For metals, an additional metallurgical mining process is needed. The definitions of the processes are reported in section 1.3A and summarised in Figure 4 for metals and Figure 5 for industrial minerals and coal.

For metals, in this report we will use the term **"pure metal"** for the generic 100% pure metal element. We will use the term **"metal product"** for all the refined materials related to the metal element. For instance, for the generic metal Cu, copper is the pure metal and blister copper is one of the copper related products. For minerals and coal, the generic "pure" form is the same as the product, so product distinction is not necessary.

[3] https://ec.europa.eu/eurostat/web/environmental-data-centre-on-natural-resources-old/natural-resources/raw-materials/mineral-resources-non-metallic
[4] https://www.usgs.gov/faqs/what-are-types-coal

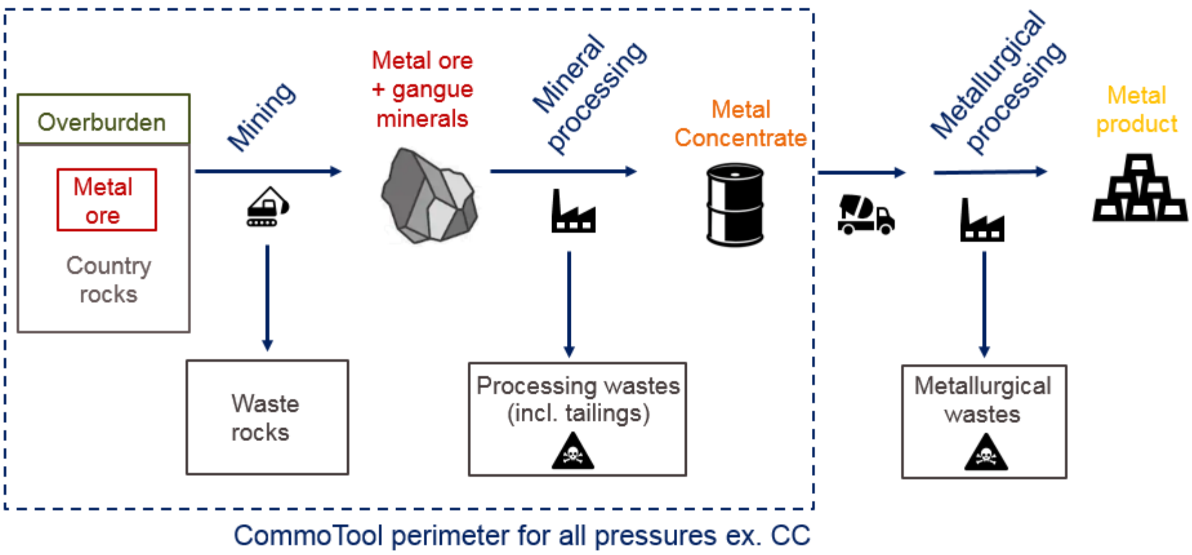

Figure 4: Metal production general layout

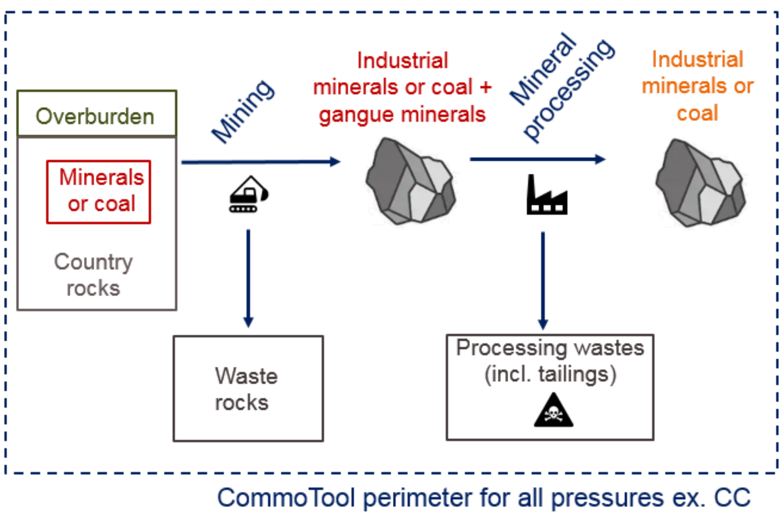

Figure 5: Industrial Mineral or coal production general layout

1.4 Mining CommoTool perimeter

In the Mining CommoTool, we focus on impacts occurring at the mine site level. Therefore, we evaluate the impacts of mining and mineral processing. Impacts due to metallurgical processing are not covered except for climate change. Indeed, we assume that this process doesn't occur at the mine site level. This is a limitation as we know that, for instance for gold and to a lesser degree for copper, hydrometallurgy processes (involving solvents) occur typically at the mine site (Lottermoser 2003). Climate change impacts are included because GHG emissions are estimated using PEF processes, which embed both on-site and off-site processes.

In GBS 1.0, several significant impacts related to mining are not covered:

- **pre operation impacts**: exploration phase to assess the feasibility of a mine site involves impacts of various nature on the concession owned by the company: land occupation at mining site, pollution, noise, infrastructure…
- **during the operation phase**: pollutants are not included, this includes pollutant emissions from mineral and metallurgical processes (including heap leaching), generation of AMD as well as deportment of dusts and particulates. Infrastructure outside of the mine site are not accounted for.
- **post operation phase**: all impacts being positive (mine site rehabilitation) or negative (lasting chemical pollution) occurring after mine closure are not included.

In the Mining CommoTool, impact factors for all pressures except those related to climate change are expressed in MSA.km² per tonne of pure metal, mineral or coal. For metal products, the impact factors can be used by weighting them by the metal content of the metal products.

For instance, for a blister copper with 98% Cu, impact factors for all pressures except those related to climate change can be used applying a 98% correcting factor to take into account the copper content of this product.

For metals, impact factors related to climate change are specific to each metal product. For metal products, minerals and coal, impact factors related to climate change cover all processes: mining, mineral process and metallurgical process. Impact factors are expressed in MSA.km² per tonne of metal product, mineral or coal.

For instance, for blister copper (98% Cu), specific impact factors for climate related pressures are computed and expressed in MSA.km² per tonne of blister copper (98% Cu) and can therefore be applied directly to the tonnage of blister copper (98% Cu).

In GBS 1.0, we cover a restricted list of metal commodities and related products, a restricted list of minerals and the 4 main types of coal. Please refer to Table 1 for the exact list.

This list will be expanded in future versions of the GBS.

Commodity	Category
Aluminum	Metal
Copper	Metal
Gold	Metal
Iron	Metal
Lead	Metal
Nickel	Metal
Rare Earths	Metal
Silver	Metal
Tin	Metal
Zinc	Metal
Lignite	Coal
Sub-bitumous coal	Coal
Bitumous coal	Coal
Anthracite	Coal
Gravel	Mineral
Perlite	Mineral
Sand	Mineral
Talc	Mineral

Commodity related product	Commodity name	Commodity content	PEF flow name
Aluminium ingot	Aluminum	100%	Aluminium ingot
Bauxite	Aluminum	17,09%	Bauxite
Copper cathode (>99.99 Cu)	Copper	99,99%	Copper cathode (>99.99 Cu)
global mix copper concentrate	Copper	28,00%	global mix copper concentrate
Gold	Gold	100%	Gold
Lignite	Lignite	100%	Hard Coal
Sub-bituminous coal	Sub-bituminous coal	100%	Hard Coal
Bituminous coal	Bituminous coal	100%	Hard Coal
Anthracite	Anthracite	100%	Hard Coal
Iron ore (valuable substance)	Iron	63,53%	Iron ore (valuable substance)
Lead (99.995%)	Lead	99,995%	Lead (99.995%)
Lead concentrate	Lead	60,00%	Lead concentrate
Natural Aggregate	Gravel	100%	Natural Aggregate
Nickel	Nickel	100%	Nickel
Nickel concentrate	Nickel	15,00%	Nickel concentrate
Perlite	Perlite	100%	Perlite (0/1)
Quartz sand	Sand	100%	Quartz sand (0/2)
Rare earth elements concentrate	Rare earths	60,00%	Rare earth elements concentrate
Silver	Silver	100%	Silver
Talc	Talc	100%	Talc
Tin (99.92%)	Tin	99,92%	Tin (99.92%)
Tin concentrate (72%)	Tin	72,00%	Tin concentrate (72%)
Zinc concentrate	Zinc	50,00%	Zinc concentrate

Table 1: Commodity and commodity related product covered in the Mining CommoTool

To define the boundaries of impact assessments, the extractive industry uses a few key concepts such as the area of influence. The GBS approach partly fits within these concepts[5].

The **area of influence** can be broken down into (i) the physical footprint, (ii) the area of direct influence and (iii) the area of indirect influence. The first two belong to the Scope 1 boundaries considered in the GBS. (iii) is partly covered by the Encroachment pressure. Thus, not all the impacts of the area of indirect influence are covered by GBS assessments.

Cumulative impacts are also not taken into account as the GBS does not specifically factor in interactions between pressures.

Direct impacts, as defined by the International Finance Corporation, fall into Scope 1.

Indirect impacts, *i.e.* "Impacts resulting from the project that may occur beyond or downstream of the boundaries of the project site and/or sometimes after the project activity has ceased." (Lammerant 2019) are only partly covered, through the Encroachment pressure.

[5] For a full definition of each concept, please refer to (Lammerant 2019).

2 Attributing the impacts of mining production

2.1 Pressures covered

As a reminder, the pressures accounted for in GBS 1.0 are

- **Terrestrial pressures**: land use (LU), encroachment (E), fragmentation (F), nitrogen deposition (N); climate change (CC)
- **Aquatic pressures**: land use in catchment of rivers (LUR) and wetlands (LUW), wetland conversion (WC), hydrological disturbance (HD, split into HD_{water}, HD_{infra} and HD_{cc}), freshwater eutrophication of lakes (FE)

The Mining CommoTool does not cover all these pressures. The detailed status of pressures covered for the extracting and concentrating phases is provided below and summarised in Table 2. Once again for refining processes other than concentrating, only climate change related pressures are covered (CC and HD_{CC}).

Climate change: as presented in (CDC Biodiversité 2020d), climate change impact is assessed based on a pressure-impact relationship involving GHG emissions.100% of the CC impacts associated to GHG emitted by mining production are attributed to it. Scope 3 downstream emissions are not attributed to mining production in GBS 1.0 (but will be in future versions).

Land use: there is no land use category for mining in GLOBIO cause-effect relationships and no data on land occupation of mines in GLOBIO-IMAGE outputs. We thus built specific methodologies to evaluate land occupation and land conversion related to mining. The impacts of LU change and occupation within the mine site are attributed to mining production.

Encroachment and Fragmentation: in GLOBIO model, these pressures are caused only by "human" land uses, *i.e.* land uses where human activity is predominant: croplands (agriculture and cultivated grazing areas) and urban areas (CDC Biodiversité 2020d). Managed forests and natural areas are subjected to them. Once again, no land use category for mining exists in GLOBIO cause-effect relationships nor in GLOBIO-IMAGE outputs. Although, we consider that mining and processing sites are "human" land use types, therefore causing both encroachment and fragmentation. The impacts assessed in the dimensioning section are 100% attributed to mining production of metals and minerals.

Atmospheric nitrogen deposition: **in default assessments**, the impacts dimensioned (relying partly on the GLOBIO-IMAGE framework) originate only from croplands and urban areas, so none is attributed to mining production. This limitation seems reasonable: in LCA databases, nitrogen emissions due to both processing and mining phases are negligible.

