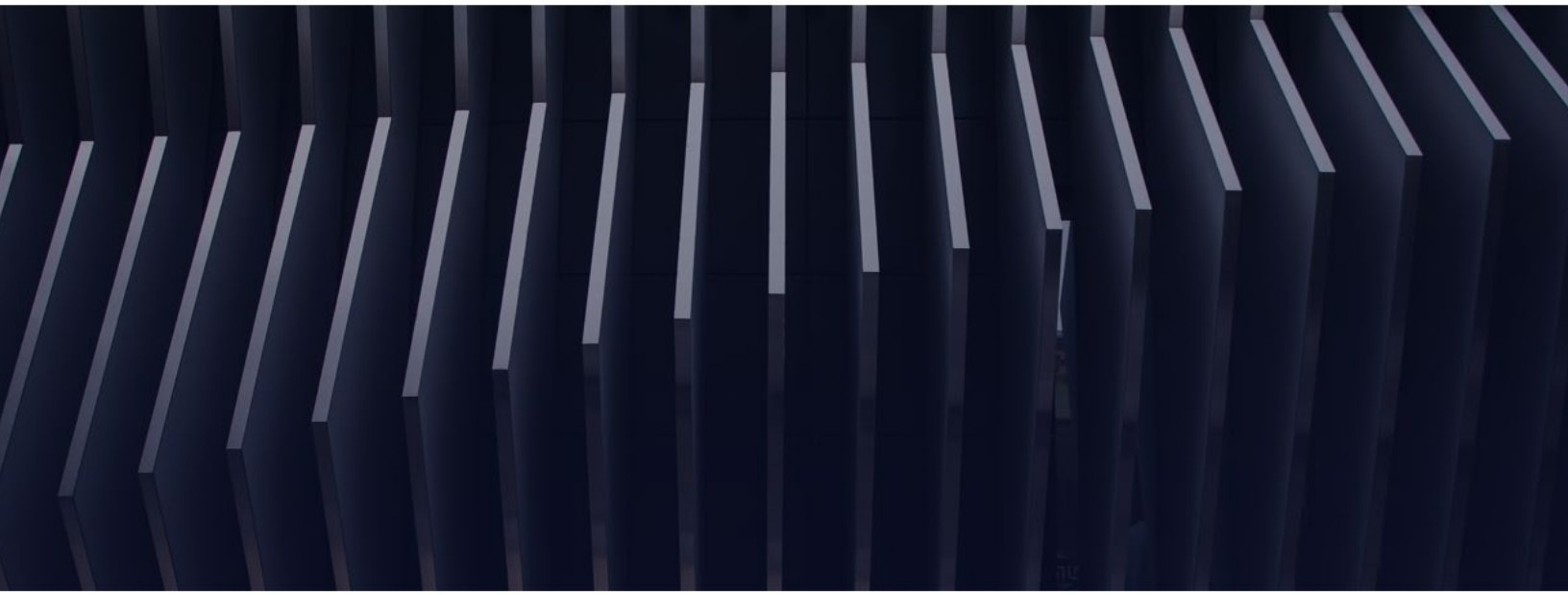
Wilshire Indexes

Carbon Emissions Model

March 2024



Contents

1 Introduction

The Wilshire Indexes Carbon Emissions Model provides comprehensive data on Scope 1, Scope 2 and Scope 3 emissions for any company. The emissions data results from a rigorous hierarchical selection process that combines both reported and estimated data (when no reported data is available or validated). The process and input data used are detailed in the next sections.

2 Definitions

2.1 Common Definitions

The following definitions are based on the GHG Protocol[1].

GHG (Greenhouse Gas): GHG are gases in the atmosphere such as carbon dioxide, methane and nitrous oxide that absorb and emit radiant energy, thus causing the greenhouse effect.

Carbon emissions: the GHG emissions caused by a company expressed in terms of CO2 equivalent (CO2eq) units, according to the IPCC and related official documentation.

Scope 1: direct carbon emissions emitted by a company during the production process.

Scope 2: indirect carbon emissions of a company linked to its energy-use during the production process. Note that Scope 2 emissions can be either "location-based" (calculated from the energy that the company has physically drawn from the energy grid) or "market-based" (calculated from the proportion and type of energy purchased by the company on the market)[2]. For reporting companies, the sustained value is "market-based". For non-reporting companies, estimates are "location-based".

