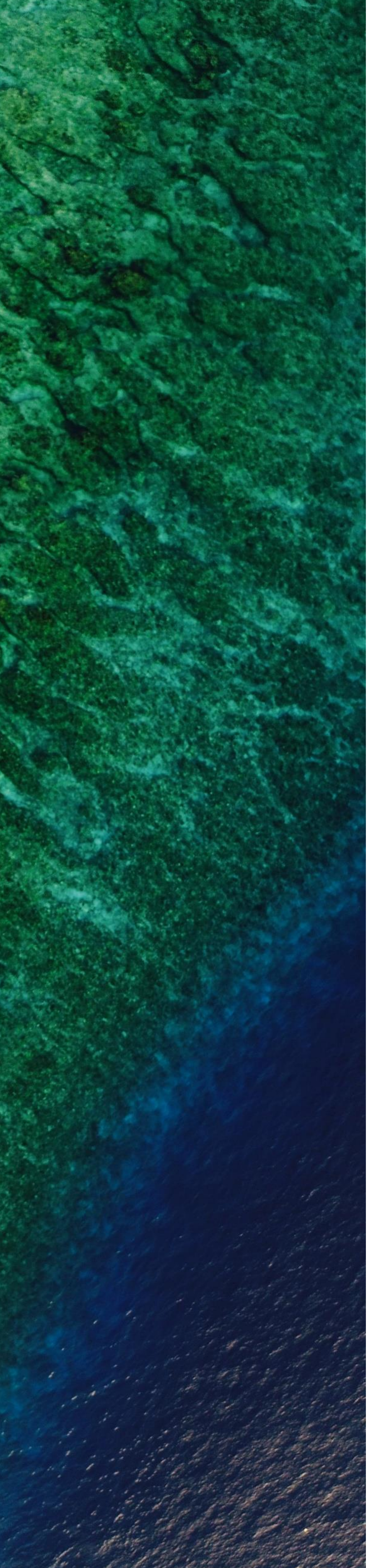

Multi-regional Input-Output (MRIO) Emissions Factors v1.0

Comparison & Validation

September 2023

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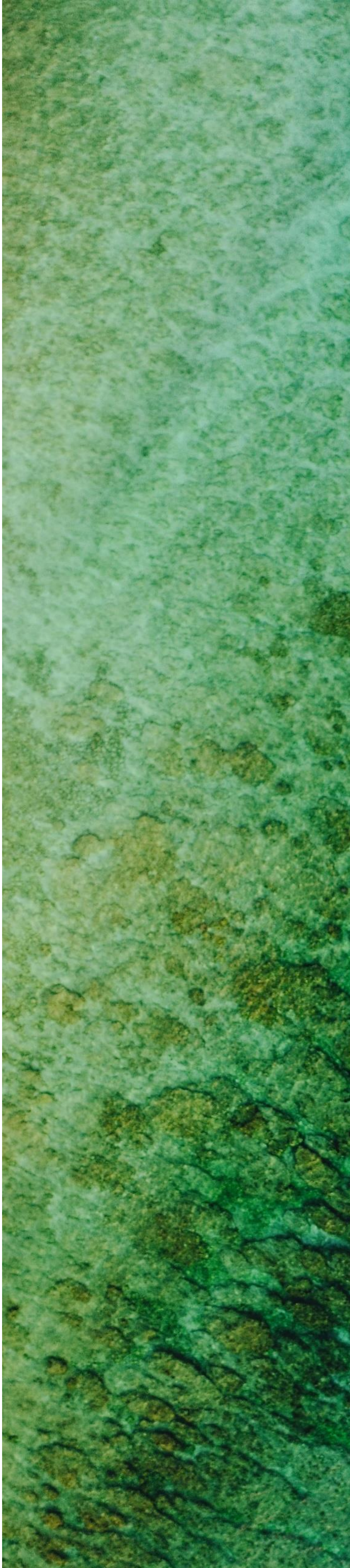
Contents



A report by Small World Consulting Ltd
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Executive Summary

This document lays out work conducted so far on comparing the results of the SWC MRIO model with other leading MRIOs. We provide likely explanations for some of the key differences. As a further test of the realism of the results of the SWC MRIO and other models, we compare their electricity emissions factors with those estimated from national electricity price and grid emissions intensity data. This provides feedback for further model development and provides evidence for users as to the likely realism of the various models.

