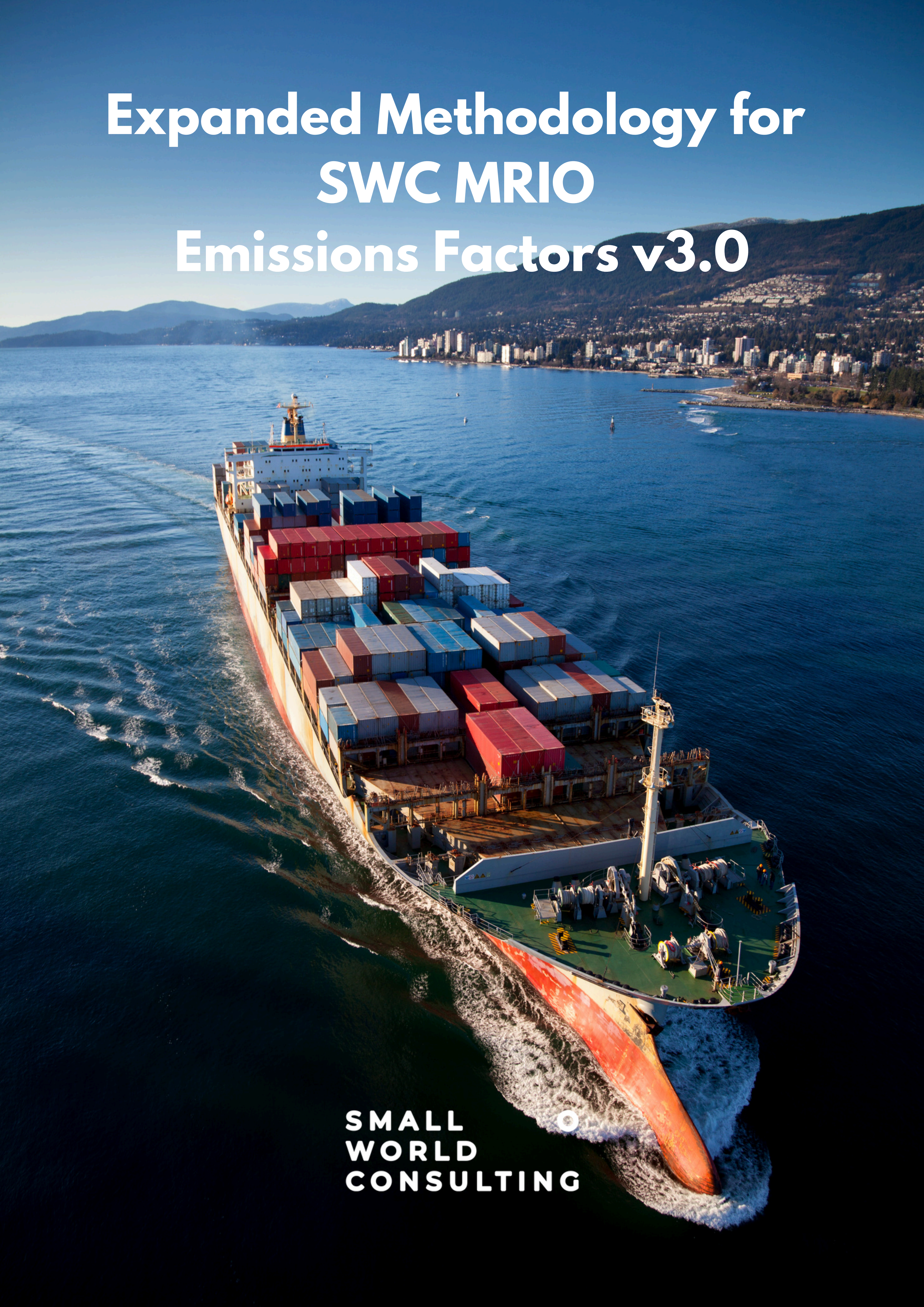
Expanded Methodology for SWC MRIO Emissions Factors v3.0



SMALL WORLD CONSULTING

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Executive Summary

Purpose

SWC's Environmentally Extended Multi-Regional Input-Output (MRIO) model has been built to help companies and other organisations estimate their supply chain emissions in a way that is complete, realistic, practical and transparent. The model is designed to reflect the differences in average carbon intensity of goods and services from each industry, supplied from or purchased within different countries.

The overall purpose of the model is to make these datasets free and publicly available, together with basic guidance on how to use them, and in doing so to raise the standard and compatibility of company supply chain emissions reporting globally.

Output

The output of the model is a set of spend-based GHG emissions factors for purchases from 102 industry categories in 79 countries. Each emissions factor is broken down into the supplier's scope 1, 2 and upstream scope 3 components. Emissions factors are reported in both basic prices and purchasers' prices; in other words, both with and without distributors' margins (wholesale, retail and transport markups) and taxes.

There is also a second set of emissions factors for use if only the country of purchase – not the country of production – is known; for example, if a company in a known country buys something but does not know where it was produced. These datasets use a weighted average of emissions factors for countries supplying the country in question with products from the industry concerned.

Usages

These emissions factors can be combined with organisational spend data to provide a rough first estimate of company supply chain emissions and some guidance as to likely hotspots. This estimate can then be improved by augmenting with elements of process-based life cycle analysis, where appropriate physical consumption data exists. In such instances, great care should be taken to preserve the system-complete boundary conditions that are essential and easy to achieve through EEIO spend-based assessments[1].

Methodology Overview

Economic input-output models use data on trade between industries to estimate, for each industry, the total output that is required, directly and indirectly, from every other industry in the economy in order to produce each industry's products. This can be 'environmentally extended' by combining with data on each industry's total emissions, to produce industry-specific estimates of the emissions arising directly and indirectly from every industry in the economy, per unit of output. A multi-regional input-output model (MRIO) distinguishes between industries in different regions of the world. Environmentally extended MRIOs seek to estimate the carbon intensity, and sometimes the water intensity, per unit of financial output of every industry in every region within the model. They rely on industry-specific data on trade between every country or region in the model, much of which is difficult or impossible to obtain with a high-level industry resolution.

This model adopts an approach designed to obtain sufficient granularity with somewhat fewer problematic requirements regarding the data, in order to increase both the realism of the results for our intended purpose and the practicality of creating and updating the model. We begin by developing an environmentally extended MRIO model by drawing upon a coarse-grained Inter-Country Input-Output (ICIO) table produced by the OECD, covering 50 industry sectors in 79 countries. We environmentally extend this using country and industry emissions data, drawn from the OECD data where this is available. Where it is not, we make estimates using energy and emissions data from the United Nations and other sources. To increase the granularity of the model, we separately produce a 104-sector EEIO based on UK data alone, using relatively high-quality data from the Office of National Statistics. We use the results of this model to upscale the 50-sector MRIO to 102 sectors by making the core approximation that the ratio of carbon intensities between each disaggregated subsector is similar in each country in the model.

A few other core methodology details deserve a mention in this short overview. The model treats capital investment as part of the supply chain for a company, so that associated emissions become part of company supply chain emissions. A markup factor of 1.7 is applied to high-altitude emissions to take account of the additional radiative

[1] This process is described in more detail in a separate document: *Integrating process-based life cycle analyses (LCAs) into spend-based environmentally extended input-output (EEIO) emissions estimates for company supply chains.* https://www.sw-consulting.co.uk/files/SWC-Hybridisation-Guide.pdf

forcing effects that occur at high altitude. Finally, the model deals with the full Kyoto basket of greenhouse gases covered by the Greenhouse Gas Protocol (GHGP) and combines these into a single metric in terms of their carbon-dioxide-equivalent warming potential over a 100-year period. The emissions units of emissions factors are expressed as kgCO_2e/£.

Please note that all of the datasets used within the SWC MRIO model, including those referred to in this document, may be found in Appendix C.

Validation

The results have been tested against process-based analyses of a simple commodity, and against other leading MRIO models. The work is ongoing, and the results so far have been both encouraging and supportive of the approach taken and assumptions made. As and when time and resources permit, we hope to make these checks and comparisons public.