Land use in catchment of rivers: in GLOBIO-Aquatic model, only "human" land uses contribute to the pressure land use in catchment for rivers. As explained above for fragmentation and encroachment pressure, we consider that mining sites (mining and production) are "human" land use types. Thus, LUR impacts are attributed to mining sites in proportion of their share of the total human area in the watershed.

Land use in catchment of wetlands: in GLOBIO-Aquatic model, land uses contribute to the pressure land use in catchment for wetlands depending on their management intensity. Only land uses with a management intensity equals to 0%, *i.e.* natural land use types, do not contribute to that pressure. Management intensity for mining sites is set to 100% (details are provided in section 3.2.B.4). LUW impacts are attributed to mining sites in proportion of their share of the total intensity-weighted area in the watershed.

Wetland conversion: 100% of the WC impacts dimensioned in the Mining CommoTool are attributed to the mining sites for default assessments. They correspond to wetlands being converted to excavation or processing areas within the mining site itself.

Hydrological disturbance: in the GBS, HD related impacts are split between climate change, water network infrastructures and direct water use. Mining activities are very water intensive (Lovelace 2009). HD impacts related to direct water use are attributed to blue water withdrawal. Mining activities can use dedicated infrastructure on the water network such as dams for energy production or residuals storage (not linked to water management as their impacts are included in the direct water use part). The energy production impacts will be treated in the next version of the tool. For other types of infrastructure linked to mining activities, we do not have global data available, thus, HD related to infrastructures is not included in the Mining CommoTool. 100% of the CC part of HD (referred to as HD_{CC} in the remaining of this report) are attributed to the GHG emitted by mining production.

Freshwater eutrophication: in GLOBIO-IMAGE outputs, only croplands and urban areas are considered as sources of N and P leaching into aquatic ecosystems (Janse, Bakkenes, and Meijer 2016). Thus, in default assessments, only the impacts caused by croplands and urban areas are dimensioned (CDC Biodiversité 2019b) so none is attributed to mining production.

2.2 Pressures status summary

	Pressure	Mining process	
		Extracting + concentrating	Refining (excluding concentrating)
Terrestrial	LU	Covered	Not covered
	E	Covered	Not covered
	F	Covered	Not covered
	N	Not relevant	Not relevant
	CC	Covered	Covered
Aquatic	LUR	Covered	Not covered
	LUW	Covered	Not covered
	WC	Covered	Not covered
	HD_{water}	Covered	Not covered
	HD_{infra}	Not covered	Not covered
	HD_{CC}	Covered	Covered
	FE	Not relevant	Not relevant

(green)	Covered
(red)	Not covered
(grey)	Not relevant

Table 2: Pressures included in the Mining CommoTool

3 Dimensioning the impacts of mining and production – Default assessment

Theoretically, pressures impact factors built in the terrestrial and freshwater modules (CDC Biodiversité 2020d; 2019b) should be used in default assessments. These impact factors rely on proxies to quantify the impact of drivers such as land use change, atmospheric nitrogen deposition, etc. The proxies come from GLOBIO-IMAGE outputs. Mining activities are however very partially taken into account into GLOBIO-IMAGE outputs. In GLOBIO-IMAGE, only the emissions (associated pressures: CC, N and FE) and water use (associated pressure HD_{water}) are exhaustive, meaning that they include all economic and non-economic activities, including mining activities. Land coverage and infrastructure data however do not include mining facilities. Therefore, the associated pressures (LU, E, F, LUR, LUW, WC, HD_{Infra}) do not consider mining activities. Consequently, for these pressures, additional impacts must be dimensioned on top of those already dimensioned in the terrestrial and freshwater modules. In-house methodologies must be developed to evaluate these impacts, which are additional to the impacts provided in GLOBIO-IMAGE outputs.

3.1 Data used

Ideally, we would need to collect data allowing the direct evaluation of biodiversity impacts based on GLOBIO cause-effect relationships and the biodiversity intensities related to terrestrial and aquatic pressures: land occupation, data on surrounding areas (land uses, size of fragmented patches), water withdrawal, GHG emissions… Unfortunately, this type of data is only partially available for mining activities and in many cases, we have to rely on proxies to evaluate the different drivers. This section lists the data sources used, while the impact computation methodology is described in Section 3.2.

A LAND USE

The evaluation of pressures related to land occupation (LU, E, F, LUR, LUW and WC), requires to evaluate land use conversion and land occupation due to mining and concentrating (when applicable) at mine site level. As it will be detailed in the section 3.2.B.2, land occupation and conversion are derived from ratios set up consulting mining experts and applied to the extracted volume of raw material needed to produce a tonne of “pure” commodity. We collect data at the mine site level, although it is important to keep in mind that **impact factors at mine site level are only used to compute national or regional averages** which are then used in default assessments. **Impact factors at mine site level are not aimed to be used directly** as they are built using assumptions as well as terrestrial and aquatic pressures impact factors that are only relevant at a sufficiently large spatial scale (CDC Biodiversité 2020d; 2019b).

We use mine site data from the USGS. This data is publicly available and can be downloaded on their website (USGS 2019). The USGS data are different for facilities outside of United-States and facilities inside the United-States. Data provided for facilities outside of the United-States ranges from 2003 to 2007. Reported fields are generic commodity name, extracted material name, facility name, facility type (mine, quarry or plant), GPS location, activity status (active or inactive), mining technique (underground or surface) and capacity. For facilities inside the US, data is from 2003 and is poorer with fewer reported fields: commodity name (refined or ore), facility name, facility type (mine or plant) and GPS location. Collected data from USGS are summarised in Table 3. Estimation methodologies for non-reported items in the US case (mining technique and capacity) is detailed in section 3.2A.

Ore grades (for metals) are also needed to evaluate land occupation and conversion. Ideally, we would like to collect it at the site level as well, unfortunately this data is not publicly available. Therefore, we collect average ore grade at the global level for the restricted list of metal ore commodities covered in GBS 1.0. Except for aluminium where Geoscience Australia source is used (Geoscience Australia 2019), all grades comes from the British Geological Survey’s mineral profiles (BGS 2016).

			Non-US (2003 to 2007)		US (2003)	
Item	Unit	Source	Granularity	Data status	Granularity	Data status
Capacity	tonnes/year	USGS	Mine	reported	Commodity (global average)	estimated
Location	GPS coordinates	USGS	Mine	reported	Mine	reported
Mining technique	N.A.	USGS	Mine	reported	Commodity (global average)	estimated
Mined commodities	N.A.	USGS	Mine	reported	Mine	reported
Ore Grades	%	litterature	Commodity (global average)	estimated	Commodity (global average)	estimated

Table 3: Summary of collected data

Densities are also needed to evaluate land occupation and conversion. Densities represent the mass of a material per unit of volume. They are not mine site specific. We use generic data from Wikipedia ('Densities of the Elements (Data Page)' 2019) expressed in g/cm^3.

B WATER WITHDRAWAL

To assess water withdrawal due to mining, we use water-use coefficient from (Lovelace 2009). They cover groundwater and surface water that is withdrawn and used for non-fuels and fuels mining. Non-fuels mining includes the mining of metal ores and minerals. Fuels mining includes the mining of coal, petroleum, and natural gas. Water is used for mineral mining, quarrying, milling (crushing, screening, washing, and flotation of mined materials) and other operations directly associated with mining activities. We assume that they cover all water withdrawals occurring on-site, meaning for extracting and concentrating (when applicable). Coefficients are summarised in Table 4.

	USGS water use coefficients In m^3 per metric tonne of ore		
Commodity type	**Minimum**	**Maximum**	**Average**
Metals	0.48	5.38	2.93
Minerals	0.10	3.42	1.76
Coal	0.17	0.20	0.19

Table 4: USGS water-use coefficients (Lovelace 2009)

C GHG EMISSIONS

For GHG emissions we use data from PEF (Product Environmental Footprint). PEF is a methodology by the European Commission's Joint Research Center (JRC) which is based on LCA (Zampori and Pant 2019). Joined to the *Environmental Footprint* LCIA method is the PEF LCI dataset, both resulting from a three-year multi-stakeholder testing period. The dataset gathers input and output data for hundreds of processes, including mining commodity production.

The mining commodities related products covered in the Mining CommoTool are directly derived from the available products in PEF. Correspondence with a PEF product in therefore straightforward and is detailed in Table 1. The only exception is for coal where only one process is available in PEF for "hard coal", *i.e.* anthracite. There are no specific processes for lignite, bituminous coal and sub-bituminous coal. Therefore, the PEF process related to Anthracite is used for the 4 types of coal. PEF processes used in the Mining CommoTool are detailed in Table 5.

Product PEF name	Commodity category	Processes covered: Extraction	Processes covered: Concentrating	Processes covered: Off-site refining	Input from a previous process	Geographical spec.	process_name
Aluminium ingot	Metal				Bauxite	EU	Aluminium_ingot_mix__consumption_mix__to_consumer__primary_production__aluminium_ingot_product__primary_production___EU_28_EFTA
Bauxite	Metal					GLO	Bauxite__mining_open_pit___production_mix__at_mine__mining_and_processing__from_open_pit_mines__minerals_gibbsite_Al_OH_3____GLO
Copper cathode (>99.99 Cu)	Metal				Copper concentrate	EU	Copper_billet_slab__smelting_and_refining_to_produce_primary_copper_cathode___single_route__at_plant__casting__8_92_g_cm3___EU_28_EFT
Copper concentrate	Metal					GLO	Copper_Concentrate__Mining__mix_technologies___single_route__at_plant__copper_ore_mining_and_processing__Copper___gold___silver___concentrate___GLO
Iron ore (valuable substance)	Metal					GLO	Ferrite__iron_ore___production_mix__at_plant__iron_ore_mining_and_processing__5_00_g_cm3___GLO
Gold	Metal					GLO	Gold__primary_route___production_mix__at_plant__primary_route__underground_mining_and_leaching__19_32_g_cm3___GLO
Lead (99.995%)	Metal					GLO	Lead__primary___production_mix__at_plant__primary_production__mining_and_processing__11_3_g_cm3___EU_28_EFTA
Lead concentrate	Metal					GLO	Lead_mining_and_concentration__production_mix__at_plant__mining_and_concentration___GLO
Nickel	Metal					GLO	Nickel__production_mix__at_plant__mining_and_processing__8_9_g_cm3___GLO
Nickel concentrate	Metal					GLO	Nickel_Mining_and_beneficiation__production_mix__at_plant__Mining_and_beneficiation___GLO
Silver	Metal					GLO	Silver__production_mix__at_plant__mining__concentration__roasting__refining__10_49_g_cm3___GLO
Tin (99.92%)	Metal					GLO	Tin__production_mix__at_plant__sand_extraction_and_processing__reduction__118_71_g_mol___GLO
Tin concentrate (72%)	Metal					GLO	Tin_ore_Mining___Benefication__production_mix__at_plant__Mining___Benefication___GLO
Zinc concentrate	Metal					GLO	Zinc_Mining___Concentrate__production_mix__at_plant__Mining___Concentrate___GLO
Natural Aggregate	Mineral					EU	Gravel_exctraction__production_mix__at_quarry__extraction___EU_28_EFTA.xlsx
Perlite (0/1)	Mineral					GLO	Perlites_Mining__production_mix__at_plant__Perlite_mining__washing__drying__Granulation_0_1__0_9__1_g_cm3___GLO.xlsx
Quartz sand (0/2)	Mineral					EU	Quartz_Silica_sand__single_route__at_plant__mining__cleaning__grinding__screening__sand_0_2___EU_28_EFTA.xlsx
Talc	Mineral					EU	Talcum__Underground_mining____production_mix__at_mine__Underground_mining___EU_28_EFTA.xlsx
Talcum powder	Mineral					EU	Talcum_powder__production_mix__at_plant__grinded_and_purified__filler__production_including_underground_mining_and_beneficiation__1_to_15_microns_grain_size___EU_28_3.xlsx
Hard coal	Coal					GLO	Hard_coal_mining__mixed___production_mix__at_plant__technology_mix__27_MJ_kg_net_calorific_value___GLO.xlsx