The SWC MRIO model emissions factors were first compared against those of EXIOBASE, by carefully selecting the appropriately aligned versions of each model to carry out a fair comparison. Some modelling layers, such as aviation radiative forcing factors and the addition of gross fixed capital formation in intermediate demand – which were present in the SWC MRIO model but not present in EXIOBASE – were also removed in order to harmonise the models. Finally, to achieve a broad comparison with like-for-like sectors, a new sector classification system was developed: a hybrid of the SWC MRIO's sectors and those in EXIOBASE. Overall, 70% of the emissions factors compared were within a factor of 2 of each other, and over half were within a factor of 1.55. We consider this to be a somewhat encouraging level of agreement, given the differences between the models in terms of the datasets used and methodological details. On average the SWC MRIO model's emissions factors were slightly larger than EXIOBASE's, with a median ratio of 1.13 which rose to 1.15 when the emissions factors were weighted by their total emissions. There were some significant outliers, with ~2.6% of emissions factors differing by a factor of more than 10 between the models. Whilst it is difficult to trace the origin of all these discrepancies, some major contributing factors can be identified.

An attempt was made to ground truth the models for one sector, the electricity sector, since a direct emissions factor may be calculated using grid intensity and price data. In this validation process, it was found that the SWC MRIO model was usually closer to the estimated "true" electricity emissions factor for each country. The median ratio of the SWC MRIO emissions factor to the estimated "true" value was 0.97, whilst the ratio for EXIOBASE was 0.46. The EXIOBASE electricity factors were volatile, with some differing from the estimated "true" value and the SWC MRIO value by a factor of more than 10, or even 100. Out of the 41 countries compared, EXIOBASE was within a factor of 2 of the estimated "true" value for only 15 of them, whilst the SWC MRIO model was within a factor of 2 for 29 countries.

Due to Eora's data not being freely available, only a limited amount of comparison could be conducted. Emissions factors from the full version of Eora, for the Netherlands only, were subjected to a three-way comparison between Eora, EXIOBASE and the SWC MRIO model, in a common 51-sector format. It was found that the SWC MRIO model's emissions factors

generally tended to fall between those of Eora and EXIOBASE, since for the 51 sectors compared, the SWC MRIO model's result was lower than that of Eora and EXIOBASE for 13 sectors, in between the two for 22 sectors, and higher than both for 16 sectors. The variability and lack of agreement between Eora and EXIOBASE made it difficult to compare the SWC MRIO model factors against any kind of consensus value – no consensus existed. One big driver of this lack of consensus is likely to be Eora's emissions accounts.

The "UKMRIO" model was developed by the University of Leeds for use with the UK government's Department for Environment Food and Rural Affairs (Defra) in order to estimate the UK's consumption-based greenhouse gas (GHG) footprint. Therefore, the model only publishes emissions factors for the UK. Again, to make the comparison as fair as possible, some modelling layers that are excluded from the UKMRIO model were removed from the SWC MRIO model, and consumption-based figures were calculated in order to be comparable with the UKMRIO's factors. It was found that the models agree relatively well, with just over half the emissions factors agreeing to within a factor of 1.35 and the vast majority agreeing within a factor of 2. There were a few outliers, with agreement beyond a factor of 2, but these were largely limited to small sectors with known boundary or data issues. Around 95% of UK emissions were represented by sectors which agreed within a factor of 2.

The analysis so far has shown that the SWC MRIO model passes sense checks and comparisons at least as well as other leading models do, and in many cases surpasses them. The variability between the results from Eora and EXIOBASE makes it difficult to compare the SWC MRIO results against a consensus value, since consensus is largely absent. However, a consensus value still would not fully validate the final emissions factors, and thus – as has been carried out here with direct electricity emissions factors – other key commodities could be compared against the MRIO models in an attempt to ground truth them. This would require a commodity which a) adequately represents the sector encompassing it and b) has good region-specific data available on the emissions required to produce it, and on its price. Commodities like steel may be good candidates for this ground truthing exercise, which would help with achieving a much-needed understanding of the true accuracy of each MRIO model.

Comparison with the EXIOBASE Model

The EXIOBASE Model

EXIOBASE is an ongoing EU-funded project, predominantly led by Richard Wood and Arnold Tukker, currently in its third iteration. The main goal of the project is to create a freely available, environmentally extended global MRIO database, with a focus on suitability for environmental analyses and compatibility with the UN's System of Environmental Economic Accounting (SEEA). The latest major release (EXIOBASE 3, in 2018) includes a supply and use table made up of 200 product sectors and 163 industry sectors, which has been used to produce MRIO tables in an Industry-by-Industry format and a Product-by-Product format. The model covers 28 EU countries, plus 16 other major economies and 5 "Rest of the World" (ROW) regions. The original input-output data series ends in 2011, but macroeconomic data have been used to forecast this forward to 2022. As the model has an environmental focus there are numerous relevant satellite accounts published, including but not limited to: land use, GHG emissions, other air pollutants, water use, material use, and energy use [1][2].