Principles of Environmentally Extended Input-Output Analysis

EEIO Modelling and Leontief

Input-Output Modelling was developed by Wassily Leontief in the late 1930s to demonstrate how changes in final demand for products and services stimulate activity in industry sectors other than the supplying sector. It is widely used in economics to estimate the impacts of economic activities. EEIO combines economic information about the trade between industrial sectors (IO tables) with environmental information about the emissions (environmental accounts) arising directly from those sectors, to produce estimates of the emissions per unit of output from each sector (emissions factors). The central technique is long established and well documented (Leontief 1986, Miller and Blair 1985). EEIO offers some key advantages, worth noting, over more traditional process-based life cycle approaches:

- EEIO does not suffer from ‘truncation error’, the systematic underestimation that process-based analyses incur through their inability to trace every single pathway in the supply chains. Although, as with process-based life cycle approaches, there may be inaccuracies in EEIO’s methods of avoiding this underestimation.
- To produce a crude, simple but complete assessment of supply chain emissions, the data requirement is very small: no more than a purchase ledger, categorised by types of goods and services purchased.
- EEIO has at its root a transparently impartial process for calculating emissions factors, whereas life cycle approaches entail more subjective judgements regarding the setting of boundaries and the selection of secondary conversion factors.
- EEIO can be used to estimate the footprints resulting from complex activities, such as the purchase of intangible services, that life cycle approaches struggle to account for.

One serious limitation of EEIO in its most basic form is that it assumes homogeneity of the direct emissions and the demands placed on other sectors, per unit of output within each sector. For example, a basic EEIO model does not account for the carbon efficiencies that may arise from switching expenditure on paper to a renewable source from a virgin source, without reducing the actual spend. In order to mitigate this weakness, adjustment multipliers may be applied to the EEIO emissions factors based on LCA data. Overall, therefore, a hybrid methodology, drawing on the strengths of both life cycle analysis and environmental input-output approaches, is widely considered to be best practice.

EEIO models are derived from IO tables, often compiled using nationally published statistical data on the supply and consumption of goods and services within each sector in an economy. The columns of the IO tables encode purchasing sectors, while the rows are filled with selling sectors, which means that each value in the table represents, in monetary units, the trade flows between each sector required to produce a given sector's output. This table is used to produce a table of 'technical coefficients' which quantify the direct financial spend on one industry by another industry per unit of the spender's output. This table is in turn used to produce the 'Leontief Inverse' matrix, which represents the cumulative required inputs of a sector all the way up the supply chain. The mathematics of this are relatively simple and can be described by the equation below, where L is the Leontief Inverse, A is the technical coefficients matrix, and I is the identity matrix.

$$L = (I - A)^{-1}$$

This model can then be environmentally extended by first taking the greenhouse gas emissions of each sector and dividing them by the total output from that sector to give a direct GHG intensity per £GBP of output. Then, multiplying each sector's total required inputs (the Leontief) by this direct GHG intensity produces an emissions factor for each sector, representing the total GHG intensity per £, which therefore encompasses each sector's entire supply chain.

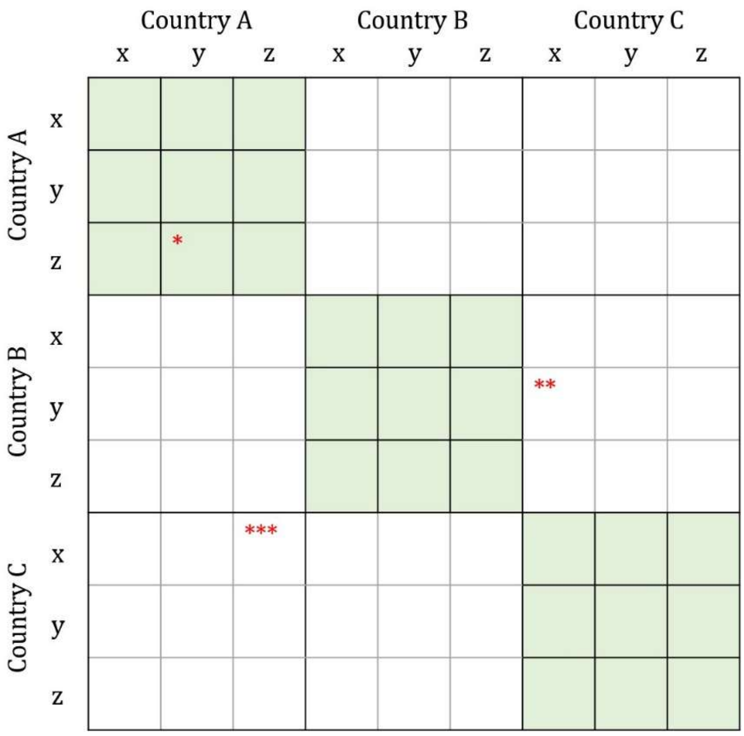
Multi-regional Input-Output (MRIO) Analysis

In a globalised world where the consumption of goods and services is often separated from the initial origins of production, it becomes more difficult to estimate the social and environmental impact of a product or service. As they undergo different stages of production, goods and services can pass through a network of several countries and be reassembled at various levels in the supply chain before reaching the end consumer. This issue necessitates an inter-regional approach to quantifying and modelling sustainability and ecological impact – including greenhouse gas emissions.

Environmentally extended multi-regional input-output analysis (MRIO) takes the concept of standard single-region input-output analysis and applies it at a larger scale by incorporating regional-level data and, crucially, the flows between regions. Often this is in the form of an input-output table which encodes not only the domestic trade of each sector within each country included in the model, but also the trade between every sector and country combination.

An MRIO table is essentially a large, amalgamated matrix, with domestic transaction matrices (national IO tables) occupying the diagonal blocks (shaded, below) whilst the off-diagonal blocks show trade matrices between countries. This general format is depicted in the figure below. * represents a domestic transaction between sectors y and z in country A, while ** and *** represent international trade between different sectors in different countries.

Most commonly, MRIOs are constructed by taking national IO tables and linking them together using trade data. This is trickier than may be expected, as trade statistics often incur disagreement due to recording complications and the fact that different countries report figures with varying levels of granularity. Consequently, a vast amount of data goes into combining these sources, aiming to create a balanced MRIO table which stays close to reality whilst allowing IO analysis to be carried out.



Construction of the SWC MRIO Model

Core Data

SWC's model makes use of data from the Organisation for Economic Co-operation and Development (OECD). The OECD publishes a set of harmonised, industry-by-industry IO tables for countries that together account for around 94% of global GDP. This set comprises separate national IO tables as well as a single large MRIO table, the intercountry input-output table (ICIO) (OECD, 2025a). The OECD makes this data freely available for anyone to use, which simplifies the task of incorporating data into the model and ensures that transparency is upheld, since anyone may access and use the source data. The OECD tables, as of the 2025 data release, cover 80 countries and 50 economic sectors in the ISIC Rev. 4 format, making them compatible with the UN's System of National Accounts 2008 (SNA08, UN 2008) and the System of Environmental-Economic Accounting (SEEA, UN 2012). The tables are available as a time series dating from 1995 up to 2022, and the unit for all values is millions of $US in current prices for each year. The list of regions and the list of sectors covered by the OECD dataset are presented in Tables 1 and 2, in Appendix A and Appendix B, respectively.

For the required environmental accounts, OECD data is employed again where possible, as the organisation also publishes Air Emission Accounts (AEAs) in the ISIC Rev. 4 format on a residence basis (OECD, 2025b). In terms of the countries and sectors concerned, these accounts overlap significantly with the IO tables and therefore require less harmonisation work before being combined in an EEIO model. An important quality of the data is that it is compiled using the residence basis, which covers all emissions under the direct control of the residents of each country, even if the emissions occur elsewhere. This contrasts with territorial-based methods, which only include emissions occurring within the borders of a given country, even if said emissions are economically linked to and directly controlled by another country. The OECD AEAs cover all the main greenhouse gases, which are converted and combined into tonnes of CO_2 equivalent (CO_2e) using standard IPCC factors.