Scope 3: indirect GHG emissions that occur upstream or downstream of the production chain of a company. These include emissions required to produce raw material used by a company or emissions associated with using products sold by a company. Scope 3 emissions are divided into 15 categories as detailed in Appendix C.

Reported carbon emissions: carbon emissions figures disclosed by a company.

Carbon intensity: the carbon emissions produced per unit of a monetary or physical metric. , The most common monetary metrics are carbon intensity per unit of sales or revenues, market value (MV), or enterprise value (EV, or EVIC if cash is included).

Fiscal year: the one-year period that companies use for accounting purposes to prepare financial statements. Note that not all fiscal years correspond with the calendar year.

NAICS (North American Industry Classification System)[3]: The North American Industry Classification System (NAICS) is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy. NAICS was developed under the auspices of the Office of Management and Budget (OMB) and adopted in 1997 to replace the Standard Industrial Classification (SIC) system. It was developed jointly by the U.S. Economic Classification Policy Committee (ECPC), Statistics Canada, and Mexico's Instituto Nacional de Estadistica y Geografia, to allow for a high level of comparability in business statistics among the North American countries.

[1] https://ghgprotocol.org/standards

[2] https://ghgprotocol.org/scope_2_guidance

[3] https://www.census.gov/naics/

NACE[4]*:* The Statistical classification of economic activities in the European Union (EU), abbreviated as NACE,is derived from the French Nomenclature statistique des Activités Economiques dans la Communauté Européenne. Various NACE versions have been developed since 1970.

Multi-Regional Input Output (MRIO) model: a MRIO model gathers all monetary flows between the major economic sectors of geographic regions. It is one of the most powerful tools used in macroeconomics to illustrate, calculate, and predict the interrelations between various activities and economic players.

Environmentally-Extended MRIO (EE-MRIO) model: an EE-MRIO model associates environmental accounts to monetary flows from MRIO, such as the direct GHG emissions from each economic sector of each geographic region during the production process.

2.2 Specific Definitions

Specific definitions are the definitions that are used by Wilshire Indexes in its internal processes.

Self-Reported data: carbon emission data that is publicly disclosed by the emitters (companies), whether they have been quality-checked or not by an external third-party. Self-Reported data is collected from time to time by various data providers and vendors, and is usually attached to a specific fiscal year.

Reported-Derived data: carbon emission data that is not directly disclosed by emitters, but is derived directly from Self-Reported data using basic interpolation (between two years) or extrapolation (derived from the two years immediately before), according to a general proxy (net sales or revenues). For Scope 3, given the limited historical coverage, we extrapolate backwards or forwards from the latest known reported emissions. Reported-Derived data is considered as part of the Reported data family, and not Estimated data. Reported-Derived data only depends on data specifically linked to the emitter (net sales or revenues, previous carbon emissions).

Estimated Data: Estimated data encompasses all carbon emissions data that is neither Self-Reported nor Reported-Derived data. Estimated data is the output of specific modelling based on macro-economic perspectives or statistical analysis of peer-groups.

Final Dataset: refers to the final dataset which assigns emission data to a company and a fiscal year, either reported or estimated.

3 Sources and Input Data

3.1 Reported Carbon Emissions Data

3.1.1 Self-Reported Carbon Data

Self-Reported corporate carbon emissions data is sourced from the ISS Climate Core dataset. It contains self-reported emissions data collected by ISS from all available sources, including company CSR and annual reports, and other direct sources of emissions data. The dataset also integrates carbon emissions data from the Carbon Disclosure Project (CDP).

3.1.2 Reported-Derived Carbon Data

To expand the coverage of reported carbon emissions, Reported-Derived emissions data is computed either by interpolating data between two reported years or by extrapolating previous carbon emission data, using computed revenue carbon intensity and current net sales or revenue in USD from no earlier than two years previously. For Scope 3, given the limited historical coverage, we extrapolate backwards or forwards from the latest known reported emissions.

[4] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)

3.2 Wilshire Indexes Global Asset Taxonomy System

The Wilshire Indexes Global Assets Taxonomy System (GATS) is a hierarchical industry classification system that is comprehensive, adaptive, flexible and incorporates green technology identification. GATS classifies companies according to their specific use case or utility within a given industry enabling a more nuanced view of an economy to be obtained.

GATS has a hierarchical structure:

- 11 industries,
- 35 supersectors,
- 59 sectors,
- 181 subsectors.