Collection and Harmonisation of Data

In order to conduct a comparison, the relevant data from the EXIOBASE project were first collected. The latest version (3.8.2) of the industry-by-industry monetary model for 2018 was chosen as the point of comparison, as this most closely relates to the approach and base year of the SWC MRIO model. From this dataset, data were collected on the monetary output, direct emissions, direct emissions intensity, and total emissions intensity for each of the country and sector combinations in the model. Where relevant, price units were then converted from Euros to Great British Pounds, using the average exchange rate for 2018 [3].

The SWC MRIO model differs from the EXIOBASE model on a couple of important inclusions which would affect the results of a comparison. The inclusions are Gross Fixed Capital Formation (GFCF) and a high-altitude radiative forcing factor for air transport. To conduct a more level comparison, a version of the SWC MRIO model without these two features was created.

The models differ in the number of countries covered, since the EXIOBASE model includes 44 countries plus 5 "Rest of the World" (ROW) regions, whereas the SWC MRIO model includes 65 countries. All countries included in the EXIOBASE model are also in the SWC MRIO model, so for comparison purposes EXIOBASE's 5 ROW regions were ignored, as were the 21 countries in the SWC MRIO model that are absent from EXIOBASE. See Appendix D for a full list of countries common to both models.

As the sectoral classification system used by EXIOBASE is different to that used by the SWC MRIO, a hybrid set of sectors was developed in order to compare the results from both models fairly. This hybrid classification aimed to retain as many common sectors as possible, and only aggregate sectors when necessary, to provide the highest number of points of comparison. The SWC MRIO model contains 105 sectors, whilst the EXIOBASE model contains 163. A large proportion of the sectors are one-to-one mappings between the models; however, several many-to-one or many-to-many mappings were also required, resulting in the final set of common sectors numbering 61. When aggregation of sectors was required for either model, monetary output and direct emissions could simply be summed. To aggregate the direct emissions intensity and total emissions intensity, a weighted average was employed using the outputs of each sector as the basis for weighting. The final set of sectors, used for mapping of both models, is shown in Table 1. The original sets – 105 sectors from the SWC MRIO and 163 sectors from EXIOBASE – can be seen in Appendix A and Appendix B respectively. In Table 1, the "Mapping" column shows the source of the sector definition. Here, "SWC" means the sector definition used is taken from the SWC MRIO model set of sectors, meaning that EXIOBASE sectors have been aggregated to match this with the number of aggregated sectors shown in the "# of sub-sectors" column. "EXIO" means the definition is taken from the EXIOBASE set of sectors and hence SWC sectors have been aggregated to match it. "Both" means both models share the same sector definition, and thus the mapping is one-to-one and no aggregation is required. "Hybrid" means that many-to-many mapping was required, and thus a new broader sector definition was created by aggregating both SWC and EXIOBASE sectors.

Sectors	Mapping	# sub-sectors
Crop And Animal Production, Hunting And Related Service Activities	SWC	17
Forestry And Logging	Both	1
Fishing And Aquaculture	Both	1
Mining Of Coal And Lignite	Both	1
Extraction Of Crude Petroleum And Natural Gas & Mining Of Metal Ores	SWC	11
Other Mining And Quarrying	SWC	3
Processing and Preserving of Meat and Production of Meat Products	SWC	4
Manufacture of Vegetable and Animal Oils and Fats	Both	1
Manufacture of Dairy Products	Both	1
Rest of Food, Beverage, Tobacco	Hybrid	7 & 6
Manufacture Of Textiles	Both	1
Manufacture Of Wearing Apparel	Both	1
Manufacture Of Leather And Related Products	Both	1
Manufacture Of Wood & Products Of Wood & Cork, Except Furniture; Manuf. Of Articles Of Straw	SWC	2
Manufacture Of Paper And Paper Products	SWC	3
Publishing, Printing and Reproduction of Recorded Media (22)	EXIO	2
Manufacture Of Coke And Refined Petroleum Products	SWC	2
Chemicals	Hybrid	7 & 5
Manufacture Of Rubber And Plastic Products	Both	1
Manufacture of Cement, Lime, Plaster and Articles of Concrete, Cement and Plaster	SWC	3
Manufacture of Glass, Refractory, Clay, Porcelain, Ceramic, Stone Products - 23.1-4/7-9	SWC	5
Manufacture of Basic Iron and Steel	SWC	2
Manufacture of Other Basic Metals and Casting	SWC	12