Table 5: PEF processes used in the Mining CommoTool for GHG emissions

3.2 Methodology to compute biodiversity impact factors related to commodity mining and on-site refining

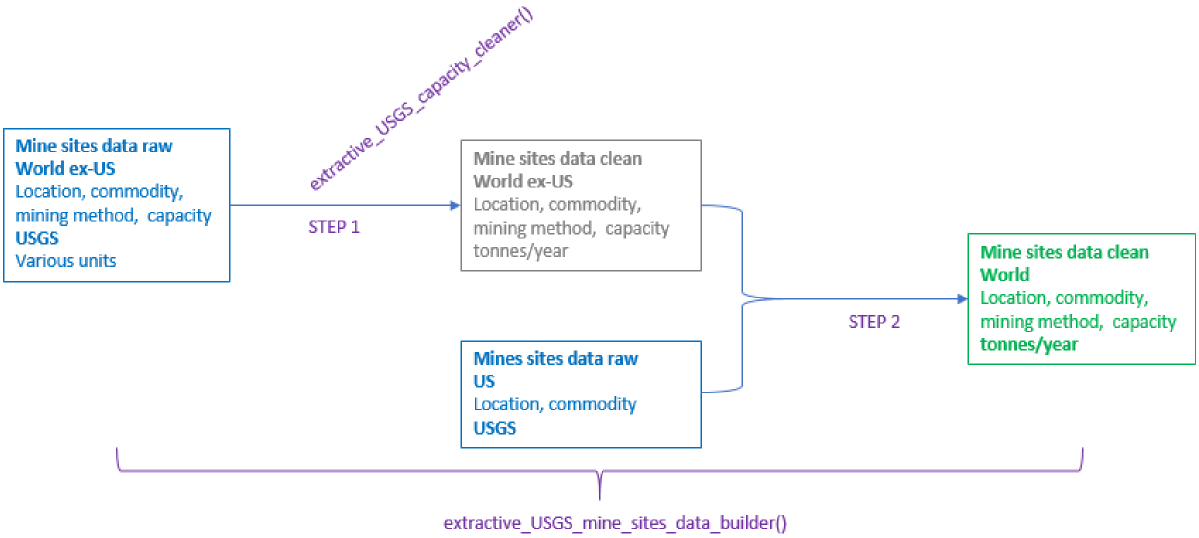

Figure 6: General layout mine sites data builder

A USGS DATA FORMATING

3.2.A.1 Outside of the United-States

(STEP 1) Mine sites data from USGS needs formatting and cleaning, especially regarding the documented capacities. As data is collected from various national sources, quantities are expressed in various units (tonnes, kilograms, cubic meters, carats…) with each unit having possibly different labels (“t”, “tons”, “million tons”…), the time period over which the quantity is produced varies as well (“day”, “month”, “year”…). Also, the reported quantity can either represent the ore (“bauxite” for instance), an intermediary refined product (“alumina” for instance) or the “pure” commodity (“aluminium” for instance).

The formatting function `extractive_USGS_capacity_cleaner()` deals with these multiple formats and provides **a standardized capacity in tonnes of pure commodity per year for each site.** For instance, when capacity is reported in ore tonnage, it needs to be adjusted by the ore grade (%).

Based on these standardized capacities in tonnes of pure commodity per year, **we apply a cut off** to exclude odd data. The cut-off is defined per commodity as a fixed percentage of the commodity world annual production. In GBS 1.0, default cut-off is set to 20% of world annual production, meaning that if the capacity is above this level, we exclude the data. 2007 annual production data is manually collected from British Geological Survey (BGS) report (Brown et al. 2018). Specifically, for gold, we had a more tailor-made approach as the default cut-off was not efficient enough to exclude odd data points. We looked for gold biggest mines in the literature and set the cut-off at twice[6] the maximum capacity (which represents only 2.5% of world production).

This capacity formatting function is integrated in a broader formatting function which:

- selects useful data from USGS: ID (`rec_id`), country (`country`), commodity generic name (`commodityAgg`), commodity specific name (`commodity`), facility name (`fac_name`), facility type (`fac_type`), GPS coordinates (`dmslat`, `dmslong`), mining technique (`nm`), activity status (`status`), mine capacity quantity and unit (`capacity` and `units`)

- filters "non active" mine sites (field "`status`" in USGS table) and mine sites with capacity equals to 0,

- selects only mine sites and quarries (field "`fac_type`" in USGS table). Other types of mining operations are listed in USGS such as refineries or smelters (reported as "`Plant`" in USGS table), but in GBS 1.0 this data is not used.

At the end of the formatting and cleaning process, we obtain a table of 2 248 active mine sites with the following data: USGS non-US ID number, country, facility name, facility type (mine or quarry), GPS coordinates, mining technique (surface or underground), capacity (expressed in tonnes per year of "pure" commodity).

3.2.A.2 In the United-States

(STEP 2) For US data, data formatting is much simpler as capacity is not reported. First it consists of:

- selecting useful data from USGS: ID (`id`), commodity name (`COMMODITY`), facility name (`SITE_NAME`), facility type (`PLANT_MIN`), GPS coordinates (`LATITUDE`, `LONGITUDE`),

- selecting only mines sites (not refining facilities).

For the remaining 648 US mine sites, capacities and mining techniques are estimated based on the non-US data we previously formatted:

- for capacity we use the average capacity of mines for that commodity from mines outside the US,

- for mining technique, we compute the average capacity-weighted ratio of surface mining for that commodity from mines outside the US.

[6] The ratio is cautiously set at 2 and not 1 due to our uncertainties regarding the comprehensiveness of the literature identified.

Then US and non-US mine sites lists are merged. USGS ID numbers for US mine sites are preceded by "US" to avoid facilities with identical IDs in the final database.

B LAND USE, ENCROACHMENT, WETLAND CONVERSION AND LAND USE IN CATCHMENT

3.2.B.1 Overview

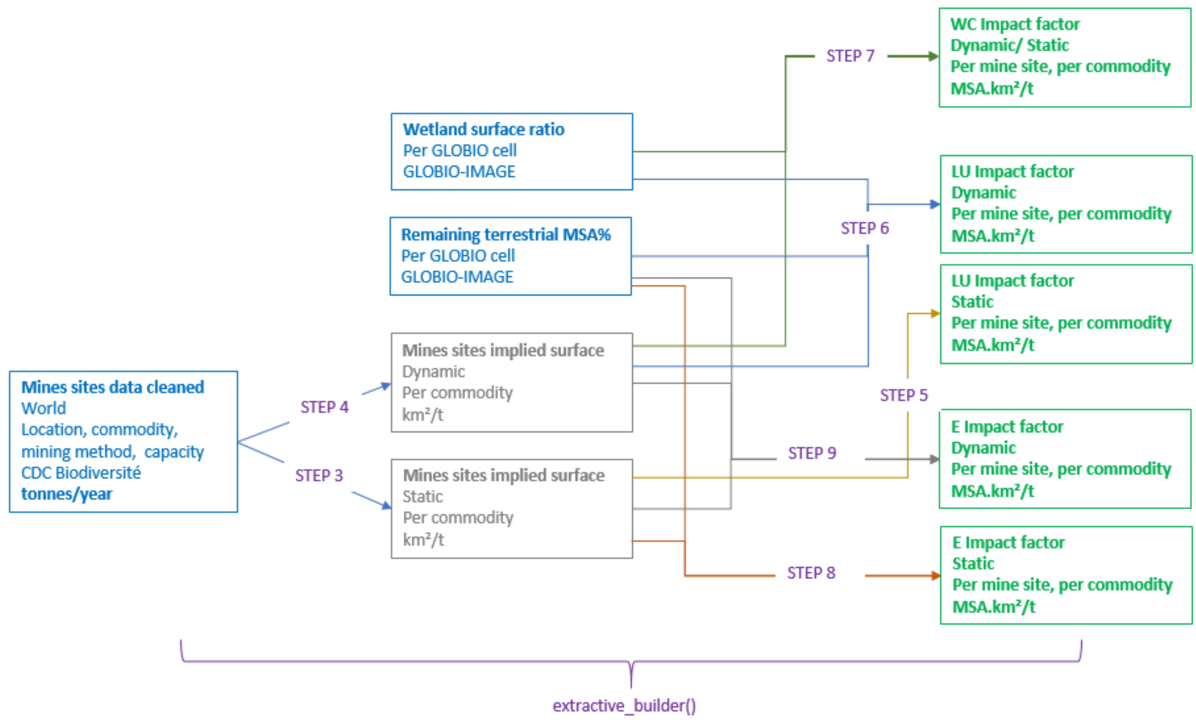

Figure 7: Methodology overview for spatial pressures (1/2): LU, WC and E

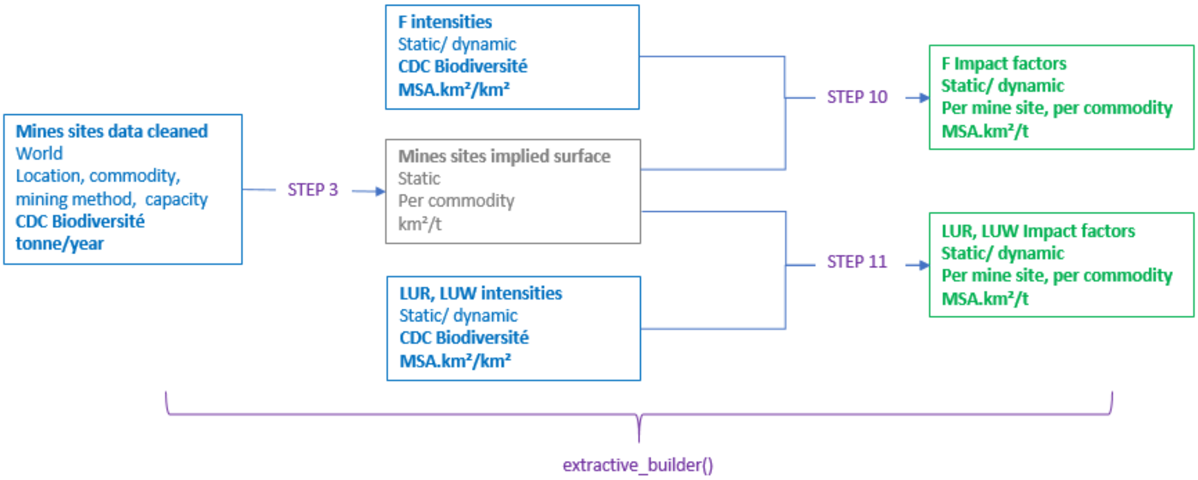

Figure 8: Methodology overview for spatial pressures (2/2): F, LUR and LUW

3.2.B.2 Land conversion induced by the production of 1 tonne of "pure" commodity

We try here to estimate the land conversion (additional surface area) induced by the production of 1 tonne of "pure" commodity at the mine level.