Companies are classified via an automated process:

1. Raw product segments[5] disclosed by companies are translated into NAICS segments
2. NAICS segments are aggregated at subsector level
3. The primary subsector assigned to a company is the subsector from which its revenue mainly comes.

For more details, see Wilshire Indexes Global Assets Taxonomy System.

3.3 Fundamental Data

3.3.1 Net Sales or Revenues in USD

For industrials, "Net Sales or Revenues" represents gross sales and other operating revenue less discounts, returns and allowances. For banks, insurance, and other financial companies, it represents the total operating revenue of the company.

Note that all the financial statements reported by companies in local currency are converted to USD using the exchange rate given in the statements, or where it is not available, using the fiscal year-end exchange rate linked to the country of primary listing of the shares traded by the company.

3.3.2 Other Data

Companies are assigned to the country in which the corporate office of a company is located.

Fiscal years and associated fiscal periods start and end dates that are used in the process are initially sourced from our data provider. However, when there are missing fiscal years for a company, a fiscal period is created which starts at the end of the latest available fiscal period and ends at the beginning of the next available one. Note that before applying this, checks are made to ensure that the company is active during the created period and that the dates of the initial periods are not consecutive.

[5] Raw product segments represent the revenue as disclosed by a company from each of its product lines.

3.4 Environmentally Extended Multi-Regional Input Output model (EE-MRIO)

The Exiobase[6] v.3 dataset is the Environmentally Extended Multi-Regional Input Output model (EE-MRIO) used, in part, to estimate non-reported carbon emissions. Key features of this dataset can be found in the table below:

Key features of Exiobase3

Number of countries and geographic regions	Number of economic sectors	Economic sectors classification	Currency of monetary data
44 countries* **5 Rest of World regions***	163 industries	NACE Rev. 1.1 except energy-linked sectors	EUR[7]

*Source: Exiobase. *See Appendix A for a detailed list of Exiobase countries and regions.*

4 Methodology

4.1 Overview

There are a variety of models and approaches available for estimating missing carbon emission data. The fundamental reason why these models are still employed lies with the limited proportion of companies reporting and disclosing their emissions for the various scopes. Despite significant progress over time and increased regulation asserting the material risk either in producing emissions (climate change risk) or failing to report such emissions (transparency & litigation risk), investors wanting a comprehensive view of the investment universe must continue to make substantial use of models that estimate non-reported emission data.

Such models are usually characterized according to two perspectives:

1. Is the model derived from a top-down, macro-economic view linking economies, sectors, and emitters together? Or is it derived from bottom-up observations related to some peer-group average?
2. Regarding the potential breakdown of activities of the emitter and its specific carbon intensity factors, is the emitting company considered as a portfolio of separate activities (multi-segment) or as a pure play (one-segment only)?

[6] Exiobase is a global, detailed Multi-Regional Environmentally Extended Supply-Use Table (MR-SUT) and Input-Output Table (MR-IOT). It was developed by harmonizing and detailing supply-use tables for a large number of countries, estimating emissions and resource extractions by industry. Exiobase was developed by a consortium of several research institutes in projects financed by the European research framework programs. Three versions of Exiobase are available. (https://www.exiobase.eu/)

[7] To make Exiobase data, in EUR, comparable with segments data, in USD, the EUR to USD exchange rate from the OECD exchange rate table (https://data.oecd.org/conversion/exchange-rates.htm) is applied to the Exiobase monetary figures.

This is summarized in the following table.

Comparing the modelling strategies

	Top-Down Approach	Bottom-Up Approach
Corporates as One-Segment Only	Examples: - Meta Sector Analysis (factor coefficients)	Examples: - Median/Mean - 1Factor / Multifactor Regression analysis
Corporates as Multi-Segment Portfolio	Examples: - EE-MRIO	Examples: - Interpolation

Source: Wilshire Indexes (NB. The list of solutions presented here is not exhaustive and displayed only for illustrative purpose).

The Wilshire Indexes Carbon Emissions model covers the two main, complimentary types of solutions:

- A Bottom-Up Approach applied to companies viewed as One-Segment Only, with multi-level weighted adjusted-median estimates, and
- A Top-Down Approach applied to companies viewed as Multi-Segment Portfolios, with the EE-MRIO-based estimated data and the model for estimating Scope 3 emissions.

Additionally, a third-party estimate (from ISS) is also introduced into the final estimate computation, to increase the stability across sectors and over time.