A key issue with the OECD environmental accounts is that most countries for which they are available are in Europe. Environmental accounts are not always available for some of the most economically and environmentally important countries (such as India, China, Russia, and the USA), since many of these countries do not publish annual GHG data in sufficient granularity to create a set of accounts. For all the countries absent from the OECD data, a set of environmental accounts needed to be estimated via other sources, in accordance with the guidelines set out by the SEEA-approved "Manual for Air Emissions Accounts" from Eurostat (Eurostat, 2015).

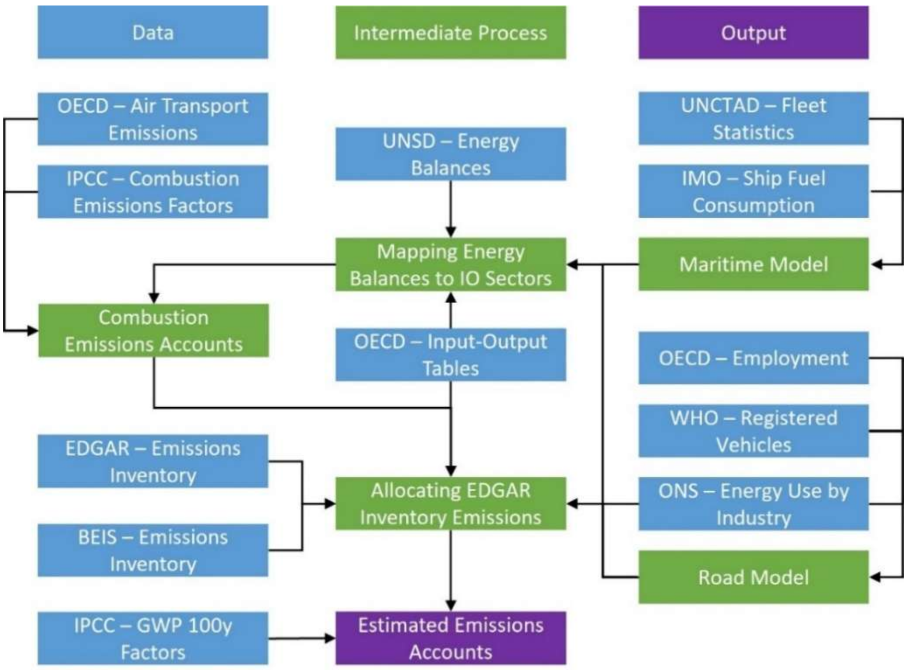
Estimating Environmental Accounts

Overview

The basis for this estimation is energy balance data from the United Nations Statistics Division (UNSD) (UNSD, 2025), which provides information on the supply and use of various energy commodities and fuels within each country and sector. The first step is to convert the data from a territorial basis to a residence basis by remapping international aviation and shipping via two sub-models. This ensures compatibility with the OECD IO tables and other environmental accounts. The data is then mapped onto the relevant sectors to create a set of accounts relating to emissions-relevant energy use. Using the standard IPCC emissions factors for GHG emissions arising from the burning of different fuels, the data is further transformed into a set of combustion emissions accounts.

To complete the environmental accounts, data from the EU's Emission Database for Global Atmospheric Research (EDGAR, 2025) is used to fill in the remaining gaps relating to non-combustion-related emissions, including agricultural, as well as various other minor GHGs. This process requires mapping from EDGAR's lower-resolution sectoral classification system to the ISIC Rev. 4 classification employed by the OECD IO tables. This is why the more compatible UN energy balance data is used to estimate the initial combustion emissions, versus simply disaggregating EDGAR data for the whole set of accounts.

Finally, the IPCC's global warming potential (GWP) factors for a 100-year time scale are applied in order to combine all the different GHGs into one CO_2-equivalent (CO_2e) figure. The final estimated environmental accounts span the same 45 sectors as the OECD IO tables, to ensure compatibility, and they include CO_2, CH_4, N_2O, SF_6, NF_3, HFCs and PFCs. With both the MRIO table and the environmental accounts available, the IO analysis can be performed. The estimation process is summarised in the diagram below before a more detailed description is provided.



Estimating Energy-Related Emissions

As previously stated, the most central dataset in the estimation of the emissions accounts is the set of "Energy Balances" published by the UN Statistics Division (UNSD). The UNSD energy balances detail the fuel consumption by different areas of the energy system within each country. The UNSD compile these statistics based on its energy questionnaire, which is sent to every country annually. The dataset is in the format of tables for each country and each year, which are compiled on a territorial basis, meaning energy flows within the transport sector need to be adjusted at some stage. These energy balances need to be converted into sets of emissions relevant energy use accounts on a residence basis to be able to calculate combustion-related CO_2 emissions for different sectors. The columns in the data tables represent groups of energy commodities such as coal, oil, and gas, whilst the rows represent energy flows in different sectors of the country's energy system. This may be seen in the figure below.

Total energy supply
Primary production
Imports
Exports
International marine bunkers
International aviation bunkers
Stock changes
Statistical differences
Transfers and recycled products
Transformation
Electricity CHP & Heat Plants
Electricity Plants
CHP plants
Heat plants
Coke ovens
Briquetting plants
Liquefaction plants
Gas works
Blast furnaces
NGL & gas blending
Oil refineries
Other transformation
Energy industries own use
Losses
Final consumption
Final Energy Consumption
Manufacturing const. and mining
Iron and steel
Chemical and petrochemical
Non-ferrous metals
Non-metallic minerals
Transport equipment
Machinery
Mining and quarrying
Food and tobacco
Paper pulp and printing
Wood and wood products
Textile and leather
Construction
Industry n.e.s
Transport
Road
Rail
Domestic aviation
Domestic navigation
Pipeline transport
Transport n.e.s
Other Consumption
Agriculture forestry and fishing
Commerce and public services
Households
Other consumption n.e.s
Non-energy use

Primary Coal and Peat
Coal and Peat Products
Primary Oil
Oil Products
Natural Gas
Biofuels and Waste
Nuclear
Electricity
Heat
Total Energy
memo: Of which Renewables

(Left) The structure of the energy flow rows in the UNSD "Energy Balances" dataset. (Right) The groups of energy commodities included in the data.

The values within the tables are all in common units of terajoules (TJ). The energy flows are split into three main portions: the top supply block, the middle transformation block, and the bottom consumption block. The top supply block represents the flow of energy entering the country's territory through primary production and imports, as well as the energy exiting the territory through exports and bunkering. International marine and aviation bunkers involve the country supplying other territories with fuel for international journeys of ships and planes. This does not, however, represent the country's fuel use for its own international shipping and aviation. Although this supply block is useful in understanding a given country's energy system, none of these flows are relevant in constructing a set of energy use accounts for the purposes of calculating emissions.

The middle transformation block details the flows in which energy is transformed between different commodities, such as from crude oil to petrol or natural gas to electricity. Many of these flow transformation processes are not emissions relevant, as the energy is transformed rather than used up. Some energy is, of course, required to carry out the transformation, and this is embedded in the "Energy industries' own use" flow. When considering energy use relevant to emissions, the mapping of the energy use in electricity, CHP and heat plants is simple and can be assigned to sector 35 in the ISIC Rev.4 format, "Electricity, gas, steam and air conditioning supply". Less simple is the mapping of 'Energy industries own use', since embedded within this one flow is energy used primarily by coke producers, oil refineries, oil & gas extractors and coal miners, which require mapping to separate ISIC Rev.4 sectors. Therefore, for this flow, an inventory-based approach was opted for instead, which is detailed later. The 'Blast furnaces' flow involves the production of blast furnace gas during the process of reacting coke with iron ore to produce pig iron. This is a transformation process, but it is difficult to separate out since it is also partially burned in the furnace, as well as often being used elsewhere in the metal plants. Therefore, despite this being a process of transformation, it can be reasonably assumed that most of it will be used in the iron and steel sector at some point in their manufacturing processes and thus can be assigned as emissions-relevant energy use to that sector.

