Metadata: Material Footprint

1. Definition, concepts, and classifications

1.a. Definition

Material Footprint (MF) is the attribution of global material extraction to domestic final demand of a country. The total material footprint is the sum of the material footprint for biomass, fossil fuels, metal ores and non-metallic minerals.

1.b. Indicator concepts

Domestic Material Consumption (DMC) and MF need to be looked at in combination, as they cover the two aspects of the economy, production and consumption. The DMC reports the actual amount of material in an economy, MF the virtual amount required across the whole supply chain to service final demand. A country can, for instance, have a very high DMC because it has a large primary production sector for export or a very low DMC because it has outsourced most of the material intensive industrial process to other countries. The MF corrects for both phenomena.

1.c. Unit of measure

Tonnes.

2. Methodological considerations

2.a. Methodology concept

The Global Footprint Tool combines two main types of information to calculate a country's material footprint (MF). First, it uses national data on physical material extraction (e.g., raw materials extracted within the national territory) that users provide to represent the base material inputs of the economy. Second, the tool uses a global economic model (the GLORIA multi–regional input-output (MRIO) tables) to trace how these materials are embodied in goods and services that are produced, traded, and ultimately consumed or invested across countries and sectors. Using these components, the tool allocates both direct and supply-chain-related material use to national final demand.

2.b. Description of the footprint calculation methodology

The Material Footprint (MF) measures the amount of materials consumed directly and indirectly as a result of economic activities of final demanders, including households, the government and the capital sector. MF includes material consumption from the entire upstream supply chains underlying a national economy. It is derived from input-output data[1] according to:

$$MF = DE + \mathbf{my},$$

[1] Representing the economy as *N* intermediate sectors (e.g. agriculture, forestry, fishing, mining, manufacturing, utilities, construction, trade, transport, services), and *M* final demanders (households, the government and the capital sector).

where DE is materials directly extracted in the domestic economy during the reporting period, $\mathbf{m}$ is a $1\times N$ vector of materials *multipliers* for a range of economic sectors, and $\mathbf{y}$ is an $N\times 1$ vector of final demand of products made by these sectors.

2.c. National users' inputs

To calculate MF using the Global Footprint Tool, the template follows the requirements of Domestic Extraction, Table A of the Economy-Wide Material Flow Accounts (EW-MFA), focusing on four material categories such as A.1 Biomass, A.2 Metal ores, A.3 Non-metallic minerals, and A.4 Fossil fuels.

A.1 Biomass: According to EW-MFA conventions, DE of biomass includes all biomass of vegetable origin extracted by humans and their livestock, capture of wild fish, and the biomass of hunted animals. Biomass of livestock and livestock products (e.g. milk, meat, eggs, hides) is not accounted for as domestic extraction but considered as flows within the economic system.

A.2 Metal ores: For EW-MFA purposes, only that portion of the excavated rock, which is to be processed in some way, to obtain the desired metals, should be counted. This means that any soil or rock which is simply excavated and moved, to gain access to the metal ore itself, should not be counted as ore.

A.3 Non-metallic minerals: If accounted by mass, the vast majority of the materials of this category are sand, gravel, and clay used for construction, while the remainders are used either as decorative stones or for chemicals and fertilizers. Certain materials can be used for either industrial or construction purposes, since there is no clear and distinct differentiation between the two.

A.4 Fossil fuels: Fossil fuels are materials formed from biomass in the geological past and comprise solid, liquid and gaseous materials: coal and peat, crude oil and natural gas, oil shale and tar sands.

More information on EW-MFA is presented in the global manual "UNEP (2023). The use of natural resources in the economy: A Global Manual on Economy-Wide Material Flow Accounting" [10].

The user-provided national data represent the total amount of materials extracted within the national territory during the reporting year. Within the Global Footprint Tool, domestic extraction data are used to construct material intensity coefficients that are fully consistent with the structure of the GLORIA multi-regional input–output (MRIO) model. These coefficients link extracted materials to production activities across sectors and countries. The MRIO framework then traces how domestically extracted and imported materials are embodied along domestic and international supply chains to satisfy national final demand.