4.2 Notational Definitions

The following definitions are used throughout this methodology document:

$C_{i,t}^{r}$: self-reported r carbon emissions of a company i for the fiscal year t (see section 3.1.1),

$C_{i,t}^{rd}$: reported-derived rd carbon emissions of a company i for the fiscal year t (see section 3.1.2),

$C_{i,t}^{e}$: estimated e carbon emissions of a company i for the fiscal year t (see sections 4.4, 4.5 and 4.6),

$Revenue_{i,t}$: Net Sales or Revenue in USD of a company i for the fiscal year t,

$CI_{i,t}^{emissions\ type} = \frac{C_{i,t}^{emissions\ type}}{Revenue_{i,t}}$: revenue-based carbon intensity of a company i for the fiscal year t. Note that "emissions type" may be either self-reported, reported-derived or estimated.

Each symbol can refer to scope 1, scope 2 or scope 3 emissions.

4.3 Quality Control of Reported Data (Scope 1&2)

Before integrating reported data into the Final Dataset, the influence of outlier carbon data points is moderated through the application of the following Winsorisation process performed at GATS sector Level 3.

For each GATS sector with at least 2 companies reporting revenue-based carbon intensity, 1st and 95th percentiles are calculated. Any company's reported carbon intensity below the 1st percentile is then set to the 1st percentile. Any company's reported carbon intensity above the 95th percentile is set to the 95th percentile.

For GATS sectors with fewer than 2 reporting companies the company's revenue-based carbon intensities are left unchanged.

4.4 Estimated Data from a Third Party

The ISS Climate Core dataset includes estimated carbon emissions data for non-reporting companies. These estimates are based on the ISS classification system which allows benchmarking of non-reporting companies against their reporting peers. They are denoted below by $C_{i,t}^{iss}$.

For an overview of the methodology used by ISS, please see their Carbon Footprint Assessments methodology document available on request from ISS Climate Solutions.

4.5 Estimated Data from Wilshire Indexes

In addition to third-party data, Wilshire Indexes has developed its own estimation model for assigning carbon emissions data to non-reporting companies. Data is estimated using a process based on the combination of three strategies detailed below.

Note that the process estimates Scope 1 and Scope 2 location-based emissions and Scope 3 emissions for all companies. In particular, Scope 2 emissions estimates are mainly derived from intensity factors based on the location of the company.

4.5.1 Median-based estimated data for Scope 1 and Scope 2

This estimation strategy is based on the various medians of reported revenue-based measure of carbon intensity computed at each GATS sectoral level, whether it is industry, supersector, sector, or subsector.

The principle is that each company's carbon intensity can be approximated by various peer groups that can be considered at different levels within the GATS taxonomy (industry, supersector, sector and subsector).

A wider peer group (e.g. at industry level) will give a carbon intensity proxy which will be more stable, while a narrower peer group will give a carbon intensity proxy likely more representative of the specific characteristics of similar companies but less stable over time.

With a multi-level weighted median (described below), a corporate carbon intensity will be simultaneously approximated by the four sector level intensity medians, according to the merits (peer group size, representativeness) of each level.

Adjusted median of reported carbon intensity

Based on controlled reported revenue-based measure of carbon intensities, we compute medians for each sectoral activity s at each GATS level l ($Median\ CI^{s_l}$). We also count the overall size of each sectoral activity in each GATS level ($Size^{s_l}$) as well as the number of companies with an available controlled reported revenue intensity figure ($Reported\ Size^{s_l}$).

As stated in section 3.2, GATS has a hierarchical structure with four levels: $l = [1,2,3,4]$. Therefore, a company is assigned a unique subsector s_4 at level 4, a unique sector s_3 at level 3, a supersector s_2 at level 2 and an industry s_1 at level 1.

For each company i and fiscal period t, we derive from the size and the number of companies with reported data in each of the sectoral levels s_l assigned to the company, an adjustment coefficient regarding the size of its subsector s_4:

$$Adjustment\ Size_{i,t}^{s_l} = \frac{Size_{i,t}^{s_4} * Reported\ Size_{i,t}^{s_l}}{(Size_{i,t}^{s_l})^2}$$

This coefficient reflects the representativeness of each sectoral level in GATS regarding the corresponding subsector. Please see Appendix A for a detailed example of the computation.