The bottom consumption block is the most relevant to the production of emissions accounts. It contains the final consumption of energy commodities across the sectors of the country's economy, including manufacturing, construction, non-fuel related mining, transport, agriculture, commerce, services, and households. All of this is energy use relevant to emissions, and so it is crucial to map these flows onto the relevant ISIC Rev.4 sectors as depicted in the figure below. This can require different amounts of disaggregation using other auxiliary data. An issue with the dataset is the presence of the industry, transport, and other n.e.s. (not elsewhere specified) flows which, in theory, contain a specific set of ISIC sectors; however, in practice, they can contain any of the sectors in that section which have not specifically been reported. For example, if the rows for 'Machinery' were left blank, they may be included in the 'Industry n.e.s.' flow. The specificity of reporting depends on a country's resources to collect data at the necessary resolution and, therefore, in practice, the 'Industry n.e.s.' flow can contain any combination of sectors, which must be first disaggregated to the other flows in that section. This is an important process which many other models do not take into account.

Non-energy use	Other consumption n.e.s	Households	Commerce and public services	Agriculture forestry and fishing	Transport n.e.s	Pipeline transport	Domestic navigation	Domestic aviation	Rail	Road	Industry n.e.s	Construction	Textile and leather	Wood and wood products	Paper pulp and printing	Food and tobacco	Mining and Quarrying	Machinery	Transport equipment	Non-metallic minerals	Non-ferrous metals	Chemical and petrochemical	Iron and steel	Losses	Energy industries own use	Other transformation	Oil refineries	NGL & gas blending	Blast furnaces	Gas works	Liquefaction plants	Briquetting plants	Coke ovens	Heat plants	CHP plants	Electricity Plants	International aviation bunkers	International marine bunkers	OECD (ISIC 4) → UNSD ↓
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	A01
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	A02
0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	A03
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	B05
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	B06
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	B07
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	B08
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	B09
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C10T12
0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C13T15
0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C16
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	C19
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C20
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C21
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C22
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C23
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	C24A
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C24B
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C25
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C26
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C27
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0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C29
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C301
0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	C302T309
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0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H49
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	H50
0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	H51
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H52
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	H53
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	I
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	J58T60
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	J61
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	J62_63
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	K
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	L
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	M
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	O
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	P
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Q
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	R
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	S
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	T
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	HH&Other

The correspondence between the relevant flows of the UNSD energy balances and the sectors of the OECD IO tables for the purposes of constructing emissions accounts.

To transform the energy balances into a set of energy accounts, the energy balance sectors need to be mapped onto the same set of sectors as used by the OECD IO tables. Many of these mappings are straightforward; however, there are also many cases of many-to-one mapping which require auxiliary data to disaggregate the necessary sectors. The correspondence between the UN set of sectors and the OECD set of sectors is shown in the above figure, which was constructed using information from the IPCC's inventory guidelines as well as from the UNSD's guidelines on its annual energy questionnaire. The first task in carrying out the mapping is to disaggregate the industry, transport and other n.e.s. flows and allocate them to the other sectors within their respective categories.

Allocating 'n.e.s.' Flows

Since the necessary 'Industry n.e.s.' allocation varies by country depending on the level of reporting, the disaggregation and allocation process needs to be specific to each country. This is achieved with the use of two binary matrices, the first simply encodes whether a value has been reported for a given energy flow/commodity combination with a 0; if no value is reported then it is assigned a value of 1. The second matrix represents whether a given energy commodity is typically used by a given sector. This is calculated by summing up all the energy balances from each country into one energy balance table representing a substantial amount of the world's energy flows. From this, it can be discerned which types of energy are generally used by which sectors by calculating each energy commodity's percentage of the total energy used by a given sector. A limit of 0.5% was set such that if a sector obtains less than 0.5% of its energy requirements from a certain energy commodity, then it is assigned a value of 0 in the second binary matrix. Conversely, if more than 0.5% of a sector's energy is derived from the commodity then it is assigned a value of 1. Taking the two binary matrices and multiplying them together elementwise produces a third binary matrix, which encodes which combinations of sectors and commodities should receive part of the allocation of the 'n.e.s.' flow. This method prevents allocation of the 'n.e.s.' flow to sectors which typically don't use that type of energy, whilst also ignoring sector/commodity combinations for which there is already data.

The allocation process makes use of the monetary data in the IO tables for each country. The inputs in the IO tables from the energy industries to the sectors which make up each of the energy balance industry flows are first imported from the IO table and then used as a disaggregation key. In other words, the industry flows which spend more in the energy sectors will receive a greater portion of the 'Industry n.e.s.' flow. Different inputs from different energy sectors are used as disaggregation keys depending on the energy commodity to be disaggregated. The inputs from each energy industry are used as follows:

- Sector 05 "Mining of coal and lignite" is used to disaggregate the 'Primary Coal and Peat' energy commodity.
- Sector 06 "Extraction of crude petroleum and natural gas" is used to disaggregate the 'Primary Oil' energy commodity.
- Sector 19 "Coke and refined petroleum products" is used to disaggregate the 'Coal and Peat Products', 'Oil Products', and 'Biofuels and Waste' energy commodities.
- Sector 35 "Electricity, gas, steam and air conditioning supply" is used to disaggregate the 'Natural Gas', 'Nuclear', 'Electricity', and 'Heat' energy commodities. 'Nuclear', 'Electricity', and 'Heat' are not emissions relevant here but are included for completeness.

The 'Other consumption n.e.s.' flow also requires a similar approach to the 'Industry n.e.s.' flow. The combination of two binary matrices is again used to find out which 'Other consumption' flows require allocation from the 'n.e.s.' flow, and again the inputs from energy sectors within the IO tables are used to portion out the 'n.e.s.' flow. One complication here is that, unlike the 'Industry n.e.s.' flow, which specifically contained sectors 22, 31, and 32, there are no whole sectors which fit into the 'Other consumption n.e.s.' flow. This is an issue because the situation can arise where the expected combinations of flows and commodities already contain data, whilst there is still data in the 'Other consumption n.e.s.' flow, which makes it unclear as to how this should be allocated. This is dealt with by taking the remainders left in the 'Other consumption n.e.s.' flow after the initial allocation and distributing it across all the other flows within the 'Other consumption' section, again using IO table data to do so. This ensures that no energy is missed out in the process in lieu of other information.

The handling of the 'Transport n.e.s.' flow is much simpler. This flow may contain emissions from a range of modes of transport, including even ski lifts and funiculars. However, the predominant source of emissions in this flow is likely to be internal combustion engine (ICE) vehicles which do not fully meet the criteria for the 'Road' flow, such as airport shuttles and loading and unloading vehicles. Therefore, the 'Transport n.e.s.' flow is wholly allocated to the road flow in the absence of any other data which may allow for a truer disaggregation.

With the 'n.e.s.' flows handled, the process of mapping the energy balance flows to the OECD IO table sectors can be carried out. In some cases, this is simple, as the allocation is either one-to-one or many-to-one; however, there are other cases which involve one-to-many mappings which require disaggregation. In most cases, the disaggregation process is achieved using monetary data from IO tables in a similar manner to the distribution of the n.e.s. flows. There are some exceptions, however, seen in the transport sectors due to the need to transform the data from a territory to a residence basis. It is also the case in the energy-producing industries, as the 'Energy industries own use' flow in the energy balances would not be suitable for disaggregation using the IO tables, since inputs for own use are not recorded separately. For the transport sectors, separate models are implemented to allocate energy and emissions accurately, whilst the own use component of the energy industry is instead taken from a different emissions inventory dataset employed later.

Road Transport

All road transportation for private, domestic, and public use is contained within the 'Road' flow in the UNSD energy balances. Thus, a model needs to be implemented which can accurately disaggregate this flow across all sectors within the OECD IO tables for each country. Disaggregating the road flow using the IO tables would be inaccurate since this would entail using inputs from the petroleum refining sector, and there are many other uses of products from that sector other than road transportation.

The UK's Office for National Statistics (ONS) publish the dataset "Energy use by industry, source and fuel" which details the energy use of every sector of the economy, including domestic use, broken down by type of fuel and purpose. This dataset can be filtered to only include energy use for the purposes of road transportation, and then this can be mapped to the OECD IO sectors, yielding a sector-by-sector breakdown of fuel consumption for road transport. By calculating a fuel intensity metric using this data, a rough approximation of the road transport fuel use inherently required by each sector's activities can be made, which can then be used as an approximation for other countries.