Figure 9: Grasberg mine spatial configuration (copper, Peru)

As illustrated on Figure 9, mine sites are composed of various areas dedicated to specific processes: pit and waste rocks disposal areas for mining, facilities and tailings disposal areas for mineral processing. They also have supporting infrastructures (roads, inhabitation, offices, water treatment facilities…). It is important to keep in mind that the surface area of a mine site (in blue) is much bigger than the mining area (in orange). Therefore, to evaluate additional surface area needed to produce 1 tonne of pure commodity, we proceed in two steps. First, we estimate land use change caused directly by the mining process. Secondly, from this estimation we extrapolate the land use change over the entire mine site, based on the assumption that other processes (mineral processing) and supporting infrastructures will also require an additional surface to produce this 1 tonne of pure commodity and that this surface is proportional to the additional surface needed for mining.

To estimate the additional land use surface, we first focus on the mining site and we compute the **"implicit area" defined as the additional surface that is needed to extract the volume of raw material necessary to the production of 1 tonne of "pure" commodity**. Secondly, we use a ratio to assess the expansion of other areas beyond the mining area itself. This ratio is based on generic mine site spatial configurations described below (Figure 10 and Figure 11) and has been discussed with experts from the mining sector. We apply the ratio to the area of the mining site to estimate the actual additional surface needed to extract this 1 tonne of pure commodity at the mine level.

3.2.B.2.1 Computation of the extracted volume

First, we compute the **extracted volume of ore needed to produce 1 tonne of final commodity:**

$$V^{1t}_{extracted} = \frac{Q^{1t}_{extracted}}{d_{extracted}}$$

With $V^{1t}_{extracted}$: volume of ore needed to produce 1 tonne of final commodity (in m^3)

$Q^{1t}_{extracted}$: quantity of ore needed to produce 1 tonne of final commodity (in t)

$d_{extracted}$: average density of the extracted material (in t/m^3)

To compute the average density of the extracted material $d_{extracted}$, we consider the average density of the "pure" commodity and the density of the gangue weighted by their ore grades:

$$d_{extracted} = g_{ore} \times d_{final\ commodity} + (1 - g_{ore}) \times d_{gangue}$$

With $d_{final\ commodity}$ = density of the final commodity (in t/m^3)

d_{gangue}: density of the gangue (in t/m^3)

g_{ore}: ore grade (in %)

To compute the quantity of ore needed to produce 1 tonne of final commodity $Q^{1t}_{extracted}$ we use the ore grade g_{ore}:

$$Q^{1t}_{extracted} = \frac{1}{g_{ore}} \text{ (in t)}$$

And finally:

$$V^{1t}_{extracted} = \frac{1}{g_{ore} \times (g_{ore} \times d_{refined\ comodity} + (1 - g_{ore}) \times d_{gangue})}$$

Based on the extracted volume we compute the implicit areas for mines using two commonly surface mining techniques: **strip mining** and **open-pit mining**. In section 3.2.B.2.6, we explain how implicit areas are also used to assess spatial pressures for **underground mining**. We know that, in the real world, the surface of the pit does not change continuously with the volume extracted. Still we assume that, in order to extract more ore, the pit needs to be expanded regularly and, on average, the size of the expansion follows simple geometric rules.

3.2.B.2.2 Computation of the implicit area for strip mining

For strip mining we consider that raw material is extracted from an ore layer of height h_S which is covered by an overburden layer of height h_O, as illustrated by Figure 10. We also assume that no extra surface is needed to dispose of the waste rocks as, in this configuration, the area that was previously excavated is used to store them. Based on expert opinion, we consider that this area is big enough to fit this purpose.

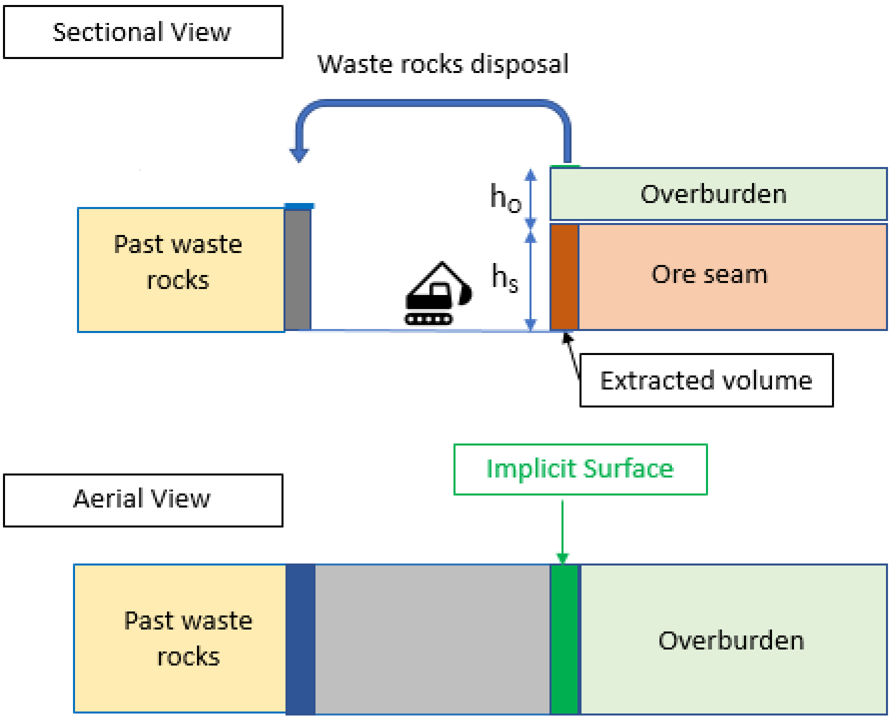

Figure 10: Layout of implicit area computation for strip-mining technique

The implicit area can be computed as follows:

$$S_{implicit} = \frac{V_{extracted}}{h_S}$$

Strip mining is mainly used for bauxite (aluminum) and coal. Coal and bauxite seams thickness varies from few centimeters to 10 meters (BGS 2016).

The default value for seam height h_S used in GBS 1.0 is 6 meters in the central, optimist and conservative calculation modes.

3.2.B.2.3 Computation of the implicit area for open pits

For open pits, we consider that the general shape of the mine site is a cone-shape pit. As for waste rocks disposal, we consider that it is done in the form of a symmetric cone shape hill as shown on Figure 11.

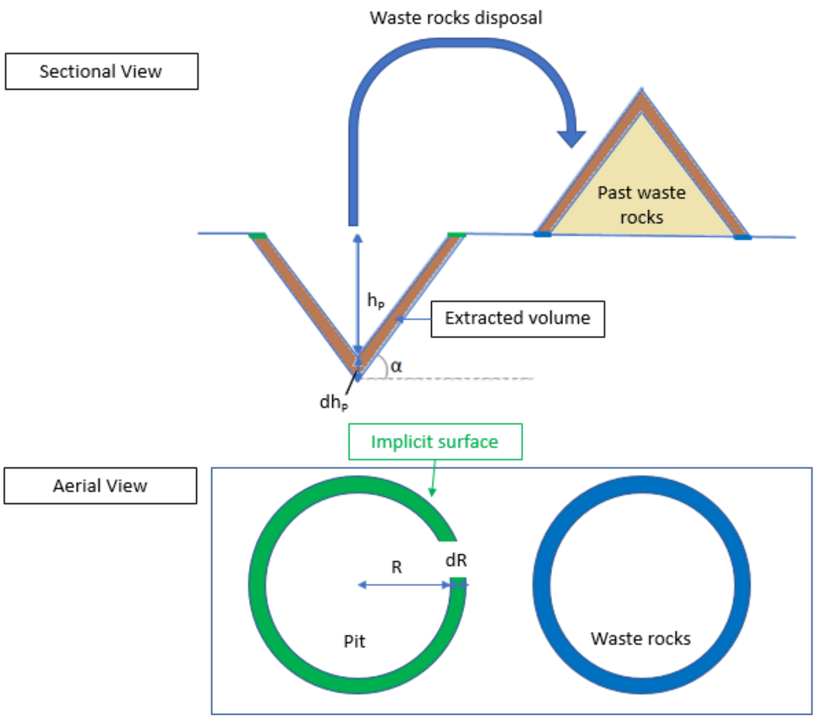

Figure 11: Layout of implicit area computation for open pit mining technique

In GBS 1.0, we assume pit slope to be constant. Therefore, extracting a certain volume implies increasing the depth of the pit as shown by Figure 11.

Based on expert opinion we set pit slope α = 30° and a typical open pit mine depth h_P = 100m (called "pit big" in the code) in all three calculation modes.

To compute dh_P, the pit depth increase induced by the excavation of the extracted volume, we need to solve a third-degree equation:

$$V = \frac{1}{3} \times \pi \times tan^2(\alpha) \times ((h_P + dh_P)^3 - h_P^3)$$

We solve it in R using a solver from the `'polynom'` package. Once δh_P is known, δR is computed thanks to a trigonometric relationship, as we assume α to be constant. The implicit area is then computed as:

$$S_{implicit} = \pi\left((R_{Pit} + dR_{Pit})^2 - {R_{Pit}}^2\right) = \pi \times tan^2(\alpha) \times ((h_P + dh_P)^2 - h_P^2)$$

3.2.B.2.4 Estimation of the land use change occurring over the entire surface of the mine site

As explained at the beginning of this section, mine sites have different areas dedicated to various functions. We differentiate 3 main types of areas: mining, tailings disposal and infrastructures. The general concept is to set simple mine spatial configurations where areas for tailings disposal and infrastructures are dimensioned proportionally to (as a ratio of) the area dedicated to mining.

For surface mining, we consider that the total surface of the mine site can be calculated as follows:

$$S_{mine\ site}^{surface\ mining} = S_{mining\ area} \times (1 + r_{waste\ rocks} + r_{tailings} + r_{infrastructures})$$

And therefore, land use change induced by the production of 1 tonne of pure commodity in the case of surface mining techniques (open pit and strip mining) is computed as follows:

$$dS_{mine\ site,1t}^{surface\ mining} = dS_{mining\ area,1t} \times \left(1 + r_{waste\ rocks} + r_{tailings} + r_{infrastructures}\right)$$

$$dS_{mine\ site,1t}^{surface\ mining} = S_{implicit} \times \left(1 + r_{waste\ rocks} + r_{tailings} + r_{infrastructures}\right)$$

With:

$dS_{mine\ site,1t}^{surface\ mining}$: mine site area change induced by the production of 1 tonne of pure commodity for surface mining techniques (in km²)

$S_{implicit}$: as define above

$r_{waste\ rocks}$ mining area multiplying ratio accounting for waste rocks disposal

$r_{tailings}$ mining area multiplying ratio accounting for tailings disposal

$r_{infrastructures}$: mining area multiplying ratio accounting for infrastructures

3.2.B.2.5 Spatial ratios estimation

Ratios are currently the same the three calculation modes.

Based on expert opinion:

- waste rocks ratio is set to 0 for strip mining (Figure 10) and to ~1.43 for open-pit mining (Figure 11). We took ~1.43 (1000/7) to account for the volume increase of the extracted material due to the creation of porosity (assumption of a 30% air proportion in the waste rocks)

- infrastructure ratio is set to 2.

For tailings ratio (metal ores only) we differentiate cases when on-site refining is needed or not.

Based on expert opinion, the rule is that, when mineral processing process occurs on site (for all metals covered except iron) tailings ratio is set to 10, otherwise tailings ratio is set to 0.

For surface mining technique, based on expert opinion we use:

- strip mining for aluminum and coal

- open pit for all the other metals with a default pit depth of h_P = 100 m,

- open pit for minerals with default pit depth h_P = 50m (called “pit small” in the code) taking into account the fact that quarries are on average smaller than open-pit mine sites.