Manufacture of Fabricated Metal Products, Except Machinery and Equipment (28)	EXIO	2
Manufacture Of Computer, Electronic And Optical Products	SWC	3
Manufacture Of Electrical Equipment	Both	1
Manufacture Of Machinery And Equipment N.E.C.	Both	1
Manufacture Of Motor Vehicles, Trailers And Semi-Trailers	Both	1
Manufacture of Other Transport Equipment (35)	EXIO	5
Manufacture of Furniture; Manufacturing N.E.C. (36)	EXIO	3
Electric Power Generation, Transmission and Distribution	SWC	14
Manufacture of Gas; Distribution of Gaseous Fuels Through Mains; Steam and Aircon Supply	SWC	2
Water Collection, Treatment And Supply	SWC	1
Sewerage	SWC	2
Waste Collection, Treatment And Disposal Activities; Materials Recovery	SWC	20
Construction	SWC	2
Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles	Both	1
Wholesale Trade, Except Of Motor Vehicles And Motorcycles	Both	1
Retail Trade, Except Of Motor Vehicles And Motorcycles	SWC	2
Rail Transport	Both	1
Land Transport Services and Transport Services Via Pipelines, Excluding Rail Transport	SWC	2
Water Transport	SWC	2
Air Transport	Both	1
Supporting and Auxiliary Transport Activities; Activities of Travel Agencies (63)	EXIO	2
Post and Telecommunications (64)	EXIO	2
Hotels and Restaurants (55)	EXIO	2
Computer and Related Activities (72)	EXIO	2
Financial Service Activities, Except Insurance And Pension Funding	Both	1
Insurance and Reinsurance, Except Compulsory Social Security & Pension Funding	Both	1
Activities Auxiliary To Financial Services And Insurance Activities	Both	1
Real Estate Activities (70)	EXIO	3
Other Business Activities (74)	EXIO	10
Scientific Research And Development	Both	1
Rental And Leasing Activities	Both	1
Public Administration And Defence; Compulsory Social Security	Both	1
Education	Both	1
Health and Social Work (85)	EXIO	3
Recreational, Cultural and Sporting Activities (92)	EXIO	5
Activities Of Membership Organisations	Both	1
Other Service Activities (93)	EXIO	2
Activities Of Households As Employers Of Domestic Personnel	Both	1

Table 1: A table showing the set of hybrid sectors developed to run an effective comparison of the SWC MRIO model and the EXIOBASE model. The “Mapping” column indicates which model the sector definition is taken from, whilst the “# of sub-sectors” column shows the number of sectors in the other model that required aggregation to meet the sector definition.

Comparison of the Models

With the regional and sectoral classification of both models aligned, their respective results could be compared. This predominantly involved calculating the ratio of one model's results to the other's, to gain a sense of how much they agree. Some sectors, for example retail, were excluded from the comparison due to differences in how margins are handled by the models. The "Households as Employers" sector was also excluded due to the high variability occurring within it. This arises due to the limitations of the data available for the sector.

The most important results to compare are the total emissions intensity or total emissions factors of each country and sector, as these are the main outputs for the models which are used in footprinting. Multiplying the 43 countries by 57 sectors (down from 61 due to the excluded sectors) gives a total of 2,451 data points that can be compared. For a given total emissions intensity of a country and sector, the ratio of the SWC MRIO model result to the EXBIOASE model result was calculated and some simple summary statistics were produced.

A histogram showing the distribution of the ratios of the results is presented in Figure 1. Note that x-axis values larger than 1 indicate that the SWC MRIO model has produced a larger total emissions factor than the EXIOBASE model. In Figure 1 it can be seen that the ratios are centred around 1 which supports that, on average, the models agree reasonably often. The median of all the ratios was calculated to be 1.15, whilst ratios between 0.5 and 2 accounted for 69.5% of the results. In other words, nearly 70% of the emissions factors from both models agreed within a factor of two. Some might consider a factor of two to be quite a large difference; however, it is indicative of the highly variable nature of MRIO modelling at the detailed level of individual sectors in individual countries. The majority of the ratios, just over 50%, indicated that most emissions factors agreed within a factor of 1.55. There were some erratic ratios, with the full spread ranging from 0.009 to 569, but these are comparatively fewer in number. 2.63% of the ratios were larger than 10 or smaller than 0.1, meaning that for around 1 in 38 emissions factors, the models' results disagreed by a factor of more than 10. The mean of all the ratios came out at 2.05, due to some of the outliers skewing the average. Calculating a weighted average, i.e. weighting a given ratio by the quantity of emissions arising from the respective sector and country, gives a weighted mean of 1.13. This suggests that the outliers skewing the mean are of lesser importance to total global emissions. In other words, the larger disagreements between the models occur more frequently in smaller sectors in small countries which contribute less to emissions.