The obvious fuel intensity metric which could be calculated is the road fuel use per unit of monetary output for each sector; however, this does not work so well since the value added for the same sector in different countries can vary greatly. In other words, the value of goods and services can vary a lot between countries, whilst the inputs required to produce the monetary output can remain the same. Therefore, intensity metrics using a per-unit monetary output basis may not be the best option for allocating road transport. Instead, a per number of employees basis is used to calculate the road fuel intensity as this is more likely to scale with the inputs required to produce a given amount of physical output.

The employment data is obtained from the OECD from their "Trade in Employment (TiM)" database, which features employment numbers by ISIC Rev.4 sector for over 50 countries. This has the advantage of the data already being in the same 45-sector format as the IO tables, as well as covering most countries included in the model. Unfortunately, some countries which are included in the IO tables are not included in the employment dataset. For these countries, the road fuel intensity is instead calculated on a per unit monetary output basis, although it may be possible in future work to assemble a set of employment accounts.

For the domestic portion of road use, a separate road fuel intensity metric must be calculated since households have neither an output nor employees. Calculating the metric on a population basis would not be sensible, as household vehicle ownership and use vary a great deal between countries. Instead, the fuel intensity metric is calculated using the total number of registered vehicles in each country. Of course, not all registered vehicles are used by households, but the majority are, and so this is more likely to scale better than on a population basis. The data on registered vehicles is obtained from the World Health Organisation (WHO), which lists the number of vehicles in nearly every country.

Using both the industry road fuel intensity per employee and the domestic road fuel intensity per registered vehicle, the share of road fuel use across sectors for any country may be estimated by multiplying the intensities by the relevant employee and vehicle numbers and calculating the share of the total fuel use. This was then used to distribute the ‘Road’ flow in the energy balances across all sectors and households.

International Maritime Transport

As the energy balances are collated on the territory principle instead of the residence principle, the figures listed in the ‘International marine bunkers’ flow do not accurately represent the consumption of marine bunker fuel by each country. A separate model of countries’ bunker consumption is thus required. Several datasets from the UN Conference on Trade and Development’s (UNCTAD) fleet statistics were employed, namely the “Merchant fleet by flag of registration and by type of ship” dataset by both number and deadweight tonnage (DWT), and the “Merchant fleet by country of beneficial ownership” dataset in percentage of total ships.

The former dataset details the number and total deadweight tonnage of countries’ ships used for the purposes of international transport by type of ship for the years 2011-2024. In international shipping, however, the country to which a vessel is registered is not necessarily the country which owns it and thus benefits from it economically. This is where the latter dataset is used, as it details, for the countries with the top 20 largest fleets on a registration basis, the percentage of a country’s fleet which is within economic ownership of any other country. Using this information, the former dataset may be adjusted to represent the international shipping activities of each country more accurately. As mentioned, however, this data is only available for the countries with the 20 largest fleets due to the often-difficult nature of tracing the nationality of a ship’s true owners, and so a fully accurate adjustment to the data cannot be carried out.

Once the data on ships by type for each country in number and DWT format has been adjusted, an average is calculated for each type of ship for each country by dividing the total number of ships of that type by the total DWT of ships of that type. This yields the average ship size for a given country and type of ship, which may be used in conjunction with data on the average fuel consumption by ship type and size to estimate the total marine fuel consumption of each country’s fleet. For each country, the number of ships of a given type and average DWT may be multiplied by the average fuel consumption for that type of ship to produce an estimate for the total fuel consumption. Countries which are included within the OECD IO tables may then be separated, and a percentage of the total marine fuel consumption may be calculated for these countries. This percentage share for each country can then be applied to the UNSD energy balance data by multiplying the share by the sum of the 'International marine bunkers' flow across all countries.

From Energy to Emissions

To finalise the energy use accounts, air travel must also be translated to the residence principle and energy use for 'Energy industries own use' must be assigned to each of the energy industries. However, these processes are applied later as an inventory-first approach is used instead, and the emissions associated with this energy use are taken from other sources. With the previously noted exceptions, the UNSD energy balances have been transformed into energy use accounts in a format compatible with the OECD IO tables. The energy use accounts are used to calculate a set of accounts covering emissions of CO_2, CH_4, and N_2O resulting from energy use by using default emissions factors from the IPCC for different energy commodities.

Since the set of accounts are now in units of emissions, the aviation portion may be added in. All aviation emissions are taken from the "Air Transport CO_2 Emissions" OECD dataset, which derives its figures from a sophisticated model of air travel emissions detailing every commercial, freight, and general flight, on a residence and a territory basis. The core of the OECD's methodology is a database compiled by the International Civil Aviation Organisation (ICAO) containing every flight in the world. For each flight, the database includes information on the departure and arrival airports, the operating airline and the type of aircraft flown. This is combined with the CO_2 emission calculator from Eurocontrol, which, when provided with an aircraft type, engine type, and the distance flown, can estimate the quantity of fuel burnt and CO_2 emitted. This includes factoring in the variation in these figures during take-off, cruising, and landing. Since the operating airline is also known, this may be used to assign emissions to countries on either a territorial or residence basis. Hence, the aviation emissions of any country on a residence basis can be taken from the OECD's dataset and added to the set of combustion accounts. Note that a factor of 1.7 is also applied to the OECD data to factor in the greater levels of radiative forcing brought about by emitting GHGs at a higher altitude. This figure is in line with currently recommended practices (DESNZ, 2025).

Allocating Non-Energy Related Emissions

Combustion emissions cover the majority of GHG emissions for any given country; however, they are not the only contributor. There are non-energy and process-related emissions to consider in the emissions accounts as well. An inventory approach is used to account for these emissions with data taken from the EU Joint Research Council's (JRC) Emissions Database for Global Atmospheric Research (EDGAR). EDGAR includes CO_2, CH_4, N_2O, SF_6, NF_3, PFCs, and HFCs emissions in kilo tonnes for every country, broken down by sector on a territorial basis. The format is based on the UN CRF format and is highly aggregated regarding energy use emissions; for example, all of manufacturing's energy use emissions are considered together. This means it would be unsuitable to use these figures for the emissions from combustion, which is why the previously described methodology involving the UNSD's energy balances is carried out. The EDGAR inventory is, however, well-suited to cover the emissions from industries such as agriculture, cement production, and fossil fuel extraction. As with the UNSD energy balances, many of the categories into which the EDGAR data is divided can be directly allocated to an OECD IO table sector, whilst others need to be disaggregated. The correspondence between the EDGAR UN sectoral format and the OECD IO table ISIC Rev.4 format can be seen in the figure below.

It should be noted that the EDGAR emissions figures for '1.A.1.a Main Activity Electricity and Heat Production' are allocated wholly to sector 35, electricity production. This is instead of using the previously calculated combustion emissions from the UNSD energy balances due to the fact that the EDGAR figure includes emissions related to energy own use, whereas the energy balance-derived figure does not.

The first categories of the EDGAR inventories which require allocation are '1.A.1.bc Petroleum Refining - Manufacture of Solid Fuels and Other Energy Industries', '1.B.1 Solid Fuels', and '1.B.2 Oil and Natural Gas'. The first of these categories covers emissions from energy own use in the energy extraction and refining industries, corresponding to the OECD IO sectors 05 "Mining of coal and lignite", 06 "Extraction of crude petroleum and natural gas" and 19 "Coke and refined petroleum products". The latter two categories relate to fugitive emissions within the same sectors as well as in the sectors associated with transporting and distributing the produced energy commodities. For these three categories, two models are developed based on higher fidelity data on UK emissions from the ONS.

The allocation of the '1.A.1.bc' category makes use of the ONS dataset detailing energy use by industry, fuel, and purpose (ONS, 2025). This dataset was filtered to show only the energy use by sectors 05, 06 and 19, the energy extraction and refining sectors, then the total emissions for each were calculated. This was carried out using the IPCC default emissions factors to convert the quantities of each fuel type used by each sector into CO_2. An emissions intensity was calculated for each sector by dividing the emissions by the total output in basic prices for the sectors from the UK OECD IO tables. These intensities were then used to estimate the emissions for these sectors from any other country in the model by multiplying the country's total output of each sector by the relevant intensity. These estimates are not the final allocated figures but are instead used to allocate a share of the emissions from the '1.A.1.bc' EDGAR category.