A summary of mining area multiplying ratios per commodity is shown in Table 6.

Commodity	Category	Concentrating	Surface mining technique	Mining area multiplying ratios		
				Waste rocks	Tailings	Infrastructure
Aluminum	Metal	Yes	Strip	0%	1000%	200%
Copper	Metal	Yes	Open pit	130%	1000%	200%
Gold	Metal	Yes	Open pit	130%	1000%	200%
Iron	Metal	No	Open pit	130%	0%	200%
Lead	Metal	Yes	Open pit	130%	1000%	200%
Nickel	Metal	Yes	Open pit	130%	1000%	200%
Rare Earths	Metal	Yes	Open pit	130%	1000%	200%
Silver	Metal	Yes	Open pit	130%	1000%	200%
Tin	Metal	Yes	Open pit	130%	1000%	200%
Zinc	Metal	Yes	Open pit	130%	1000%	200%
Lignite	Coal	No	Strip	0%	0%	200%
Sub-bitumous coal	Coal	No	Strip	0%	0%	200%
Bitumous coal	Coal	No	Strip	0%	0%	200%
Anthracite	Coal	No	Strip	0%	0%	200%
Gravel	Mineral	No	Open pit	130%	0%	200%
Perlite	Mineral	No	Open pit	130%	0%	200%
Sand	Mineral	No	Open pit	130%	0%	200%
Talc	Mineral	No	Open pit	130%	0%	200%

Table 6: Mining area spatial ratios per commodity

3.2.B.2.6 Case of underground mining

For underground mining, we consider that no surface is consumed for mining but areas for waste rocks disposal, tailings disposal and infrastructures are needed and can be estimated the same way than for surface mining. In practice, we apply the waste rocks, tailings and infrastructures ratios to a fictive implicit area computed for pit mining with hP=100 m.noted $S_{implicit}^{pit\ h_P=100}$.

$$dS_{mine\ site,1t}^{underground} = S_{implicit}^{pit\ h_P=100} \times \left(r_{inert\ wastes} + r_{tailings} + r_{infrastructures}\right)$$

With $dS_{mine\ site,1t}^{underground}$: mine site area change induced by the production of 1 tonne of pure commodity for underground mining technique.

3.2.B.3 Land occupation needed to produce 1 tonne of "pure" commodity

We try here to estimate the surface area occupied to produce 1 tonne of "pure" commodity.

The general concept is that we evaluate the total surface of the mine. Then, the occupied surface for 1 tonne of "pure" commodity is evaluated as a share of the mine surface. The share is proportionate to the extracted volume needed to extract this tonne relatively to the total annual extracted volume of the mine.

(Kobayashi, Watando, and Kakimoto 2014) approximate the surface of a mine site to a disc with a radius equal to R_{mine} which depends on the annual volume extracted from the mine:

$$R_{mine} = C \times V_{extracted\ mine}{}^{1/3}$$

With R_{mine}= radius of the mine (in m)

$V_{extracted\ mine}$: total annual extracted volume of the mine (in m^3)

C: normalization constant (unitless)

C is a normalization constant set so that the maximum radius for any mine is 10 km, an approximate of the radius of the biggest existing mines like Grasberg in Indonesia or Hamersley in Australia.

As the value of C constant is not explicitly stated in the paper, we compute it following the same method: we calibrate C on the biggest known mine sites, here Escondida (Copper, Chile) and Grasberg (Copper/Gold, Indonesia). Results are presented in Table 7.

Mine	Annual extracted volume (m3)	C
Escondida	127 000 000	1,99E-02
Grasberg	125 477 249	2,00E-02

Table 7: C constant calibration results

Results are close for both mine sites. We chose the value calibrated on Grasberg as it is more conservative.

In GBS 1.0, we set **C = 2.00.10^{-2}**

Since the equation involves the total annual volume extracted, cases when multiple ores are extracted in the same mine should also be considered. Therefore:

$$V_{extracted}^{mine} = \sum V_{extractred\ commodity\ j}^{mine}$$

With $V_{extracted}^{mine}$: total annual extracted volume of the mine (in m^3)

$V_{extractred\ commodity\ j}^{mine}$: annual extracted volume of the mine for commodity j (in m^3).

The annual extracted volume of the mine for commodity *j* is defined as:

$$V_{extractred\ commodity\ j}^{mine} = \frac{Q_{extractred\ commodity\ j}^{mine}}{g_{ore\ j} \times d_{extracted\ ore\ j}}$$

With $Q_{extractred\ commodity\ j}^{mine}$: annual production of the mine for final commodity j (in tonnes)

$g_{ore\ j}$: ore j grade (in %)

$d_{extracted\ ore\ j}$: average density of the extracted material for ore j (in t/m^3)

The average density of the extracted material for ore j is computed as:

$$d_{extracted\ ore\ j} = g_{ore\ j} \times d_{final\ commodity\ j} + (1 - g_{ore\ j}) \times d_{gangue}$$

With $d_{commodity\ j}$ = density of the final commodity j (in t/m^3)

d_{gangue}: density of the gangue (in t/m^3)

$g_{ore\ j}$: ore j grade (in %)

Combining these equations thus gives:

$$V_{extracted}^{mine} = \sum_j \frac{Q_{extractred\ commodity\ j}^{mine}}{g_{ore\ j} \times \left(g_{ore\ j} \times d_{final\ commodity\ j} + (1 - g_{ore\ j)} \times d_{gangue}\right)}$$

From there, mine surface is computed as follows:

$$S_{mine} = \pi \times \left[\min\left(C \times V_{extracted}^{mine\ \frac{1}{3}}, 10\right)\right]^2$$

We cap mines' radius to 10 km. In theory, it wouldn't be necessary to do that as C constant was calibrated on the biggest mines. We essentially do that to have another control to avoid odd inputs (on top of cleaning procedures of USGS mine sites data des cribed in section 3.1A).

And then S_{1t} the surface occupied for the production of 1 tonne of "pure" commodity is computed as follows:

$$S_{1t} = \frac{V_{extracted\ 1t}}{V_{extracted}^{mine}} \times S_{mine}$$

With $V_{extracted\ 1t}$ computed following formula of previous section on land use change evaluation.

3.2.B.4 Land use (LU)

Based on unpublished assumptions from the PBL we consider that the MSA% of mines is 0:

$MSA\%_{mine} = 0\%$.

In section 3.2.B.2 we estimated the mine surface increase linked to the production of 1 tonne of "pure" commodity dS_{1t}. As mentioned earlier, mines are not accounted for in GLOBIO-IMAGE outputs, therefore, we have no estimation of the of land uses converted into mines. Therefore, we will assume that land conversion happens on an area representative of the average mix of surrounding land uses.

As noted in the Core concepts and Terrestrial pressures documents (CDC Biodiversité 2020a; 2020d), the best would be to use direct measurement of these surrounding land uses (*e.g.* satellite data) but we have not been able to find comprehensive and global data sets fit for this purpose. In practice we thus use GLOBIO-IMAGE outputs. We identify GLOBIO-IMAGE's cell to which the mine sites GPS coordinates belong using the function `get_GLOBIO_cell_id_from_GPS` from `GBStoolbox` package (for more details about this function please refer to (CDC Biodiversité 2019d)). Then we evaluate **for this cell**:

- $MSA\%_{cell}^{terrestrial}$: average MSA% for terrestrial land uses (in %) in the cell of interest,
- $ratio\ wetland_{cell}$:surface ratio of wetlands in the cell (in %).

$ratio\ wetland_{cell}$ is computed based on GLOBIO-IMAGE terrestrial and aquatic outputs which provide respectively $S_{emerged\ cell}$ the total surface of emerged land per cell including wetlands ("`totalArea`") and - $S_{wetlands\ cell}$ the wetlands surface ("`AreaWetlands`"). Then $ratio\ wetland_{cell}$ is computed as follows:

$$ratio\ wetland_{cell} = \frac{\min\left(S_{wetlands\ cell}, S_{emerged\ cell}\right)}{S_{emerged\ cell}}$$

We constrain that wetland surface cannot be greater than emerged lands including wetlands. By construction this case should not be encountered but in practice it happens for 336 cells (0.5% of total number of cells with emerged land) probably due to spatial projections differences between the aquatic and terrestrial model runs.

From there, the **land use dynamic impact factor** (in MSA.km²/t) is computed as follows:

$$Impact\ factor\ _{dynamic}^{LU} = dS_{1t} \times (1 - ratio\ wetland_{cell}) \times (MSA\%_{cell} - MSA\%_{mine})$$

$$Impact\ factor\ _{dynamic}^{LU} = dS_{1t} \times (1 - ratio\ wetland_{cell}) \times MSA\%_{cell}$$

Following the same rationale, the **land use static impact factor** (in MSA.km²/t) is computed as follows:

$$Impact\ factor\ _{static}^{LU} = S_{1t} \times (1 - ratio\ wetland_{cell}) \times (100\% - MSA\%_{mine})$$

$$Impact\ factor\ _{static}^{LU} = S_{1t} \times (1 - ratio\ wetland_{cell})$$

3.2.B.5 Encroachment (E)

Human encroachment comprises anthropogenic activities in otherwise non-human land use type areas. Direct (noise, pollutions, etc.) and indirect impacts (right of way for hunting, tourism, etc.) are accounted for. In GLOBIO cause-effect relationships, an MSA discount of 85% is applied within a 10 km buffer zone around human land use type areas. As a reminder, 10km is the area within which birds and mammals are assumed to be impacted by the encroachment pressure (hunting and habitat disturbance) in GLOBIO3 cause-effect relationships. It is based on unpublished data from Benítez-López et al. (Schipper et al. 2016). GLOBIO4 substitutes this pressure with a meta-analysis (Benítez-López et al. 2017). In GLOBIO-IMAGE outputs, this pressure applies to all land uses where human activity is predominant (agriculture and urban areas). We assumed that mine sites also cause such encroachment. For more details about encroachment pressure in GBS 1.0 please refer to the review report on terrestrial pressures (CDC Biodiversité 2020d).

We consider mine sites as a “human” land use and therefore we apply an 85% MSA multiplier with a 10 km buffer zone around them.

To evaluate encroachment impact factors, mine sites are modeled as a disc of radius R, which is evaluated with the Kobayashi methodology explained in section 3.2.B.3. The encroachment caused by a mine site is illustrated by Figure 12.