2.d. Multi-regional input-output (MRIO) framework

The MRIO data used in the Global Footprint Tool are taken from the GLORIA MRIO database, which provides globally consistent multi-regional Supply–Use / Input–Output tables and associated environmental satellite accounts. The GLORIA structure enables attribution of upstream emissions

across regions and sectors to national final demand, consistent with international statistical standards (SNA and SEEA).

The System of National Accounts ([1], §28.37) states the fundamental input-output relationship as:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y},$$

where $\mathbf{x} = \mathbf{T}\mathbf{1}^{\mathbf{T}} + \mathbf{y}\mathbf{1}^{\mathbf{y}}$ denotes a vector of sectoral *total output*, $\mathbf{T}$ is an *N*×*N* *intermediate demand* matrix, $\mathbf{y}$ is an *N*×*M* *final demand* matrix, $\mathbf{1}^{\mathbf{T}} = \{\underbrace{1, \dots, 1}_{N}\}$ and $\mathbf{1}^{\mathbf{y}} = \{\underbrace{1, \dots, 1}_{M}\}$ are summation operators, $\mathbf{I}$ is an *N*×*N* identity matrix, and $\mathbf{A} = \mathbf{T}\hat{\mathbf{x}}^{-1}$ holds *N*×*N* intermediate *input coefficients*. The *N*×*N* matrix $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is called the *Leontief inverse* (see §28.38 in [1] and §20.F in [2]), which facilitates the analytical power of input-output analysis for the purpose of enumerating footprints. $\mathbf{T}$, $\mathbf{y}$ and $\mathbf{x}$ are standard components of any official national or global input-output database, and $\mathbf{A}$ and $\mathbf{L}$ are derived from these. The Global Footprint Tool makes use of global, multi-regional input-output (MRIO) data (see [3] and §17 in [2]).

In compliance with the System of Environmental-Economic Accounting (see §29.105 in [1] and §13 in [2]), material data distinguishing *K* material types are arranged into a so-called *satellite account* $\mathbf{Q}$, sized *K*×*N*. The combination of material and monetary input-output data enables the calculation of embodied material footprints [4]. Pre-multiplying the fundamental input-output relationship with materials *intensities* $\mathbf{q} = \mathbf{Q}\hat{\mathbf{x}}^{-1}$ yields material footprints *MF* as:

$$\mathbf{q}\mathbf{x} = \mathbf{q}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} =: \mathbf{m}\mathbf{y} = MF.$$

The material *multipliers* are $\mathbf{m} = \mathbf{q}(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{q}\mathbf{L}$, and – as with the Leontief inverse $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ – incorporate the entire supply-chain network underpinning the production of goods and services ultimately consumed by final demanders (§20.K in [2]).

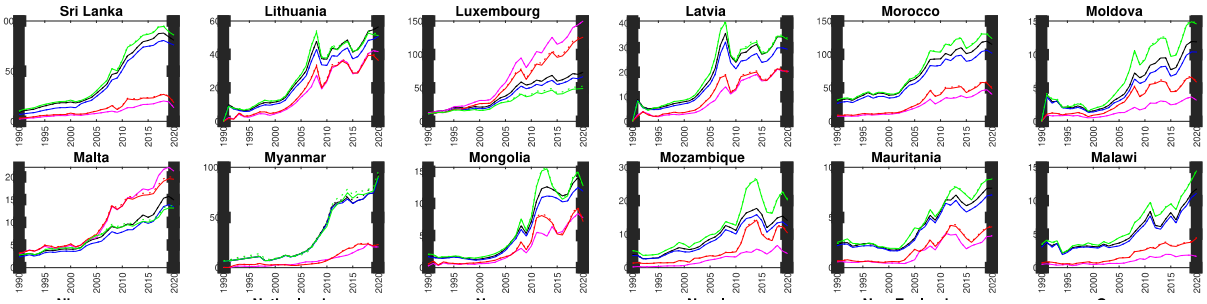
For the attribution of the material footprint of final demand in the Global Footprint Tool, global multi-regional input-output (MRIO) analysis and data are employed (§17 in [2]). The MRIO data are taken from the GLORIA MRIO database [5]. The primary data underlying this database are described in the GLORIA Release Notes. These notes also contain explanations of GLORIA's multi-region Supply-Use structure (see §17.B in [2]), detailed descriptions of compilation procedures, a visualisation of Material Footprint trends for 159 countries (see Annex 1), as well as a plain-English short philosophy of MRIO-building and a plain-English explanation of MRIO-based footprinting.