Furthermore, to minimize the impact of potential abnormal changes of the sectoral median from one fiscal period to the next, we use a 3-year trailing average to smooth every median of each sectoral level assigned to a company:

$$Smooth\ Median\ CI_{i,t}^{s_l} = \frac{\sum_{t=1}^{3} Median\ CI_{i,t}^{s_l}}{3}$$

The adjusted median of reported carbon intensity of company i for a fiscal period t is then the average of the smoothed medians of the four sectoral levels assigned to it, weighted by the corresponding adjustment size coefficients:

$$Adjusted\ Median\ CI_{i,t} = \frac{\sum_{l=1}^{4} Adjustment\ Size_{i,t}^{s_l} * Smooth\ Median\ CI_{i,t}^{s_l}}{\sum_{l=1}^{4} Adjustment\ Size_{i,t}^{s_l}}$$

Multi-level weighted adjusted-median estimates

The median-based estimated carbon emissions data for a company i and a fiscal period t is the product of its adjusted median of reported carbon intensity and its net sales or revenue in USD:

$$C_{i,t}^{e\ median} = Adjusted\ Median\ CI_{i,t} * Revenue_{i,t}$$

4.5.2 EE-MRIO-based estimated data for Scope 1 and Scope 2: overview

The second carbon model, used to compliment the multi-level weighted adjusted-median estimates described in Section 4.5.1, is based on an Environmentally-Extended Multi-Regional Input-Output (Exiobase) table; this allows sectors and countries to be linked together with the Greenhouse Gas emissions generated and exchanged between them.

In this model, a vector of carbon coefficients per monetary unit can be computed for each sector / country in the table and then applied to the vector of revenues (revenue segment breakdown) of each company. The dot product of those two vectors is computed and aggregated for assessing and estimating the total GHG (in CO2eq) corresponding to the total revenues generated by the company.

The sector classification here is NAICS, the US industrial classification that supports GATS.

For technical details on how Exiobase is used and for the matrix computation, please see Appendix B.

Adjusted MRIO estimates

The final set of MRIO-based carbon emissions data are derived from the raw MRIO estimates by adjusting them by their distance from reported peers at the industry level. More precisely, based on the companies with both reported and MRIO-based figures in each GATS industry (level 1), an MRIO adjustment coefficient ($\beta^{industry}$) is derived from the distance between MRIO-based figures and their reported peers.

Finally, this adjustment coefficient is applied to the raw MRIO estimates to obtain the final MRIO-based carbon emissions:

$$C_i^{e\ mrio} = Raw\ C_i^{e\ mrio} * \beta_i^{industry}$$

where $industry$ is the GATS industry assigned to the company i and $\beta_i^{industry}$ the adjustment coefficient associated to the company i.

4.5.3 Estimated data for Scope 3

Modeling Scope 3 emissions poses challenges due to its scope falling beyond a company's direct activities, leading to limited reported data availability. To enhance accuracy and coverage, we integrate various models. These include:

Third-party estimates

In addition to self-reported emissions, we receive Scope 3 GHG emissions estimates from the ISS Climate Core dataset. The methodology was established in 2010 in collaboration with researchers from ETH Zurich; sector and sub sector specific

models were developed. Readers interested in the full Carbon Footprint methodology can request it here ISS Climate Solutions.

GHG emissions estimates are refined by computing the average between the intensity and median intensity over the preceding three years. This process serves to mitigate year-on-year fluctuations. To address outliers, any intensity falling below one-third or exceeding three times the median intensity is substituted with the median intensity.

Multi-level weighted median estimates

A limitation of the median approach is the choice of the peer group used for estimation. A wide group, at the industry level, is more stable over time but does not account for sectoral specificities. A narrow group, at the subsector level, will give more accurate results but is sensitive to outliers if the subsector's size is limited.

As such, the Scope 3 median-based carbon emissions model follows a similar logic to Scope 1&2's estimation strategy. We leverage the reported revenue-based carbon intensity to account for the relationship between emissions and revenues and control for the limited reporting by using different sector levels.

The multi-median revenue-based carbon intensity is calculated using the median intensity at the subsector and sector level (respectively GATS level 4 and 3). To control for potential outliers at the subsector level, intensities are weighted with respect to the number of reporting companies in the following manner:

$$CI_t^{e\ median,s} = \frac{(Reported\ Size_t^s * Median\ CI_t^s) * (Reported\ Size_t^{s_3-s} * Median\ CI_t^{s_3}))}{(Reported\ Size_t^{s_3})}$$

where:

- $Reported\ Size_{i,t}^s$ is the number of companies in subsector s with reported emissions,
- $Reported\ Size_t^{s_3-s}$ is the number of companies in the corresponding sector (GATS level 3) that are not in subsector s,
- $Median\ CI_t^s$ is the median revenue carbon intensity of subsector s (or corresponding sector s_3).