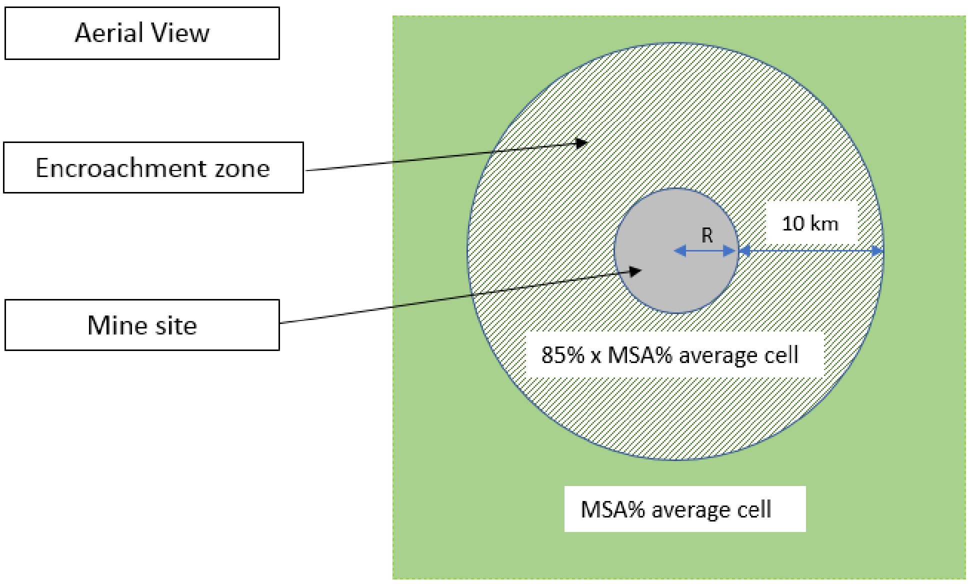

Figure 12: Example of the encroachment pressure caused by a mine with a radius R

To compute the dynamic impact factor due to encroachment, first we compute dR_{mine} the radius variation of the mine caused by the mine site surface increase dS_{1t} (as computed in section 3.2.B.2). Initial mine radius R_{mine} is computed with the Kobayashi method as described in section 3.2.B.3. Then the dynamic impact factor due to encroachment related to the production of one tonne of pure commodity is:

$$Impact\ factor^{E}_{dynamic} = \pi \times [(R_{mine} + 10 + dR_{mine})^2 - (R_{mine} + 10)^2] \times MSA\%_{cell} \times (1 - 85\%)$$

$$Impact\ factor^{E}_{dynamic} = \pi \times dR_{mine} \times [R_{mine} + 2R_{mine} + 20] \times MSA\%_{cell} \times 15\%$$

To compute the static impact factor related to encroachment, we use the same principle as for static impact factor for land use. We compute the mine site total impact and we attribute a share of it to 1 tonne of pure commodity in the proportion of the extracted volume needed to produce it relatively to the mine's total annual extracted volume.

$$Impact\ mine\ site^{E}_{static} = \pi \times [(R+10)^2 - R^2] \times MSA\%_{cell} \times (1 - 85\%)$$

$$Impact\ factor^{E}_{static} = \frac{V_{extracted\ 1t}}{V_{extracted\ mine\ site}} \times Impact\ mine\ site^{E}_{static}$$

$$Impact\ factor^{E}_{static} = \frac{V_{extracted\ 1t}}{V_{extracted\ mine\ site}} \times \pi \times [(R+10)^2 - R^2] \times MSA\%_{cell} \times (1 - 85\%)$$

Our current approach means that for a given mine, and *a fortiori* for a given country or EXIOBASE region, it is as if the radius of the mine was somehow "reset" with a value of R, based on the capacity reported in USGS, for every reporting year. The radius increase of dR is not added to the radius of the mine for future reporting.

This approach is not entirely satisfactory but public data on mine expansion and construction year are lacking, so registering any radius increase in the GBS would be arbitrary and we cannot know if it would be more or less accurate as the current approach.

In future versions of the GBS, we will continue to seek data on mine expansion to better represent the evolution of dynamic and static spatial impacts.

3.2.B.6 Wetland conversion (WC)

In line with terrestrial assumption, based on expert opinion we consider that aquatic MSA% for mines is equal to 0%.

$$MSA\%^{aquatic}_{mine\ LU} = 0\%$$

Based on the same rationale as for land use described in section 3.2.B.4, dynamic and static impact factors for wetlands conversion (WC) are computed as follows:

$$Impact\ factor^{\ WC}_{\ dynamic} = dS_{1t} \times ratio\ wetland_{cell} \times (100\% - MSA\%^{aquatic}_{mine\ LU})$$

$$Impact\ factor^{\ WC}_{\ dynamic} = dS_{1t} \times ratio\ wetland_{cell}$$

$$Impact\ factor^{\ WC}_{\ static} = S_{1t} \times ratio\ wetland_{cell} \times (100\% - MSA\%^{aquatic}_{mine\ LU})$$

$$Impact\ factor^{\ WC}_{\ static} = S_{1t} \times ratio\ wetland_{cell}$$

3.2.B.7 Remaining pressures with impacts factors expressed per unit of area (F, LUR, LUW)

For fragmentation, land use in catchment for rivers and for wetlands, the same approach is used. We apply associated national intensities evaluated in the terrestrial (CDC Biodiversité 2020d) and aquatic (CDC Biodiversité 2019b) modules (in MSAkm²/km² of human land use type area) to the occupied surface needed to produce 1 tonne of "pure" commodity S_{1t}.

The underlying assumptions are:

- mine falls into human land use types,

- at the country level, mine areas contribute to those pressures at the average intensity of human land use type considered in GLOBIO-IMAGE: agriculture, cultivated grassland and urban.

Therefore, dynamic and static impact for pressure X (X being F, LUR or LUW) are computed as follows:

$$Impact\ factor\ ^{X}_{dynamic/static} = S_{1t} \times Intensity^{X}_{dynamic/static}$$

C PRESSURES WITH IMPACT FACTORS EXPRESSED PER EMISSION OF GHG

The contributions of GHG emissions to terrestrial Climate change (CC) and freshwater Hydrological disturbance due to climate change (HD_{CC}) pressures are assessed by specific functions introduced in the terrestrial (CDC Biodiversité 2020d) and freshwater module papers (CDC Biodiversité 2019b), namely `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()`. Practically, both functions compute a **biodiversity impact in MSA.km² linked to a given GHG emission in tonnes CO_2-eq**.

We combine these impact intensities to mining GHG emission data documented in PEF for commodity related products described in section 3.1C.

D PRESSURE WITH IMPACT FACTORS EXPRESSED PER M^3

For the pressure **hydrological disturbance from direct water use** (HD_{water}), we use impact intensities for **withdrawn water expressed in MSA.km² per m^3** from the GBS aquatic module (CDC Biodiversité 2019b). In the central calculation mode, the impact intensities from the central calculation mode ("wm" for weighted-mean in the code) are used.

These are combined to water coefficients from USGS (Lovelace 2009) described in section 3.1B.

E IMPACT FACTORS AT THE COUNTRY LEVEL

Based on mine sites level impact factors, impacts factors are computed at the country level for each commodity as an average of relevant mine sites impacts factors weighted by their respective capacity for the given commodity.

The computed impact factors for LU, WC and E fall into data quality tier 1, because they are based on global world average parameters (ore grades).

The computed impact factors for F, LUR, LUW, and HD_{water}, fall into data quality tier 2, because they are based on tier 2 pressures impact factors (CDC Biodiversité 2020d; 2019b).

The computed impact factors for CC and HD_{CC}, fall into data quality tier 1, because they are based on tier 1 impact factors ($MSA.km^2/kg\ CO_2$-eq).

In this version of the GBS the three calculation modes (central, conservative and optimistic) have the same value. In future versions, conservative and optimistic values will be distinguished.

3.3 Example

We compute impacts for the fictive sourcing summarised in Table 8. This sourcing is designed to illustrate two types of granularity, at the product level with multiple products from Australia, and at the country level with copper cathode produced in various countries. This is a fictive example where we intentionally took an unrealistic figure for gold to show the importance of the ore grade in the biodiversity assessment.

Country	Product name	Product quantity (tonnes)	Commodity content
Australia	Copper concentrate	1000	28%
Australia	Copper cathode (>99.99 Cu)	1000	99,99%
Australia	Gold	1000	100%
Australia	Lignite	1000	100%
Australia	Quartz sand	1000	100%
Chile	Copper cathode (>99.99 Cu)	1000	99,99%
Poland	Copper cathode (>99.99 Cu)	1000	99,99%

Table 8: Example fictive sourcing

A COMPARISON OF FIVE PRODUCTS IN AUSTRALIA

Results are summarised in **Erreur ! Source du renvoi introuvable.**.

Product name	Country	Terrestrial total		Aquatic total	
		Dynamic	Static	Dynamic	Static
		MSA.m²	MSA.km²	MSA.m²	MSA.km²
Copper concentrate	Australia	8 956	0,573	87	0,020
Copper cathode (>99.99 Cu)	Australia	23 511	2,045	226	0,073
Gold	Australia	305 698 324	10 026	6 351 837	430
Lignite	Australia	484	0,017	2,55	0,0002
Quartz sand	Australia	263	0,209	24	0,0086

Table 9: Dynamic and static terrestrial and aquatic footprint results for 1000 t of five products in Australia

Absolute impact are highly related to ore grade and the ore grades for the selected products are very different, ranging from 0.00044% for gold to 100% for sand. Thus, the ore grade effect is preponderant in the results (especially since the quantities of products are all 1000 t). We can observe the dilution effect from copper cathode to copper concentrate.

To neutralize the ore grade effect, the next tables present the impacts for 1000 tonnes of <u>ore</u>. Results for terrestrial biodiversity are shown in Table 10 and for aquatic biodiversity in Table 11. Parameters are shown in Table 12.

Commodity	Country	Terrestrial total		Terrestrial split						
		Dynamic	Static	Dynamic (MSA.m²)				Static (MSA.m²)		
		MSA.m²	MSA.m²	LU	E	F	CC	LU	E	F
Copper cathode (>99.99 Cu)	Australia	106	9 201	53	25	-	28	3 317	5 842	43
global mix copper concentrate	Australia	144	9 202	53	25	-	66	3 317	5 843	43
Gold	Australia	550	18 046	47	32	-	471	4 468	13 516	62
Lignite	Australia	484	16 941	220	125	-	138	5 101	11 774	66
Quartz sand (0/2)	Australia	263	208 643	50	39	-	174	46 004	161 969	670

Table 10: product analysis example, impact of the production of 1000 t of ore on terrestrial biodiversity

Commodity	Country	Aquatic total		Aquatic split								
		Dynamic	Static	Dynamic (MSA.m²)					Static (MSA.m²)			
		MSA.m²	MSA.m²	WC	LUR	LUW	Hd water	HD CC	WC	LUR	LUW	HD water
Copper cathode (>99.99 Cu)	Australia	1	326	0	0	1	0	0	7	0	149	170
global mix copper concentrate	Australia	1	326	0	0	1	0	1	7	0	149	170
Gold	Australia	11	774	6	0	1	0	5	386	0	217	170
Lignite	Australia	3	246	0	0	1	0	1	7	0	228	11
Quartz sand (0/2)	Australia	24	8594	13	0	9	0	2	6159	1	2331	103

Table 11: product analysis example, impact of the production of 1000 t of ore on aquatic biodiversity

			Dynamic part				Static part			
Commodity name	Country	Average surrounding MSA%	Surface mining technique	Surface mining ratio	Ore implied surface (m²/tonne)	Average wetland ratio	Average mine radius (km)	Ore mine capacity (tonnes)	Ore implied surface (m²/tonne)	Ore average water withdrawal (m3/ tonne)
Copper	Australia	80%	Pit big	26%	0,11	0,3%	4,95	11 444 444	3,33	2,9
Gold	Australia	70%	Pit big	83%	0,11	7,0%	3,60	5 034 483	4,55	2,9
Lignite	Australia	48%	Strip	100%	0,39	0,0%	5,23	22 666 667	3,69	0,2
Sand	Australia	51%	Pit small	100%	0,10	11,8%	1,30	450 000	11,87	1,8

Table 12: Explanatory factors of the footprint results related to the production of 1000 t of ore

The results lead to the following observations:

- lignite terrestrial dynamic footprint is higher than other extracted ores. It means that, for the same extracted material volume, terrestrial dynamic impact is higher at lignite mines than for other ores. It is mainly due to the fact that lignite is mined using strip mining technique which is more surface consuming than open pit mining for the same extracted volume.

- climate change related impacts are higher for lignite and gold as PEF reports higher GHG emissions for these processes. The limitation here is that the perimeter is note the same.