2.e. Description of the data forecast methodology

Most primary data underlying the GLORIA MRIO database are up-to-date until 2023. The forecast of all monetary tables starting 2024 until 2028 is based on GDP projections by the International Monetary Fund [6] and the World Bank [7]. Satellite entries are forecast by extrapolating a linear fit of the 1990-2023 data.

2.f. Validation

The GLORIA Release Notes contain a number of validation visualisations, for example through a country-by-country comparison of GLORIA aggregates (GDP, value added, imports, exports, labour wages) with corresponding values in the United Nations SNA Main Aggregates database [8] and the ILO labour database [9]. These comparisons illustrate the adherence of GLORIA data and national accounts aggregates.



Excerpt from the GLORIA – UN Main Aggregates comparison.
UN Main Aggregates solid lines, GLORIA dashed lines.

2.g. Quality assurance

The compilation of the GLORIA MRIO database includes a series of Quality Assurance (QA) diagnostics tests. These tests are offered alongside the data download [5] and as excerpts in the Release Notes. These diagnostics tests assure that GLORIA data:

- adhere as much as possible to primary data such as from the United Nations Statistics Division (UNSD), the OECD, the International Labour Organisation (ILO), the United Nations Food and Agriculture organisation (FAO), and the United Nations Industrial Development Organisation (UNIDO);
- yield realistic relationships with physical data; for example (a) dividing GLORIA's monetary wages and salaries data by ILO's employment statistics should yield realistic per-worker wages across various sectors and regions, and (b) dividing GLORIA's monetary household consumption data by FAOSTAT's food balances should yield realistic per-capita energy and macronutrient intakes across various sectors and regions.

3. Data sources

Countries are encouraged to use statistics from the national Economy-Wide Material Flow Accounts (EW-MFA) or, if the country does not develop EW-MFA, national statistics and data on agriculture, forestry and fishing, as well as mining and energy.

International statistical sources for MF include the International Energy Agency, the United Nations Statistical Division, the United States Geological Survey, British Geological Survey, the Food and Agriculture Organization databases.

4. Data availability and disaggregation

4.a. Data availability

The Global Footprint Tool allows to calculate the Material Footprint indicator for 159 countries (see Annex 1).

4.b. Time series

The Material Footprint indicator can be calculated since 1970.

4.c. Disaggregation

The Materials Footprint indicator is disaggregated into 63 material categories (see Annex 2).

5. Comparability / deviation from international standards

The Materials Footprint is calculated in accordance with international standards such as the System of National Accounts 2008, the System of Environmental-Economic Accounting – Central Framework 2012, and the global manual "UNEP (2023). The use of natural resources in the economy: A Global Manual on Economy-Wide Material Flow Accounting".

6. References

[1] UN, System of National Accounts 2008, United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank, New York, USA, 2009.

[2] UNSD, Handbook on Supply, Use and Input-Output Tables with Extensions and Applications, United Nations Statistics Division, New York, USA, 2018.

[3] W.W. Leontief, A.A. Strout, Multiregional input-output analysis, in: T. Barna (Ed.), Structural Interdependence and Economic Development, Macmillan, London, UK, 1963, pp. 119-149.