In addition, if no reported emissions can be found at the subsector level the intensity at the supersector level is assigned.

Adjusted MRIO estimates

Scope 3 MRIO estimates are calculated for downstream and upstream emissions in a similar fashion to Scope 1 & 2.

The Scope 3 estimates aggregation rule is detailed in the next section.

4.6 Final Estimated Data

4.6.1 Final estimated data for Scope 1 and Scope 2

The final estimated carbon emissions data for Scope 1 and Scope 2 assigned to a non-reporting company i for a fiscal period t results from the combination of the estimates of the 3 modelling strategies such as:

$$C_{i,t}^e = \frac{C_{i,t}^{e\ iss} + C_{i,t}^{e\ median} + C_{i,t}^{e\ mrio}}{3}$$

4.6.2 Final estimated data for Scope 3

The final estimated Scope 3 GHG emissions $C_{i,t}^{e}$ is defined below:

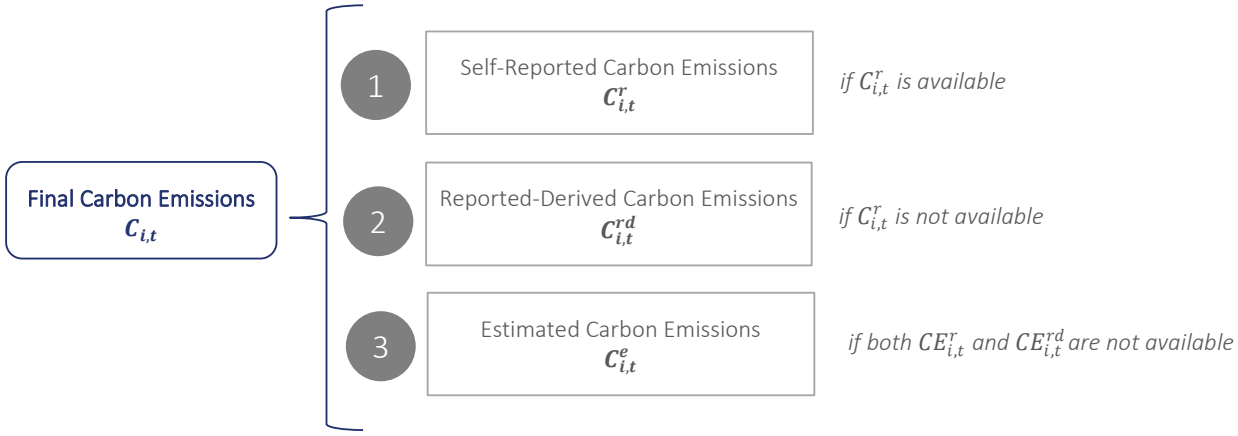
$$C_{i,t}^{e} = \begin{cases} C_{i,t}^{e\ iss} & \text{if} \quad C_{i,t}^{e\ wilshire} < C_{i,t}^{e\ iss} \ \text{ or } \ C_{i,t}^{e\ wilshire} > 1.5 * C_{i,t}^{e\ iss} \\ \frac{1}{2}\left(C_{i,t}^{e\ iss} + C_{i,t}^{e\ wilshire}\right) & \text{otherwise} \end{cases}$$

$C_{i,t}^{e\ wilshire}$ is defined as the median or MRIO estimate that is closest in value to $C_{i,t}^{e\ iss}$.

4.7 Selection Algorithm

The final carbon emissions data for a company and a fiscal period is selected as below:

Final carbon emissions data selection process



The final carbon emissions values are used in the determination of the FT Wilshire Climate Change Indexes through their incorporation into company Emission Intensities (see Section 2.1.1 of FT Wilshire Climate Change Indexes Methodology).

Approval

This Carbon Emissions Model was approved by the Wilshire Indexes Index Management Committee.