- land use related static impacts (LU, E, WC) for sand are higher than for other ores. This is due to the fact that the implicit area required to extract 1 tonne of sand is two to three times larger than for other commodities due to smaller ore mine capacities and despite a smaller average mine radius (1.3 km).

- for terrestrial static impacts, E is always predominant, and its weight increases as the mine radius decreases.

- water withdrawals for metals are higher than for coal and minerals, leading to higher HD_{water} impacts for metal related products.

- wetland conversion impacts, both static and dynamic, are higher for gold and sand. This is due to the fact that the GLOBIO-IMAGE cells around gold and sand mines contain more wetlands than the other commodities used in the example.

B COMPARISON OF COPPER CATHODE WITH ORE MINED FROM THREE COUNTRIES

This second part of the example compares 1000 t of copper cathode product with the ore sourced from three countries. Since we currently use only a global ore grade for each commodity (so the ore grade of copper is the same in Australia, Chile and Poland), ore grade has no effect in the analyses displayed. Results are shown in Table 13 for terrestrial biodiversity and in Table 14 for aquatic biodiversity. Explaining factors are shown in Table 15.

		Terrestrial Total		Terrestrial split						
		Dynamic	Static	Dynamic (MSA.m²)				Static (MSA.m²)		
Product Name	Country	MSA.m²	MSA.m²	LU	E	F	CC	LU	E	F
Copper cathode (>99.99 Cu)	Australia	42 743	2 051 131	18 989	9 125	-	14 628	737 857	1 303 727	9 546
Copper cathode (>99.99 Cu)	Chile	39 288	838 671	18 223	6 437	-	14 628	430 833	373 282	34 555
Copper cathode (>99.99 Cu)	Poland	25 965	2 975 692	7 175	4 162	-	14 628	948 570	1 964 092	63 030

Table 13: Dynamic and static ***terrestrial*** *footprint results for 1000 t of copper cathode in three countries*

		Aquatic Total		Aquatic split								
		Dynamic	Static	Dynamic (MSA.m²)					Static (MSA.m²)			
Product Name	Country	MSA.m²	MSA.m²	WC	LUR	LUW	HD water	HD CC	WC	LUR	LUW	HD water
Copper cathode (>99.99 Cu)	Australia	333	59 572	66	0	124	-	143	1 632	21	33 005	24 914
Copper cathode (>99.99 Cu)	Chile	309	9 078	134	0	32	0	143	2 251	59	6 091	677
Copper cathode (>99.99 Cu)	Poland	158	7 841	-	0	5	10	143	-	668	4 091	3 082

Table 14: Dynamic and static ***aquatic*** *footprint results for 1000 t of copper cathode in three countries*

			Dynamic part				Static part		
Commodity name	Country	Average surrounding MSA%	Surface mining technique	Surface mining ratio	Commodity implied surface (m²/tonne)	Average wetland ratio	Average mine radius (km²)	Commodity mine capacity (tonnes)	Commodity implied surface (m²/tonnes)
Copper	Australia	80%	Pit big	26%	24	0,3%	4,95	51 500	740
Copper	Chile	73%	Pit big	100%	25	0,5%	7,99	272 474	433
Copper	Poland	28%	Pit big	100%	25	0,0%	3,54	40 800	949

Table 15: Explanatory factors for the footprint results for 1000 t of copper cathode in three countries

The results lead to the following observations:

- we can observe once again the effect of the mine productivity (related to its capacity and its radius) on the static impacts for pressures related to land use, especially LU and E here. The smaller the productivity (which here goes hand in hand with smaller capacities and smaller radius), the higher the impact per tonne of product.

- here also, for terrestrial static impacts, E is always predominant, and its weight increases as the mine radius decreases.

- for Poland, the LU dynamic impact is relatively small despite a dynamic implicit surface comparable to the others. This is due to the fact that surrounding MSA% is lower in the GLOBIO-IMAGE cells near the copper mines of this country , inducing a smaller impact from land conversion as the model expects conversion to occur on more degraded ecosystems.

- HD_{water} is much higher in Australia despite water withdrawal intensities being the same. It is due to a higher HD_{water} impact factor in Australia, the GBS freshwater module reflecting implicitly a higher water stress in Australia than other countries (CDC Biodiversité 2019b).

3.4 Tests

Various tests are conducted and several reference values are calculated to ensure that impact factors computation is conducted correctly. We also use them as reference values to check the stability of the code when updates are performed. The following calculations are performed (Table 17):

- We check that capacities figures from the USGS data for non-US mine sites are consistent with global productions figures. As USGS capacity data are provided from 2005 to 2007, we compare the total production to BGS 2007 figures. We do not expect it to be exactly in line with BGS's figures, but we want to detect odd figures that could reveal an error in the implementation. Copper production from USGS is abnormally high (260% of BGS reported figure). On the other side, USGS figures for minerals are too low. Finally, the overall figure for coal is in line but the split between coal categories is not. All these discrepancies have to be investigated further.

Indeed, as we saw in the example, small capacities for a commodity leads to small mine radius and high static impacts for spatial pressures (LU, E, WC, LUR, LUW). Therefore, we expect to be over conservative for minerals and to have distortion effects between the different coal categories.

-We compute the total mine surface based on BGS 2007 world production: around 31 000 km², approximately the size of Belgium.

- We compute the average surrounding MSA% weighted by capacities: around 46%.

- We compute the average of the mine radius weighted by capacities: 6.1 km and without weighting: 2.5 km.

- Based on BGS 2007 production, for each pressure, we compute the total impact (both static and dynamic) and we compare it to the associated global impact from the GLOBIO-IMAGE model for 2019. Climate change related impacts (for CC and HD_{CC}) are computed based on data from PEF processes (cf. 3.2C). When possible, only the process limited to mining and mineral processing are used. Otherwise, broader processes which include off-site refining are used (cf. Table 1). Total impacts relative to total GLOBIO-IMAGE impacts are summarised in Table 16. As expected, the impacts from mining range from 0.1% to 7.5% of the total impacts assessed in the GLOBIO-IMPACT outputs.

	Terrestrial				Aquatic				
	LU	E	F	CC	WC	LUW	LUR	HD_{water}	HD_{CC}
Static	0,12%	1,25%	0,06%		5,37%	0,09%	0,09%	0,99%	
Dynamic	1,33%	4,66%	0,004%	3,31%	7,45%	0,12%	0,07%	0,18%	7,84%

Table 16: Impacts of BGS 2007 world production relative to global biodiversity impacts modelled by GLOBIO-IMAGE for the year 2019

- Based on BGS 2007 production, we compute the share of mining GHG emissions compared to total GHG emissions with the approach described above: they amount for 5.1% of total world emissions estimated in 2007 by the IPCC,

- Based on BGS 2007 production, we compute the share of water withdrawal related to mining over total water withdrawal. It amounts to 0.27% of total withdrawal estimated in AQUEDUCT (CDC Biodiversité 2019b).

- We use global production checks to decide whether or not USGS production data can be used. We apply a 35% absolute threshold, meaning that if USGS annual production is below 65% or above 135% of the BGS reported production, then USGS data production is not used for that given commodity. USGS production data is used to estimate the radius of the mine site, when USGS data is found not reliable we use the global average of mine site radius that we evaluated for other commodities with consistent USGS production data.

Category	Description	Previous
USGS mine data file production (ratio USGS/ BGS for world production 2007 ex US)	Aluminum	130,6%
	Anthracite	110,9%
	Bituminous coal	5,5%
	Copper	259,7%
	Gold	77,8%
	Gravel	0,1%
	Iron	60,2%
	Lead	121,1%
	Lignite	235,8%
	Nickel	52,4%
	Perlite	23,2%
	Rare earths	11,7%
	Sand	8,7%
	Silver	174,4%
	Sub-bituminous coal	3,4%
	Talc	12,4%
	Tin	61,2%
	Zinc	86,5%
Mines	Total mine surfaces	30 952
	Total mine LU static impact	30 952
	Total mine dynamic impact	2 702
	Weighted mean of mine radius	6,1
	Mean of mine radius	2,5
	Median of mine radius	2,1
	Weighted mean of surrounding MSA%	46,1%
Commodity IA: LU & WC	Total LU static impact	30 165
	Total LU static impact vs GLOBIO	0,12%
	Total WC static impact	787
	Total WC static impact vs GLOBIO	5,37%
	check: total LU static + total WC static - total mine surface	0
	Total LU dynamic impact	1 463
	Total LU dynamic impact vs GLOBIO	1,33%
	Total WC dynamic impact	74
	Total WC dynamic impact vs GLOBIO	7,45%
	Implied MSA% for surrounding areas	55,7%
Commodity IA: E	Total E static impact	79 483,3
	Total E static impact vs GLOBIO	1,25%
	Total E dynamic impact	625,5
	Total E dynamic impact vs GLOBIO	4,66%
Human land use type area	World human land use type area share	0,08%
Commodity IA: F	Total F static impact	1 340,4
	Total F static impact vs GLOBIO	0,06%
	Total F dynamic impact	0,02
	Total F dynamic impact vs GLOBIO	0,004%
GHG emissions	Total GHG emissions share based on BGS production and PEF	5,1%
Commodity IA: CC & HDCC	Total CC dynamic impact	5 003,4
	Total CC dynamic impact vs GLOBIO	3,31%
	Total HDCC dynamic impact	48,8
	Total HDCC dynamic impact vs GLOBIO	7,84%
Intensity weighted area	World intensity weighted area share	0,11%
Commodity IA: LUW	Total LUW static impact	1 152,1
	Total LUW static impact vs GLOBIO	0,09%
	Total LUW dynamic impact	5,9
	Total LUW dynamic impact vs GLOBIO	0,12%
Commodity IA: LUR	Total LUR static impact	0,2
	Total LUR static impact vs GLOBIO	0,09%
	Total LUR dynamic impact	37,1
	Total LUR dynamic impact vs GLOBIO	0,07%
Water withdrawal	Total water withdrawal based on BGS production	31 939 797 040
	Share versus AQUEDUCT total withdrawal	0,27%
Commodity IA: HD water	Total HD water static impact	5 906
	Total HD water static impact vs GLOBIO	0,99%
	Total HD water dynamic impact	1,1
	Total HD water dynamic impact vs GLOBIO	0,18%

Table 17: Mining CommoTool tests results

4 Dimensioning the impacts of mining production – Refined assessment

If the assessed entity can provide **custom and more precise ore grade, land use change and occupation, water withdrawal and consumption, greenhouse gas emissions data** related to the mines their commodities are sourced from, the data will be used to replace the values from USGS, PEF, GLOBIO-IMAGE and our own assumptions in impacts computation.

Environmental Impact Assessments (EIA) conducted before the launch or modification of mines and Environmental Management Plan (EMP) updated regularly during the operations of mines to ensure compliance with the recommendations of EIA can also provide useful data to conduct refined assessments, especially if special care was taken to adapt the indicators tracked to the needs of the biodiversity footprint assessments. The way approaches such as EIA which, for their biodiversity part, focus on taxa and habitats, could link to approaches such as the GBS focusing on aggregated metrics (like the MSA) has been explored in the Aligning Biodiversity Measures for Business (ABMB) collaboration (ABMB 2019; Lammerant 2019), and has also fed into the approach recommended for Pressures in the Biodiversity Indicators for Extractive methodology developed by UNEP-WCMC, CI and FFI. We list below what could be extracted from EIA to feed GBS assessments.