OECD (ISIC Rev.4) → / EDGAR (UN) ↓	1.A.1.a Main Activity Electricity and Heat Production	1.A.1.bc Petroleum Refining - Manufacture of Solid Fuels	1.A.2 Manufacturing Industries and Construction	1.A.3.a Civil Aviation	1.A.3.b Road Transportation	1.A.3.c Railways	1.A.3.d Water-borne Navigation	1.A.3.e Other Transportation	1.A.4 Other Sectors	1.A.5 Non-Specified	1.B.1 Solid Fuels	1.B.2 Oil and Natural Gas	2.A.1 Cement production	2.A.2 Lime production	2.A.3 Glass Production	2.A.4 Other Process Uses of Carbonates	2.B Chemical Industry	2.C Metal Industry	2.D Non-Energy Products from Fuels and Solvent Use	2.E Electronics Industry	2.F Product Uses as Substitutes for Ozone Depleting	2.G Other Product Manufacture and Use	3.A.1 Enteric Fermentation	3.A.2 Manure Management	3.C.1 Emissions from biomass burning	3.C.2 Liming	3.C.3 Urea application	3.C.4 Direct N2O Emissions from managed soils	3.C.5 Indirect N2O Emissions from managed soils	3.C.6 Indirect N2O Emissions from manure manageme	3.C.7 Rice cultivations	4.A Solid Waste Disposal	4.B Biological Treatment of Solid Waste	4.C Incineration and Open Burning of Waste	4.D Wastewater Treatment and Discharge	5.A Indirect N2O emissions from the atmospheric de	5.B Other
A01	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
A02	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A03	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B05	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B06	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B07	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B08	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B09	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C10T12	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13T15	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C16	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C17_18	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C19	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C20	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C23	0	0	1	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C24A	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C24B	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C25	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C26	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C27	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C28	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C29	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C301	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C302T309	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C31T33	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0
F	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
G	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H49	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H50	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H51	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H52	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H53	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J58T60	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J61	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
J62_63	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
L	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
R	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HH&Other	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The correspondence between the OECD IO table sectors (in ISIC Rev.4 format) and the EDGAR emissions inventory categories (in UN CRF format).

A similar approach is deployed for the '1.B' fugitive emissions categories; however, separate intensities for CO_2, CH_4, and N_2O are calculated due to the nature of fugitive emissions. The data used in this allocation comes from the UK National Atmospheric Emissions Inventory (NAEI), which publishes the UK's fugitive emissions broken down to a much higher granularity than the EDGAR inventory. The data is available for CO_2, CH_4, and N_2O emissions, broken down by source and activity, and is categorised using the UN CRF format, making it easy to dovetail with the EDGAR inventory.

As fugitive emissions can occur at any point before combustion, there are extra relevant sectors for the '1.B' categories on top of sectors 05, 06 and 19. These are the sectors "09 Mining support service activities", "24A Manufacture of basic iron and steel", "35 Electricity, gas, steam and air conditioning supply", and "49 Land transport and transport via pipelines". Using the UK fugitive emissions data, CO_2, CH_4, and N_2O emissions are allocated to these sectors so that CO_2, CH_4, and N_2O intensities per unit output at basic prices may be calculated for each sector. As before, these emission intensities are multiplied by the country-specific total output of each sector to estimate the emissions of each OECD IO sector contained within the EDGAR categories, '1.B.1' and '1.B.2'. The share of the emissions in each EDGAR category is then allocated proportionally to the relevant sectors according to the set of emissions estimated using the UK-derived intensities.

The remaining EDGAR categories, which require one-to-many mappings, are within the industry section, '2' and relate to industrial processes. The first of these is '2.B Chemical industry' which requires allocation to sector 20 "Chemical and chemical products", and sector 21 "Pharmaceuticals, medicinal chemical and botanical products". This is achieved by allocating the CH_4, N_2O, F-gases, and non-energy CO_2 proportionally according to previously estimated combustion CO_2. This is not an ideal method, and further methods could be explored to achieve a more accurate allocation.

The final three categories in the EDGAR dataset requiring disaggregation are '2.D Non-Energy Products from Fuels and Solvent Use', '2.G Other Product Manufacture and Use', '2.F Product Uses as Substitutes for Ozone Depleting Substances', all of which require allocation to every sector. The first category is dominated by solvents, and the second category is dominated by industrial gases. Both solvents and industrial gases are products of sector 20, the chemicals industry. Therefore, both categories, '2.D' and '2.G', are disaggregated in the same manner using data on the inputs from sector 20 to all other sectors in the IO tables. They are both allocated proportionally according to the size of each sector's inputs from the chemicals industry.

The last category comprises several sources but is largely made up of HFC emissions from industrial processes as well as refrigeration. This is allocated across each sector in a similar manner to the process used for allocating fugitive emissions described above.

UK data on HFC emissions by sector is obtained from the ONS' atmospheric GHG data, and the monetary output of each sector from the IO data allows for a HFC intensity per unit output to be calculated. As before, these emission intensities are multiplied by the country-specific total output of each sector to estimate the emissions of each sector. The share of the emissions in each EDGAR category is then allocated proportionally to the relevant sectors according to the set of emissions estimated using the UK-derived intensities. It is worth reiterating that the UK-based intensities are not used to estimate a final figure and are only used to estimate the proportion between sectors to allow for allocation.

Combining the combustion accounts estimated from the UNSD energy balances with the fully allocated EDGAR inventory emissions yields a set of emissions accounts for CO_2, CH_4, N_2O, and F-gas emissions in the same sectoral format as the OECD IO tables. All that remains is to convert the CH_4, N_2O, and F-gas emissions into units of CO_2 equivalent by applying 100-year Global Warming Potential (GWP100) factors. The factors used in this step are the most recent estimates from the IPCC in the AR6. This step completes the set of estimated emissions accounts in CO_2e for each country, which are now ready to be used alongside the OECD Air Emissions Accounts in environmentally extending the IO tables.

Calculating the Final Emissions Factors

The OECD ICIO table is used to calculate the associated 'Leontief Inverse' in the standard manner described previously, before being environmentally extended using the OECD and estimated environmental accounts. This gives a set of emissions factors covering 79 countries and 50 sectors, representing the total emissions intensity per $US of output for each sector in each country. A final demand-based set of factors is also calculated by employing both the industry output-based factors and the final demand data within the OECD ICIO table to calculate weighted average emissions factors. The final demand-based factor for each sector in each country represents the weighted average of the goods or services bought by the final consumer within that sector, taking account of the country of origin. For example, the final demand-based factor for textiles in the UK is higher than the industry output-based factor, due to the higher prevalence of carbon-intensive imports in final demand compared to the intermediate demand of UK-based textile producers.

Using the environmentally extended MRIO model, both these sets of factors can be split further into Scope 1 (direct emissions), Scope 2 (indirect emissions from electricity consumption), and Scope 3 (all other upstream indirect emissions). Each set of factors is combined with additional layers of modelling, focusing on price margins and inflation. All factors thus far are calculated at basic prices, which represent the basic cost of the product or service; however, this is not usually the price paid by the consumer.

Purchasers' prices are defined as the basic price plus taxes (less subsidies), wholesale/retail margins, and transport margins. For each sector in each country, a ratio of purchasers' prices to basic prices is estimated using supply and use tables sourced via the OECD and national statistical agencies. This ratio is used to adjust each set of emissions factors so that they can be expressed as either basic or purchasers' prices.

Data from the International Monetary Fund (IMF, 2025) on the consumer price index (CPI) for each country is used to adjust each set of factors for inflation up to 2024, thereby bringing the prices and emissions factors more up to date. Note that the factors for 2023 and 2024 are estimated using inflation-adjusted 2022 figures. The IMF CPI sectors are coarse, meaning that only a rough mapping of these indices onto the MRIO model's sectors can be carried out; however, this is still preferable to using older figures. More recent quarterly data relating to the current year has been published; however, this data is only available for selected countries and consequently has not been used. Due to recent high inflation rates, adjusting the emissions factors for specific countries of interest using the latest available CPI data would be recommended.