Appendix A: Example of the Adjustment Size from the Median-based modelling strategy

This Appendix provides an example of the computation of the Adjustment Size coefficient for a company which is assigned to the GATS subsector "Electronic Entertainment Goods". This subsector sits within the sector "Digital and Electronic Goods" which itself is part of the supersector "Digital Goods and Services". The industry associated with this supersector is "Digital Information and Services".

Example of the Adjustment Size Process

GATS level	GATS name	Size	Reporting Proportion Size	Adjusted Size weighting coefficient
Subsector (4)	Electronic Entertainment Goods	40	14	0.35 $40*(14/(40)^2)$
Sector (3)	Digital and Electronic Goods	65	36	0.34 $40*(36/(65)^2)$
Supersector (2)	Digital Goods and Services	112	53	0.16 $40*(53/(112)^2)$
Industry (1)	Digital Information and Services	434	161	0.03 $40*(161/(434)^2)$

Source: Wilshire Indexes

Appendix B: Carbon Intensity Coefficients by NAICS Sector

Introduction

As set out in section 4, EE-MRIO details the monetary values Z exchanged between, and the user demand Y within, the economic sectors of each geographic region with other sectors and regions during the whole production process, and the direct GHG emissions associated with the consumption of these quantities E.

Note that Z and Y are sparse matrices and E is a vector such that:

$$Z = \begin{pmatrix} z_{i,j}^{1,1} & \cdots & z_{i,j}^{1,m} \\ \vdots & z_{i,j}^{r,k} & \vdots \\ z_{i,j}^{m,1} & \cdots & z_{i,j}^{m,m} \end{pmatrix}$$ where $z_{i,j}^{r,k}$ is the monetary input from sector i in region r to sector j in region k;

$$Y = \begin{pmatrix} y_i^{1,1} & \cdots & y_i^{1,m} \\ \vdots & y_i^{r,k} & \vdots \\ y_i^{m,1} & \cdots & y_i^{m,m} \end{pmatrix}$$ where $y_i^{r,k}$ is the final demand of region k of the product of sector i in region r;

$$E = \begin{pmatrix} e_i^1 \\ \vdots \\ e_i^m \end{pmatrix}$$ where e_i^m is the direct GHG emissions demand of sector i in region m.

EE-MRIO GHG intensity factors

From the above matrices, the gross output GO vector can be derived, which is the overall monetary quantities consumed both as intermediary input by other sectors and regions and by final users of other regions:

$$GO = \begin{pmatrix} go_i^1 = z_{i,j}^{1,1} + \cdots + y_i^{1,1} + \cdots + y_i^{1,m} \\ \vdots \\ go_i^m = z_{i,j}^{m,1} + \cdots + y_i^{m,1} + \cdots + y_i^{m,m} \end{pmatrix}.$$

The key assumption in an MRIO framework is that the gross output vector must be equal to the total input vector. Because of this, a matrix of technical coefficients A can be derived, which expresses the monetary quantities from a sector in a region used to produce one unit of total input:

$$A = \begin{pmatrix} \frac{z_{i,j}^{1,1}}{go_i^1} & \cdots & \frac{z_{i,j}^{1,m}}{go_i^m} \\ \vdots & \frac{z_{i,j}^{r,k}}{go_i^k} & \vdots \\ \frac{z_{i,j}^{m,1}}{go_i^1} & \cdots & \frac{z_{i,j}^{m,m}}{go_i^m} \end{pmatrix}.$$

Using the total input vector, the GHG direct multiplier vector MD can be derived, which represents the direct GHG emitted from the production of one unit of total input:

$$MD = \begin{pmatrix} md_i^1 = \frac{e_i^1}{go_i^1} \\ \vdots \\ md_i^m = \frac{e_i^m}{go_i^m} \end{pmatrix}.$$

The rows of the MD matrix constitute the Scope 1 MRIO intensity factors for a sector i in a region m: $Scope\ 1_i^m = md_i^m$.

In economic analysis, MRIO is used to track the ripple effects in an economy where sectors and regions are fully interconnected. These interconnections are shown in the so-called "Leontief inverse" matrix L. This matrix expresses all direct and indirect effects on output in one sector from one region required to produce a unit of output from another sector of another region. In other words, it summarises the entire production chain (direct and indirect). It is defined by:

$L = (I - A)^{-1}$ where I is the identity matrix and A the matrix of technical coefficients.

