GHG emissions metadata

1. Definition, concepts, and classifications

1.a. Definition

Carbon Footprint (CF) is the attribution of global greenhouse gases (GHG) emissions to domestic final demand of a country. The total carbon footprint is the sum of the carbon footprint for carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6).

1.b. Concepts

CF reports the amount of GHG emissions emitted across the whole supply chain to service final demand. A country can, for instance, have a higher CF than territorial emissions if it has outsourced most of the emission-intensive industrial processes to other countries.

1.c. Unit of measure

kilotonnes of carbon dioxide equivalents (kt CO_2-e)

2. Methodological considerations

2.a. Description of the footprint calculation methodology

A carbon footprint *CF* measures the amount of GHG emitted directly and indirectly as a result of economic activities of final demanders, that is households, the government and the capital sector. Carbon footprints include emissions from the entire upstream supply chains underlying these economic activities. They are derived from input-output data[1] according to

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

where DE are GHG directly emitted by households (eg through the combustion of petrol in private cars or combustion of gas in household appliances), $\mathbf{m}$ is a $1\times N$ vector of GHG emissions *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 ([7], §28.37) states the fundamental input-output relationship as

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

[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).

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 [7] and §20.F in [8]), 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 [9] and §17 in [8]).

in compliance with the United Nations' System of Environmental and Economic Accounting (see §29.105 in [7] and §13 in [8]), emissions data distinguishing *K* emission types are arranged into a so-called *satellite account* **Q**, sized *K*×*N*. The combination of emissions and monetary input-output data enables the calculation of embodied emissions and carbon footprints [10]. Pre-multiplying the fundamental input-output relationship with GHG emissions *intensities* $\mathbf{q} = \mathbf{Q}\hat{\mathbf{x}}^{-1}$ yields carbon footprints *CF* as

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

The carbon *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 [8]).

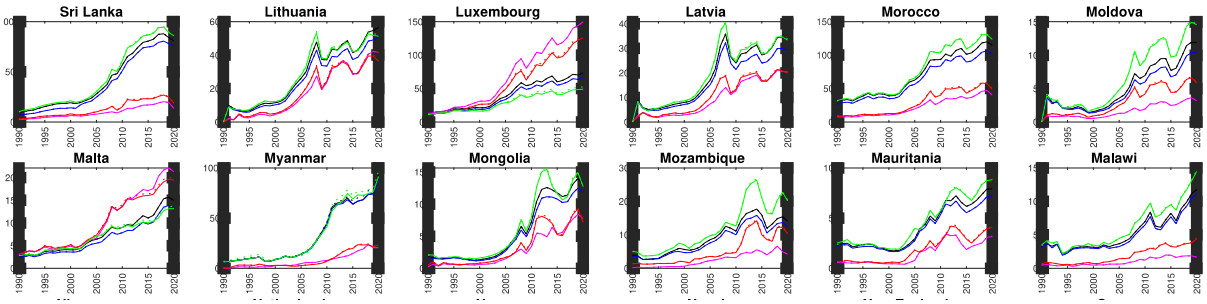
For the attribution of the GHG emissions to carbon footprints of final demand in the UNEP Footprint Tool, global multi-regional input-output (MRIO) analysis and data are employed (§17 in [8]). The MRIO data are taken from the GLORIA MRIO database [11]. The primary data underlying this database are described in the GLORIA Release Notes. These notes also contain explanations of GLORIA's multi-region Supply-Use structure (see §17.B in [8]), detailed descriptions of compilation procedures, a visualisation of carbon 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 2027 is based on GDP projections by the International Monetary Fund (IMF 2022) and the World Bank (World Bank 2023a). 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 [12] and the ILO labour database [13]. 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 [11] 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

Countries' emissions data are based on primary GHG emissions data available from the EDGAR database [1], covering 210 countries/regions, and from the OECD emissions database [2], covering 40 OECD countries. The latter are identical with emissions data reported by Eurostat [3].

3.b. Data compilation methods

Constructing an emissions satellite account (see Section 2.b) for the GLORIA database requires arranging primary emissions data into *activities* (rows) and *emitting industry sectors* (columns).

GHG emissions data in their primary form are mapped from their native regional and sectoral classifications to the 164 regions and 20 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.

The mapping procedure makes use of both the EDGAR and OECD data sources. More specifically, EDGAR's *activity* values are mapped into OECD's *industries*, using detailed definitions of activity reporting items from

the IPCC Guidelines for National Greenhouse Gas Inventories [4], and corresponding ISIC industries from the UN's International Standard Industrial Classification of All Economic Activities (ISIC) [5]. Additional data sources [6] were consulted to split aggregate road transport emissions into private vehicles (allocated to households), and commercial road freight, buses and taxis, and postal and courier services. The final GHG emissions data adhere to EDGAR *activity* totals but incorporate OECD's *industry* splits.

4. Data availability and disaggregation

4.a. Data availability

The data cover 164 countries.

4.b. Time series

The Carbon Footprint data set covers a time period of 38 years (1990-2027).

4.c. Disaggregation

The Carbon Footprint indicator is disaggregated into four main GHG categories (CO2, CH4, N2O and Other GHGs).

5. Comparability / deviation from international standards

The Carbon 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] EC (2021) Emission Database for Global Atmospheric Research (EDGAR), release version 7.0. Internet site https://data.jrc.ec.europa.eu/collection/edgar, Bruxelles, Belgium, European Commission Joint Research Centre (JRC).
[2] OECD (2023) Air and GHG emissions. Internet site https://data.oecd.org/air/air-and-ghgemissions.htm, Paris, France, OECD.
[3] Eurostat (2023) Greenhouse gas emission statistics - emission inventories. Internet site: https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Greenhouse_gas_emission_statistics_-_emission_inventories, Bruxelles, Belgium, European Commission.
[4] IPCC, Reporting Guidance and Tables, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Geneva, Switzerland, 2006.
[5] UNSD, International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4, United Nations Department of Economic and Social Affairs, Statistics Division, Statistical papers Series M No.4/Rev.4, ST/ESA/STAT/SER.M/4/Rev.4, New York, USA, 2008.
[6] F. Pomponi, M. Li, Y.-Y. Sun, A. Malik, M. Lenzen, G. Fountas, B. D'Amico, O. Akizu-Gardoki, M. Luque Anguita, A Novel Method for Estimating Emissions Reductions Caused by the Restriction of Mobility: The Case of the COVID-19 Pandemic, Environmental Science & Technology Letters 8(1) (2021) 46-52.

[7] 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.
[8] UNSD, Handbook on Supply, Use and Input-Output Tables with Extensions and Applications, United Nations Statistics Division, Studies in Methods Series F No.74, Rev.1, New York, USA, 2018.
[9] 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.
[10] W. Leontief, D. Ford, Environmental repercussions and the economic structure: an input-output approach, Review of Economics and Statistics 52(3) (1970) 262-271.
[11] M. Lenzen, M. Li, The GLORIA MRIO database, The University of Sydney, Release 058, https://ielab.info/resources/gloria/supportingdocs, Sydney, Australia, 2023.
[12] UNSD, National Accounts Main Aggregates Database, United Nations Statistics Division, Internet site https://unstats.un.org/unsd/snaama/, New York, USA, 2022.
[13] ILO, ILOSTAT - Statistics on employment, International Labour Organization, Internet site https://ilostat.ilo.orghttps://ilostat.ilo.org/topics/employment/, Genève, Switzerland, 2022.