[4] W. Leontief, D. Ford, Environmental repercussions and the economic structure: an input-output approach, Review of Economics and Statistics 52(3) (1970) 262-271.

[5] M. Lenzen, M. Li, The GLORIA MRIO database, The University of Sydney, Sydney, Australia, 2023.

[6] IMF, Gross domestic product, current prices, 2020-2028, International Monetary Fund, Washington, D.C., USA, 2023.

[7] World Bank, Global Economic Prospects, World Bank,, Washington DC, USA, 2023.

[8] UNSD, National Accounts Main Aggregates Database, United Nations Statistics Division, New York, USA, 2022.

[9] ILO, ILOSTAT - Statistics on employment, International Labour Organization, Genève, Switzerland, 2022.

[10] UNEP. The use of natural resources in the economy: A Global Manual on Economy-Wide Material Flow Accounting. Nairobi, Kenya, 2023.

[11] UN. System of Environmental-Economic Accounting Central Framework (SEEA CF) 2012. United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organisation for Economic Co-operation and Development, the World Bank. New York, USA, 2014.

Annex 1: List of countries for which the Material Footprint indicator can be calculated using the Global Footprint Tool

#	Country acronyms	Country names
1	AFG	Afghanistan
2	AGO	Angola
3	ALB	Albania
4	ARE	United Arab Emirates
5	ARG	Argentina
6	ARM	Armenia
7	AUS	Australia
8	AUT	Austria
9	AZE	Azerbaijan
10	BDI	Burundi
11	BEL	Belgium
12	BEN	Benin
13	BFA	Burkina Faso
14	BGD	Bangladesh
15	BGR	Bulgaria
16	BHR	Bahrain
17	BHS	Bahamas
18	BIH	Bosnia and Herzegovina
19	BLR	Belarus
20	BLZ	Belize
21	BOL	Bolivia
22	BRA	Brazil
23	BRN	Brunei Darussalam
24	BTN	Bhutan
25	BWA	Botswana
26	CAF	Central African Republic
27	CAN	Canada
28	CHE	Switzerland
29	CHL	Chile
30	CHN	China
31	CIV	Cote d'Ivoire
32	CMR	Cameroon
33	COD	DR Congo
34	COG	Rep Congo
35	COL	Colombia
36	CRI	Costa Rica
37	CUB	Cuba
38	CYP	Cyprus
39	CZE	Czech Republic
40	DEU	Germany

41	DJI	Djibouti
42	DNK	Denmark
43	DOM	Dominican Republic
44	DZA	Algeria
45	ECU	Ecuador
46	EGY	Egypt
47	ERI	Eritrea
48	ESP	Spain
49	EST	Estonia
50	ETH	Ethiopia
51	FIN	Finland
52	FRA	France
53	GAB	Gabon
54	GBR	United Kingdom
55	GEO	Georgia
56	GHA	Ghana
57	GIN	Guinea
58	GMB	Gambia
59	GNQ	Equatorial Guinea
60	GRC	Greece
61	GTM	Guatemala
62	HND	Honduras
63	HKG	Hong Kong
64	HRV	Croatia
65	HTI	Haiti
66	HUN	Hungary
67	IDN	Indonesia
68	IND	India
69	IRL	Ireland
70	IRN	Iran
71	IRQ	Iraq
72	ISL	Iceland
73	ISR	Israel
74	ITA	Italy
75	JAM	Jamaica
76	JOR	Jordan
77	JPN	Japan
78	KAZ	Kazakhstan
79	KEN	Kenya
80	KGZ	Kyrgyzstan
81	KHM	Cambodia
82	KOR	South Korea
83	KWT	Kuwait
84	LAO	Laos
85	LBN	Lebanon