Therefore, the dot product of the Leontief inverse matrix and the GHG direct multiplier vector gives both direct and indirect GHG emissions associated to each sector and region of the whole production chain:

$$MT = (L * MD) = \begin{pmatrix} l_{i,j}^{1,1} md_i^1 & \cdots & l_{i,j}^{1,m} md_i^m \\ \vdots & \ddots & \vdots \\ l_{i,j}^{m,1} md_i^1 & \cdots & l_{i,j}^{m,m} md_i^m \end{pmatrix}$$

Note that, by construction, the direct GHG multipliers vector is only included in the diagonal of MT.

Based on the MT matrix, we deduce Scope 2 MRIO intensity factors for a sector i of a region m as the sum of all the rows of MT associated with energy producing sectors j:

$Scope\ 2_i^m = \sum_j l_{i,j}^{m,m} md_i^m$

where j includes only energy producing sectors of the production chain of the sector i.

Raw MRIO estimates

The first set of MRIO-based estimates is obtained by combining the previous MRIO outcomes with NAICS segments data.

Before computing estimated carbon emissions, we associate each NAICS activity to a single Exiobase industry and each country to an Exiobase region thanks to tables of correspondence provided by the Exiobase working group[8].

Note that an Exiobase industry can be associated with various NAICS activities. From these tables, we derive intensity factors for each NAICS activities $naics$ and country c as:

$$MRIO\ GHG\ {}^{c}_{naics} = \frac{\sum_i go_i^m * GHG_i^m}{\sum_i go_i^m}$$

where GHG represents either $Scope\ 1$ or $Scope\ 2$ intensity factors, m is the Exiobase region associated with country c, and i represents the Exiobase sectors associated with the $naics$ activities.

For a company k, the raw MRIO-based carbon emissions results from the sum of its NAICS segments weighted by the associated NAICS-Country MRIO intensity factors:

$$Raw\ C_k^{e\ mrio} = \sum_{naics}^{NAICS} MRIO\ GHG\ {}^{c}_{naics} * segment_{naics}$$

where $segment_{naics}$ represents the revenue of the company in the segment $naics$, $NAICS$ represents all its $naics$ segments, and c is the country associated to the company.

[8] https://ntnu.app.box.com/s/ziox4zmkgt3cdsg549brr0qaecskgjsd

Appendix C: Scope 3 Categories

The Scope 3 GHG emissions categories as referred to by the GHG Protocol are shown below.

Upstream categories	Downstream categories
1. Purchased goods and services	9. Downstream transportation and distribution
2. Capital goods	10. Processing of sold products
3. Fuel – and energy – related activities	11. Use of sold products
4. Upstream transportation and distribution	12. End of life treatment of sold products
5. Waste generated in operations	13. Downstream leased assets
6. Business travel	14. Franchises
7. Employee commuting	15. Investments
8. Upstream leased assets	

Source: GHG Protocol.

Appendix D: Countries and Geographic Regions from Exiobase

D.1 Countries

Exiobase Code	ISO3 Code	Name
AT	AUT	Austria
AU	AUS	Australia
BE	BEL	Belgium
BG	BGR	Bulgaria
BR	BRA	Brazil
CA	CAN	Canada
CH	CHE	Switzerland
CN	CHN	China
CY	CYP	Cyprus
CZ	CZE	Czech Republic
DE	DEU	Germany
DK	DNK	Denmark
EE	EST	Estonia
ES	ESP	Spain
FI	FIN	Finland
FR	FRA	France
GB	GBR	United Kingdom
GR	GRC	Greece
HR	HRV	Croatia
HU	HUN	Hungary
ID	IDN	Indonesia
IE	IRL	Ireland
IN	IND	India
IT	ITA	Italy
JP	JPN	Japan

KR	KOR	South Korea
LT	LTU	Lithuania
LU	LUX	Luxembourg
LV	LVA	Latvia
MT	MLT	Malta
MX	MEX	Mexico
NL	NLD	Netherlands
NO	NOR	Norway
PL	POL	Poland
PT	PRT	Portugal
RO	ROM	Romania
RU	RUS	Russia
SE	SWE	Sweden
SI	SVN	Slovenia
SK	SVK	Slovakia
TR	TUR	Turkey
TW	TWN	Taiwan
US	USA	United States
ZA	ZAF	South Africa

Source: Exiobase.

D.2 Rest of World regions

Exiobase Code	Name
WA	RoW Asia and Pacific
WE	RoW Europe
WF	RoW Africa
WL	RoW America
WM	RoW Middle East

Source: Exiobase.

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