Four scopes (total, scope 1, scope 2, scope 3), two bases (country of production -based, and country of demand -based), and two prices (basic and purchasers') give a total of 16 different variations of the original set of factors from the MRIO model for each year. The final step entails incorporating these factors with the SWC UK single-region model described below. The purpose: to upscale the sectoral resolution from 50 to 102 sectors by assuming that some SWC subsectors within each OECD/MRIO sector have a similar ratio to each other. This is achieved by applying sector- and country-specific multipliers, derived from the emissions factors from the full MRIO model, to the 2018 - 2022 SWC UK models. The multipliers are calculated using the 2018 - 2022 single-region OECD IO tables for the UK, in order to calculate a baseline emissions factor comparable to the SWC UK model. Every emissions factor from each of the 16 variant sets of the MRIO model is then divided by the relevant sector's baseline emissions factor from the OECD-based UK single-region model, resulting in a multiplier which can be used to adjust the 2018 - 2022 SWC UK models.

The final dataset of emissions factors, therefore, covers 79 countries, 102 sectors, 4 scopes, 2 bases, 2 prices, and 7 years to give a total of 902,496 emissions factors in units of kgCO_2e / £GBP.

SWC UK Model Methodology

The following methodology describes the SWC UK model to which the MRIO-derived multipliers are applied. In the UK, the main data sources are the combined supply and use matrix for 104 sectors provided by the Office of National Statistics (ONS, 2024a) and the UK environmental accounts (ONS, 2024b). The specific model used for this project was developed by Small World Consulting with Lancaster University (Berners-Lee et al., 2011).

Description of EEIO Modelling

A technical coefficients matrix of inputs from each sector per unit output of each sector is derived from Table 2: “Industries’ intermediate consumption, The ‘Combined Use’ matrix”, in combination with Table 4: “Gross fixed capital formation by industry”, based on 2018-2022 data and figures obtained from the ONS (2024a). This matrix summarises the inter-industry spending of industries in the UK economy by 104 industry groups. This information is usually derived from use tables of inputs at basic prices, which are output prices before distributors’ margins, taxes, or subsidies have been applied. However, for the UK, basic prices have not been published since 1995, the ‘Combined Use’ matrix now being published in purchasers’ prices. Therefore, the latter are used in subsequent calculations. This entails the assumption that demand at purchasers’ prices (including taxes, subsidies and distributors’ margins) is as good a guide to industry activity as demand at basic prices. The summation of the ‘Combined Use’ matrix and the ‘Gross fixed capital formation by industry’ table forms the basis of the IO model. From this, the technical coefficients matrix and the Leontief Inverse are constructed using the standard method described previously.

The dataset *Atmospheric emissions: greenhouse gases by industry and gas* (ONS, 2024b) gives the GHG emissions during 2018-2022 arising directly from 131 Standard Industrial Code (SIC 2007) sectors. These are mapped onto the 104 ONS IO Table industry groups using a process of combining SIC codes into single Input-Output industry groups. Emissions from aviation at altitude are known to have a higher global warming impact than the same emissions at ground level. An emissions weighting factor of 1.7 was therefore applied to the CO_2 emissions associated with the air transport sector, to reflect additional radiative forcing per unit of GHG emitted. This is the figure currently recommended by DESNZ (2025). The application of this multiplier provides a first approximation of the impact of a complex yet poorly understood set of scientific phenomena surrounding aviation emissions.

UK output by sector at basic prices (ONS, 2024a) is combined with UK GHG emissions arising directly from each sector to derive coefficients of emissions per £GBP of UK output from each sector at basic prices. The total GHG emissions arising from each industry, covering their whole supply chain, may then be calculated by multiplying the Leontief Inverse matrix and the direct GHG intensity of each industry. This produces total GHG emissions factors in units of $kgCO_2e$ per £GBP of industry output at basic prices.

Other Key Notes on Methodology

Treatment of High-Altitude Emissions

High-altitude aeroplane emissions are known to have a higher global warming impact than their low-altitude counterparts. Although the science of this is still poorly understood, this study has applied a multiplier of 1.7 to aircraft emissions to take account of their higher impact. This is the figure currently recommended by DESNZ (2025).

Gross Fixed Capital Formation

The SWC UK model includes in its IO modelling gross fixed capital formation (GFCF), which is not a typical feature of many environmentally extended IO and MRIO models. However, since large, fixed assets can be key to certain industries and do indeed require the emission of GHGs in order to be produced, GFCF is included.

Uncertainties

There is great uncertainty over supply chain emissions resulting from the purchase of goods and services. The EEIO methodology adopted here removes the problem of systematic underestimation that compromises traditional life cycle approaches. Nevertheless, as with all footprint studies, the best estimates should be viewed as a broad guide.

A weakness is that the model is based on financial transactions, so there is no link to physical processes. This means it has the potential to be unrealistic when applied to the production of commodity materials. EEIO models depend on the structure of the national accounts, which usually aggregate a wide range of products into industry sectors, and so the results are very general. For example, a basic EEIO model does not take into account the carbon efficiencies that may arise from switching expenditure on paper from a virgin source to a renewable source, without reducing the actual spend.

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Appendix A: Regional Coverage of the OECD ICIO Tables

OECD economies		Non-OECD economies	
AUS	Australia	**AGO**	**Angola**
AUT	Austria	**ARE**	**United Arab Emirates**
BEL	Belgium	ARG	Argentina
CAN	Canada	BGD	Bangladesh
CHL	Chile	BLR	Belarus
COL	Colombia	BRA	Brazil
CRI	Costa Rica	BRN	Brunei Darussalam
CZE	Czechia	BGR	Bulgaria
DNK	Denmark	KHM	Cambodia
EST	Estonia	CMR	Cameroon
FIN	Finland	**COD**	**Democratic Republic of the Congo**
FRA	France	CHN	China (People's Republic of)
DEU	Germany	CIV	Côte d'Ivoire
GRC	Greece	HRV	Croatia
HUN	Hungary	CYP	Cyprus
ISL	Iceland	EGY	Egypt
IRL	Ireland	IND	India
ISR	Israel	IDN	Indonesia
ITA	Italy	JOR	Jordan
JPN	Japan	HKG	Hong Kong, China
KOR	Korea	KAZ	Kazakhstan
LVA	Latvia	LAO	Lao PDR
LTU	Lithuania	MYS	Malaysia
LUX	Luxembourg	MLT	Malta
MEX	Mexico	MAR	Morocco
NLD	Netherlands	MMR	Myanmar
NZL	New Zealand	NGA	Nigeria
NOR	Norway	PAK	Pakistan
POL	Poland	PER	Peru
PRT	Portugal	PHL	Philippines
SVK	Slovak Republic	ROU	Romania
SVN	Slovenia	RUS	Russian Federation
ESP	Spain	SAU	Saudi Arabia
SWE	Sweden	SEN	Senegal
CHE	Switzerland	SGP	Singapore
TUR	Turkey	**STP**	**Saõ Tomé and Príncipe**
GBR	United Kingdom	ZAF	South Africa
USA	United States	THA	Thailand
		TUN	Tunisia
		UKR	Ukraine
		VNM	Viet Nam

Table 1. The list of regions covered by the OECD IO tables in the latest 2025 release, split into OECD members and non-OECD members. The shading signifies countries for which the OECD also publishes Air Emission Accounts (AEAs) in sufficient sectoral detail to match the IO tables. Countries in bold are new additions.

