Materials metadata

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. 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 material footprint corrects for both phenomena.

1.c. Unit of measure

Tonnes

2. Methodological considerations

2.a. Description of the footprint calculation methodology

A Materials Footprint *MF* measures the amount of materials consumed directly and indirectly as a result of economic activities of final demanders, that is households, the government and the capital sector. Material footprints include material consumption from the entire upstream supply chains underlying these economic activities. They are derived from input-output data[1] according to

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

where DE are materials directly consumed by households, $\mathbf{m}$ 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.b. Multi-regional input-output (MRIO) framework

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

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

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

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 UNEP Footprint Tool makes use of global, multi-regional input-output (MRIO) data (see [3] and §17 in [2]).

In compliance with the United Nations' System of Environmental and 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* **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]).

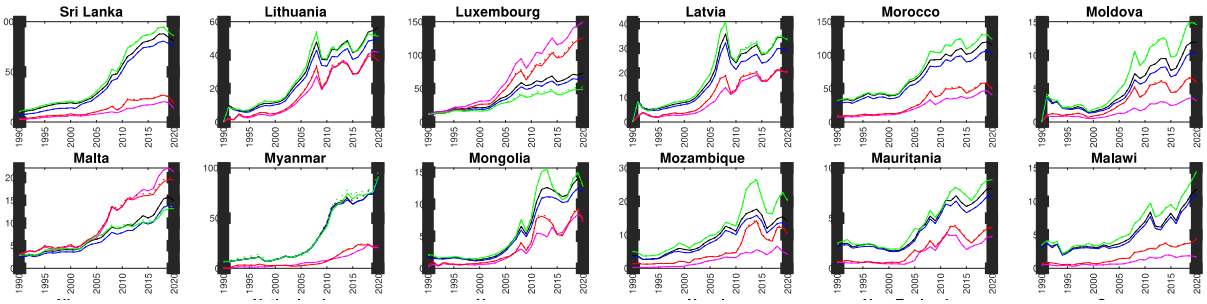
For the attribution of the material footprints of final demand in the UNEP Footprint Tool, global multi-regional input-output (MRIO) analysis and data are employed (§17 in [2]). The MRIO data are taken from the GLORIA MRIO database [5]. The primary data underlying this database are described in the GLORIA 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 Materials Footprint trends for all 164 regions and countries, as well as a plain-English short philosophy of MRIO-building and a plain-English explanation of MRIO-based footprinting.

2.c. Description of the data forecast methodology

Most primary data underlying the GLORIA database are up-to-date until 2021. The forecast of all monetary tables starting 2022 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 1990-2021 data.

2.d. 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.e. 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 Statistical 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

3.a. Data sources

The global estimation for MF is based on data available from different national and international datasets in the domain of material flow accounts, agriculture, forestry, fisheries, mining and energy statistics. 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 and COMTRADE databases.

3.b. Data compilation methods

Raw material extraction data from UN IRP Global Material Flows Database [10] are used. The publicly available online database presents domestic extraction data for four main material categories (with seven additional categories for trade) and provides further disaggregation of these four main domestic extraction categories into 13 sub-categories (with an additional nine categories for trade). The process of collating and /or modelling of data was actually performed at a much higher level of disaggregation, using a classification system with 367 different categories.

Material data in their primary form are mapped from their native regional and sectoral classifications to the 164 regions and 120 sectors adapted in the UNEP Footprint Tool. This mapping is achieved by using a concordance matrix, i.e. a binary matrix that bridges between two classifications, showing values of 1 wherever there is a connection between two regions/sectors from different classifications, and 0 otherwise.

More details on the UN IRP Global Material Flows Database and access to the data are available at https://www.resourcepanel.org/global-material-flows-database.

4. Data availability and disaggregation

4.a. Data availability

The data cover 164 countries.

4.b. Time series

The Materials Footprint data set covers a time period of 59 years (1970-2028).

4.c. Disaggregation

The Materials Footprint indicator is disaggregated into 63 material categories.

5. Comparability / deviation from international standards

The Materials Footprint is calculated in accordance with international standards, recommendations, and classifications such as the System of National Accounts 2008, the System of Environmental-Economic Accounting – Central Framework 2012, the Balance of Payments and International Investment Position, the International Standard Industrial Classification of All Economic Activities (ISIC), the Central Product Classification (CPC) and the Framework for the Development of Environment Statistics.

5. 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.
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[10] UN IRP, 2021. Global Material Flows Database: Version 2021. International Resource Panel. , Paris. Available at http://www.resourcepanel.org/global-material-flows-database