86	LBR	Liberia
87	LBY	Libya
88	LKA	Sri Lanka
89	LTU	Lithuania
90	LUX	Luxembourg
91	LVA	Latvia
92	MAR	Morocco
93	MDA	Moldova
94	MDG	Madagascar
95	MEX	Mexico
96	MKD	Macedonia
97	MLI	Mali
98	MLT	Malta
99	MMR	Myanmar
100	MNG	Mongolia
101	MOZ	Mozambique
102	MRT	Mauritania
103	MWI	Malawi
104	MYS	Malaysia
105	NAM	Namibia
106	NER	Niger
107	NGA	Nigeria
108	NIC	Nicaragua
109	NLD	Netherlands
110	NOR	Norway
111	NPL	Nepal
112	NZL	New Zealand
113	OMN	Oman
114	PAK	Pakistan
115	PSE	Palestine
116	PAN	Panama
117	PER	Peru
118	PHL	Philippines
119	PNG	Papua New Guinea
120	POL	Poland
121	PRK	North Korea
122	PRT	Portugal
123	PRY	Paraguay
124	QAT	Qatar
125	ROU	Romania
126	RUS	Russian Federation
127	RWA	Rwanda
128	SAU	Saudi Arabia
129	SDS	South Sudan
130	SEN	Senegal

131	SGP	Singapore
132	SLE	Sierra Leone
133	SLV	El Salvador
134	SOM	Somalia
135	SRB	Serbia
136	SDN	Sudan/North Sudan (2010/2011)
137	SVK	Slovakia
138	SVN	Slovenia
139	SWE	Sweden
140	SYR	Syria
141	TCD	Chad
142	TGO	Togo
143	THA	Thailand
144	TJK	Tajikistan
145	TKM	Turkmenistan
146	TUN	Tunisia
147	TUR	Turkey
148	TZA	Tanzania
149	UGA	Uganda
150	UKR	Ukraine
151	URY	Uruguay
152	USA	United States of America
153	UZB	Uzbekistan
154	VEN	Venezuela
155	VNM	Viet Nam
156	YEM	Yemen
157	ZAF	South Africa
158	ZMB	Zambia
159	ZWE	Zimbabwe

Annex 2: List of 63 material categories

#	Material
1	Rice
2	Wheat
3	Maize
4	Cereals n.e.c.
5	Roots, tubers
6	Sugar crops
7	Pulses
8	Nuts
9	Oil bearing crops
10	Vegetables
11	Fruits

12	Fibres
13	Spice, beverage, pharmaceutical crops
14	Tobacco
15	Other crops n.e.c.
16	Straw
17	Other crop residues (sugar and fodder beet leaves, other)
18	Fodder crops (including biomass harvest from grassland)
19	Grazed biomass
20	Timber (Industrial roundwood)
21	Wood fuel and other extraction
22	Wild fish catch
23	All other wild aquatic animals catch
24	Wild aquatic plant harvest
25	Wild terrestrial plant harvest n.e.c. (incl. gathering)
26	Wild terrestrial animal catch (incl. hunting)
27	Iron ores concentrates and compounds
28	Aluminium ores concentrates and compounds
29	Silver ores concentrates and compounds
30	Gold ores concentrates and compounds
31	Chromium ores concentrates and compounds
32	Copper ores concentrates and compounds
33	Manganese ores concentrates and compounds
34	Nickel ores concentrates and compounds
35	Lead ores concentrates and compounds
36	Platinum group metal ores concentrates and compounds
37	Tin ores concentrates and compounds
38	Titanium ores concentrates and compounds
39	Uranium ores concentrates and compounds
40	Zinc ores concentrates and compounds
41	Other metal ores concentrates and compounds nec. including mixed
42	Ornamental or building stone
43	Chalk
44	Dolomite
45	Limestone
46	Chemical and fertilizer minerals
47	Salt
48	Gypsum
49	Structural clays
50	Specialty clays
51	Industrial sand and gravel
52	Sand and gravel for construction
53	Other non-metallic minerals n.e.c.
54	Lignite (brown coal)
55	Other sub-bituminous coal
56	Anthracite

57	Coking coal
58	Other bituminous coal
59	Peat
60	Crude oil
61	Natural gas
62	Natural gas liquids
63	Oil shale and tar sands