Appendix B: Sectoral Classification of the OECD ICIO Tables

Code	Industry	ISIC Rev.4
A01	Agriculture and hunting	01
A02	Forestry and logging	02
A03	Fishing and aquaculture	03
B05	Mining of coal and lignite	05
B06	Extraction of crude petroleum and natural gas	06
B07	Mining of metal ores	07
B08	Other mining and quarrying	08
B09	Mining support service activities	09
C10T12	Food products, beverages and tobacco	10, 11, 12
C13T15	Textiles, textile products, leather and footwear	13, 14, 15
C16	Wood and products of wood and cork	16
C17_18	Paper products and printing	17, 18
C19	Coke and refined petroleum products	19
C20	Chemical and chemical products	20
C21	Pharmaceuticals, medicinal chemical and botanical products	21
C22	Rubber and plastic products	22
C23	Other non-metallic mineral products	23
C24A	Manufacture of basic iron and steel	24.1-3
C24B	Manufacture of basic precious and other non-ferrous metals	24.4-5
C25	Fabricated metal products	25
C26	Computer, electronic and optical equipment	26
C27	Electrical equipment	27
C28	Machinery and equipment, nec	28
C29	Motor vehicles, trailers and semi-trailers	29
C301	Building of ships and boats	30.1
C302T309	Manufacture of other transport equipment	30.2-9
C31T33	Manufacturing nec; repair and installation of machinery and equipment	31, 32, 33
D	Electricity, gas, steam and air conditioning supply	35
E	Water supply; sewerage, waste management and remediation activities	36, 37, 38, 39
F	Construction	41, 42, 43
G	Wholesale and retail trade; repair of motor vehicles	45, 46, 47
H49	Land transport and transport via pipelines	49
H50	Water transport	50
H51	Air transport	51
H52	Warehousing and support activities for transportation	52
H53	Postal and courier activities	53
I	Accommodation and food service activities	55, 56
J58T60	Publishing, audiovisual and broadcasting activities	58, 59, 60
J61	Telecommunications	61
J62_63	IT and other information services	62, 63
K	Financial and insurance activities	64, 65, 66
L	Real estate activities	68
M	Professional, scientific and technical activities	69 to 75
N	Administrative and support services	77 to 82
O	Public administration and defence; compulsory social security	84
P	Education	85
Q	Human health and social work activities	86, 87, 88
R	Arts, entertainment and recreation	90, 91, 92, 93
S	Other service activities	94,95, 96
T	Activities of households as employers; undifferentiated goods- and services-	97, 98

Table 2: The full list of the 50 sectors covered by the OECD IO tables.

Appendix C: Full List of Data Sources by Organisation

The following is an exhaustive list of the data sources used within the SWC MRIO model, broken down by the organisation supplying the data.

OECD

- Air Emissions Accounts
  https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_AEA@DF_AEA&df[ag]=OECD.SDD.NAD.SEEA
- Input-Output Tables (IOTs) 2025 ed.
  https://www.oecd.org/sti/ind/input-outputtables.htm
- Inter-Country Input-Output (ICIO) Tables 2025 ed.
  https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm
- Air Transport CO2 Emissions
  https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_AIR_TRANSPORT@DF_AIR_TRANSPORT&df[ag]=OECD.SDD.NAD.SEEA
- Maritime Transport CO2 Emissions
  https://data-explorer.oecd.org/vis?df[ds]=DisseminateArchiveDMZ&df[id]=DF_MTE&df[ag]=OECD&df[vs]=1.0
- Trade in Employment (TiM) 2023 ed.
  https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_TIM_2023@DF_TIM_2023&df[ag]=OECD.STI.PIE
- Supply and Use Tables
  https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_NASU@DF_SUPPLY_T1500&df[ag]=OECD.SDD.NAD

UN

- UN Statistics Division (UNSD) - Energy Balances
  https://unstats.un.org/unsd/energystats/pubs/balance/
- UN Conference on Trade and Development (UNCTAD) - Merchant fleet by flag of registration and by type of ship, annual
  https://unctadstat.unctad.org/datacentre/dataviewer/US.MerchantFleet

- UN Conference on Trade and Development (UNCTAD) - Merchant fleet by country of beneficial ownership, annual https://unctadstat.unctad.org/datacentre/dataviewer/US.FleetBeneficialOwners
- UN Economic Commission for Latin America and the Caribbean (ECLAC) **-** Supply and Use Tables https://statistics.cepal.org/repository/cou-mip/index.html?lang=en

EU Joint Research Centre (JRC)

- Emissions Database for Global Atmospheric Research (EDGAR) https://edgar.jrc.ec.europa.eu/emissions_data_and_maps

IPCC

- Global Warming Potential (GWP) AR6 2021 ed. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FGD_Chapter07_SM.pdf
- Emission Factor Database https://www.ipcc-nggip.iges.or.jp/EFDB/main.php

World Health Organisation (WHO)

- Registered Vehicles Data by Country https://apps.who.int/gho/data/node.main.A995

International Maritime Organisation (IMO)

- Annual Average Total Fuel Consumption by Ship Type and Capacity https://greenvoyage2050.imo.org/fleet-and-co2-calculator/

Asian Development Bank (ADB)

- Supply and Use Tables https://data.adb.org/search/content/type/dataset/type/dataset/tags/supply-and-use-tables-sut-132

Misc. Government Statistical Agencies

- Egypt Supply and Use Tables
  https://censusinfo.capmas.gov.eg/Metadata-en-v4.2/index.php/catalog/518
- Jordan Supply and Use Tables
  https://dosweb.dos.gov.jo/nationalaccount/input-and-output/
- Kazakhstan Supply and Use Tables
  https://stat.gov.kz/en/industries/economy/national-accounts/publications/109691/
- Philippines Supply and Use Tables
  https://psa.gov.ph/statistics/supply-and-use-input-output
- Saudi Arabia Supply and Use Tables
  https://www.stats.gov.sa/en/1158
- Tunisia Supply and Use Tables
  http://www.ins.tn/en/publication/national-accounts-2017-2021
- Ukraine Supply and Use Tables
  https://www.ukrstat.gov.ua/operativ/menu/menu_e/nac_r.htm

International Monetary Fund (IMF)

- Consumer Price Index (CPI) by Country
  https://data.imf.org/?sk=4FFB52B2-3653-409A-B471-D47B46D904B5&sId=1485878708037

U.S. Department of the Treasury

- US Dollar Rates of Exchange
  https://fiscaldata.treasury.gov/datasets/treasury-reporting-rates-exchange/

Office for National Statistics (ONS)

- Energy Use: by Industry, Source and Fuel 2025 ed.
  https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsenergyusebyindustrysourceandfuel
- Input-Output Supply and Use Tables 2024 ed.
  https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables
- Atmospheric Emissions: Greenhouse Gases by Industry and Gas 2024 ed.
  https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalaccountsatmosphericemissionsgreenhousegasemissionsbyeconomicsectorandgasunitedkingdom

Department for Energy Security and Net Zero (DESNZ)

- National Atmospheric Emissions Inventory (NAEI) https://naei.energysecurity.gov.uk/

Appendix D: Key Changes From v2.0

The following details the main changes from v2.0 of the model.

OECD ICIO

The latest release of the OECD's Inter-Country Input-Output (ICIO) table has added 4 new countries to the model, as seen in Appendix A, and now includes data up to 2022. This means that v3.0 of the SWC MRIO model has added those 4 new countries, taking the total from 75 to 79, and now fully models the years 2021 and 2022. Previously, the data only included up to 2020, and the factors for 2021-2024 were estimated using inflationary adjustments. The latest OECD release also increases the granularity of the ICIO data from 45 to 50 sectors. This has allowed for a more accurate handling of sectors relating to forestry, mining, and the production of basic metals.

Retroactive Data Updates

All of the data used in the model, as listed in Appendix C, has been updated to the most recent version. Of course, this will affect factors for 2021 and 2022 as they are now fully modelled, but it also affects 2018 - 2020 factors too, as many of the datasets used to build the model retroactively update their figures. This is largely due to better data becoming available over time, methodology improvements, and error corrections. This also has a knock-on effect for the 2023 - 2024 factors since they are projected from the 2022 factors.

Inflationary Adjustments

In v2.0, the years 2021-2024 were estimated using inflationary adjustments applied to 2019 and 2020. Now that 2021 and 2022 are fully modelled, the inflationary adjustments are only required to estimate the years 2023 and 2024. These adjustments are applied to 2022.

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