EIA promote the application of the mitigation hierarchy of first avoiding impacts, then reducing impacts which cannot be avoided, and finally offsetting the remaining, or **residual**, impacts (and restoring impacted ecosystems wherever possible)[7]. Two phases can be distinguished in the life of a mine: the construction (or expansion) phase and the operational phase. The focus of Biodiversity Footprint Assessment (BFA) conducted using the GBS is on the residual impacts, both during the construction phase and the operational phase. The default assessments described in the sections above currently do not cover the construction phase impacts (such as temporary disturbance due to noise caused by construction work, GHG emitted by construction vehicles, etc.): they include only operational phase residual impacts. With appropriate data, the GBS could however cover construction phase impacts in refined assessments (if they persist beyond the construction phase). When they exist, monitoring data on the actual impacts during the operational phase are not available in the EIA (conducted before operations start) but rather on the EMP.

The following list explains how data typicall found in EIA can or cannot be used in the GBS:

---

[7] Section 1.4 provides some additional definitions and mapping of EIA concepts such as area of influence to GBS concepts.

- presence/absence of species: a list of species found on or around the mine cannot be used directly in the GBS since it provides no indication of the abundance of those species or of their undisturbed abundance. It can however be used in the qualitative analysis which goes along the quantitative part of any BFA. In order to be directly usable by the GBS, abundance data with a coverage of species as comprehensive as possible (or a choice of "representative species") would need to be collected: this is usually not realistic given time and budget constraints;

- habitat rating and mapping: polygons of habitats in geographical information system (GIS) format, with associated rating of their conservation status (good or bad) can be used as land use data (the polygons are not necessary, the surface areas can be calculated and input in spreadsheet format). This however requires to think in terms not just of habitat and conservation status but also in terms of management intensity and to link habitat & management intensity to GLOBIO land use classes;

- overlap or proximity to protected areas and critical habitats: such information cannot be used in the GBS but should feed the qualitative analysis of the BFA and in particular lead to recommendations of actions through the environmental safeguards (CDC Biodiversité 2020c);

- data on pressures: pressure data are the most valuable for the GBS but their format in EIA is usually inappropriate. EIA and EMP should strive to produce data on midpoints commonly used by biodiversity footprint assessment tools, such as the ones identified through the ABMB collaboration, or listed for refined assessment in the terrestrial and aquatic modules review documents (CDC Biodiversité 2020d; 2019b).

5 Linkage with the input-output approach

This section explains how $D_{LUEFN\_extractive}$, the D matrix related to metal ores, is built and duplicates most of the content of the Input output modelling document (CDC Biodiversité 2019c). The "used" mining provided by EXIOBASE is the total quantity of extracted gross ore without the overburden but including gangue, not the quantity of the ore of interest. The quantity of extracted gross ore is computed by EXIOBASE team based on production data per metal taken from the British Geological Survey (BGS 2014) and an estimation of ore densities obtained through interviews with experts and a literature review. Since the GBS CommoTool gives the impact per tonne of metal(CDC Biodiversité 2019e), we need to correct the data so that $D_{LUEFN\_extractive}$ documents tonnes of metal. For now, we do so by working EXIOBASE computation backwards:

1. Get BGS data and compute the total production of each metal per EXIOBASE region

2. Compute the ore density per {region; metal} by dividing the total production by the gross ore mining
3. Apply the computed ore grades to the gross ore mining data in D_{LUEFN} to get the corresponding metal mining

A path to improve the methodology in the future would be to be able to use directly the ore grades used by EXIOASE instead of re-computing them.

The 9 metals considered in the CommoTool are aluminium, copper, iron, gold, lead, nickel, silver, tin and zinc. They correspond to separate mining industries in EXIOBASE and their mining is separately documented in the environmental extensions, except for aluminium which corresponding industry is “Mining of bauxite and aluminium” and raw material is “Bauxite and aluminium”. We thus need to make an assumption on the proportion of bauxite and aluminium in the raw material extracted.

ASSUMPTION

The proportion of bauxite in the raw material “Bauxite and aluminium” is 100%. The corresponding quantity of aluminium is computed using the ratio of aluminium to bauxite, which is 16.5%.

The main code lines involved in the computation of regional ore grades and $D_{LUEFN\_extractive}$ are reproduced below. To ensure data consistency, the computed grades are compared with the highest known grade for each metal[8]. When the computed grades are higher than 1.5 the highest known grade[9], they are replaced by the maximum between the world average and half the highest grade. This replacement procedure allows to 1) maintain differentiation between mines (world average is not the only replacement figure and a high grade is allocated to mines for which a high grade was computed), 2) ensure that abnormal grades are controlled for (computed grades higher than 1.5 the highest grade are replaced), and 3) stick to a rather conservative approach (for mines with a very high computed grade, only half the world’s highest grade is used rather than the highest grade). Other abnormal computed grades (superior to 1 for instance) are replaced by the average grade.

COMPUTE ORE GRADE PER EXIOBASE REGION

```
ore_grade_per_exiobase_region <- bgs_2011_production %>%
  # Link each BGS country to the corresponding EXIOBASE region
  # […]
  # compute the ore grade per region and metal based on the production documented on BGS
data and the mining documented in EXIOBASE materials account
  group_by(ID_region, commo_name) %>%
  mutate(region_production = sum(Production_tons, na.rm = TRUE),
         ore_grade = region_production / extracted_tons) %>%
  # […]
  # convert bauxite into aluminium
```

[8] The highest ore grades for each metal can be found online rather easily on specialized sites like mining.com which provide rankings of highest-grade mines for several ores (copper, gold, lead, silver, zinc) based on private data from Mining Intelligence. We compare to 1.5 x highest grade to allow for uncertainty around the highest grade.
[9] For iron we compare to the highest grade instead of 1.5 x highest grade because the highest known grade is 0.7, hence 1.5 x highest grade would be superior to 1.

```
  mutate(ore_grade = case_when(
    commo_name == "Bauxite" ~ ore_grade * bauxite_to_alu_ratio,
    TRUE ~ ore_grade),
    commo_name = if_else(commo_name == "Bauxite", "Aluminum", commo_name)) %>%
  # computed grade analysis based on ore characteristics
  left_join(extractive_ore_specs, by = "commo_name") %>%
  group_by(commo_name) %>%
  # when the computed grade is higher than 1.5*highest_grade, we replace by the max between
highest_grade/2 and average_grade
  mutate(ore_grade = case_when(
    ore_grade > 1.5 * commo_grade_highest & commo_name != "Iron" ~
          max(commo_grade_highest / 2, commo_grade),
    ore_grade > commo_grade_highest & commo_name == "Iron" ~
          max(commo_grade_highest / 2, commo_grade),
  # use average values when the computed grade is obviously weird
  # […]

COMPUTE D_LUEFN_EXTRACTIVE
D_LUEFN_extractive <- D_LUEFN %>%
  # keep only the 9metals considered in the commotool
  # […]
  # compute the amount of metal extracted
  left_join(ore_grade_per_exiobase_region, by = c("ID_region", "commo_name")) %>%
  mutate(Quantity = Quantity * ore_grade)
```

$M_{LUEFN\_extractive}$ aggregates the impact factors of the CommoTool. A geographical matching between the CommoTool and $D_{LUEFN\_extractive}$. Since the CommoTool's impact factors are detailed by GLOBIO country, the GLOBIO country/EXIOBASE region correspondence table detailed in appendix (CDC Biodiversité 2019a) is used. The impact factors computed in section 3.2, expressed in MSA.km² per tonnes of pure commodity, are aggregated by EXIOBASE region to evaluate impacts per MEUR for all pressures except climate change related ones (CC and HD_{CC}).

For climate change related pressures (CC and HD_{CC}), we directly use GHG emissions from EXIOBASE environmental extension and apply specific functions explained in the terrestrial (CDC Biodiversité 2020d) and freshwater module papers (CDC Biodiversité 2019b), namely `ghg_get_emission_MSA_impact()` and `ghg_get_emission_MSA_impact_aquatic()`.

6 Limits and perspectives

This version of the Mining CommoTool aims to design the first skeleton of an operational and pragmatic approach to quantify biodiversity impact of mining activities for all types of commodities at a global level. In that context and knowing that publicly available free data can be very scarce for that sector, we had to use proxies and assumptions causing uncertainties, limitations and room for potential improvement. Therefore, we do not aim to be exhaustive about the limits of the methodology here, but rather be selective about the main limitations which should be addressed as they have the biggest impacts on the results and therefore on the potential improvement of the tool.

Limitation on data:

- Mine site data from USGS is old (ranging from 2005 to 2007) and uncomplete, especially for the US where capacities are not reported,

- Ore grades are global averages. Regional or mine site specific figures would be preferred if available,

Limitations reagrding impacts not covered

- Impacts for metallurgical processes are not covered (this includes heap leaching) except climate change related ones,

-Impacts from pollutants are not covered. This includes pollutant emission from mineral and metallurgical processes (including heap leaching), deportment of dusts and particulates, as well as AMD,

- Impacts from accidents such as tailing dams' failures are not covered,

- Impacts from prospection are not covered (only mining and mineral processing impacts are). Before starting a mining activity at a given place, various tests are performed on a much broader perimeter to investigate the mining potential of the concession. These tests involve heavy work and dedicated infrastructures which can be impactful,

- The impacts of surrounding infrastructures associated to the mine site are only partially covered. The CommoTool does use a ratio of surface area dedicated to infrastructures and it increases the impacts calculated based on land conversion (cf. 3.2B). However, the impacts of infrastructures such as access roads or power lines further away in the concession are not covered, and neither are other Scope 1 impacts occurring within the concession but outside of the direct surrounding of the mine itself. For mine sites in remote areas, the impacts of these infrastructures can be significant as they fragment natural habitats and allow an easier access for hunting or logging,

- Cumulative impacts are not considered. Indeed, each pressure adds up, but GLOBIO cause-effect relationships currently do not take into account interactions between them,

- Mine sites' end of life is not taken into account for the moment,

-The specificities of multi-produce mine operations are only partially taken into account. The global capacity of the mine is assessed considering all products, an allocation between the various products being done afterwards based on their respective capacity (see section 3.2.B.3). We are not able at this stage to take into account the consequences in terms of processing (mineral and metallurgical) as our data source regarding processing (PEF) does not provide that level of granularity.

Limitations on methodological choices

- The central, conservative and optimist calculation modes are identical at the moment,

- Only 3 mining techniques are modeled, open-pit, strip and underground mining. More techniques exist and for each of these different management and technical choices are possible. Not breaking down impact factors by techniques limits the accuracy of our assessments,

- The Encroachment impacts on a 10 km buffer zone around mine sites are 100% attributed to mines whereas other sources could also be partly causing them. In the future, the part attributed to mines should be appropriately reduced. Currently, the Encroachment impacts of mining are likely over-estimated,

- Kobayashi and al.'s methodology used to evaluate mine surfaces only takes into account current mine capacity. Mining history should also be considered as, assuming a constant annual production, the older a mine is, the more it expanded over the years. Having historical production data could help us to set a new model on the same rationale than the one we use for land conversion. This way, we could assess historical expansion and therefore current surface. We could not find the necessary data at a global scale,

- Scientific literature for water intensity too US focused. Other sources from other regions of the world should be considered to take into account the variety of techniques and biophysical environment around the world.

Finally, as mentioned earlier, the impacts assessed are not directly connected to the concepts of direct and indirect impacts (as defined in section 1.4) widely used in the mining industries.

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CDC BIODIVERSITÉ | Caisse des Dépôts GROUPE

102, rue Réaumur
75002 PARIS
T. +33 (0)1 80 40 15 00

contact@cdc-biodiversite.fr

www.cdc-biodiversite.fr

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RCS Paris 501 639 587
Siret 501 639 587 00028 - APE 6420Z
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