Often, the larger outlier ratios are spread out somewhat randomly between sectors and countries, which suggests that these could be driven by disagreements in the underlying data used by the models, rather than by a systematic methodological difference. Some of the larger ratios are, however, approximately grouped in certain sectors and countries, meaning that the emissions factors for these countries and sectors could be affected by the different methodological assumptions and approaches of the models. Figures 2 and 3 show summaries of the emissions factor ratios by country and by sector respectively, detailing the degree of agreement within a given level. Figure 2 roughly shows that the models tend to be more in agreement for European countries which publish high-quality data, a good basis for constructing models. At the other end are some economically significant countries such as Russia, Brazil, and India which do not publish high-quality data, for which the modelling therefore requires more estimations and assumptions. This is reflected in the greater variability and disagreement for these countries. Figure 3 shows that there is no clear pattern relating to whether agreement between the models is more likely for industry-based sectors or service-based sectors. The sectors with some of the higher levels of disagreement include sewerage, manufacture and distribution of gas, extraction of crude petroleum, and mining of coal and lignite. These are sectors which often involve large amounts of fugitive emissions which can be extremely difficult to estimate, since data tend to be scarce or at best, highly variable.

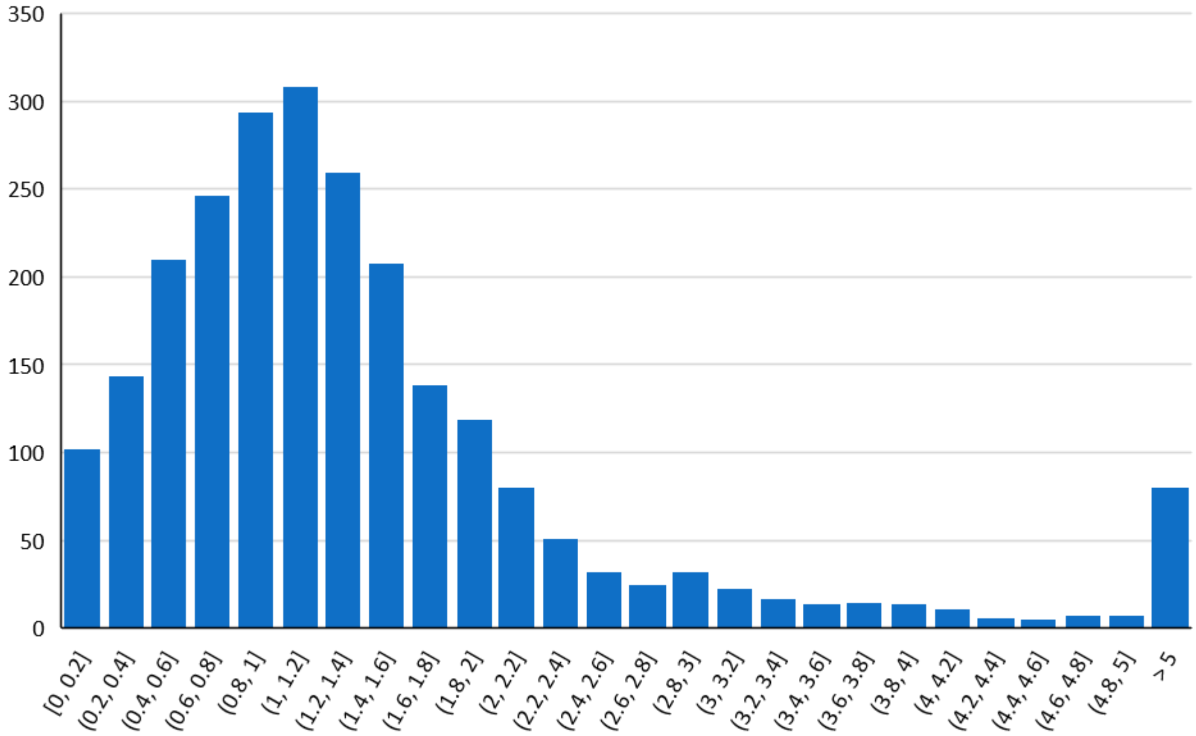

Figure 1: The distribution of the ratios of emissions factors (SWC/EXIOBASE) for each country and industry combination.

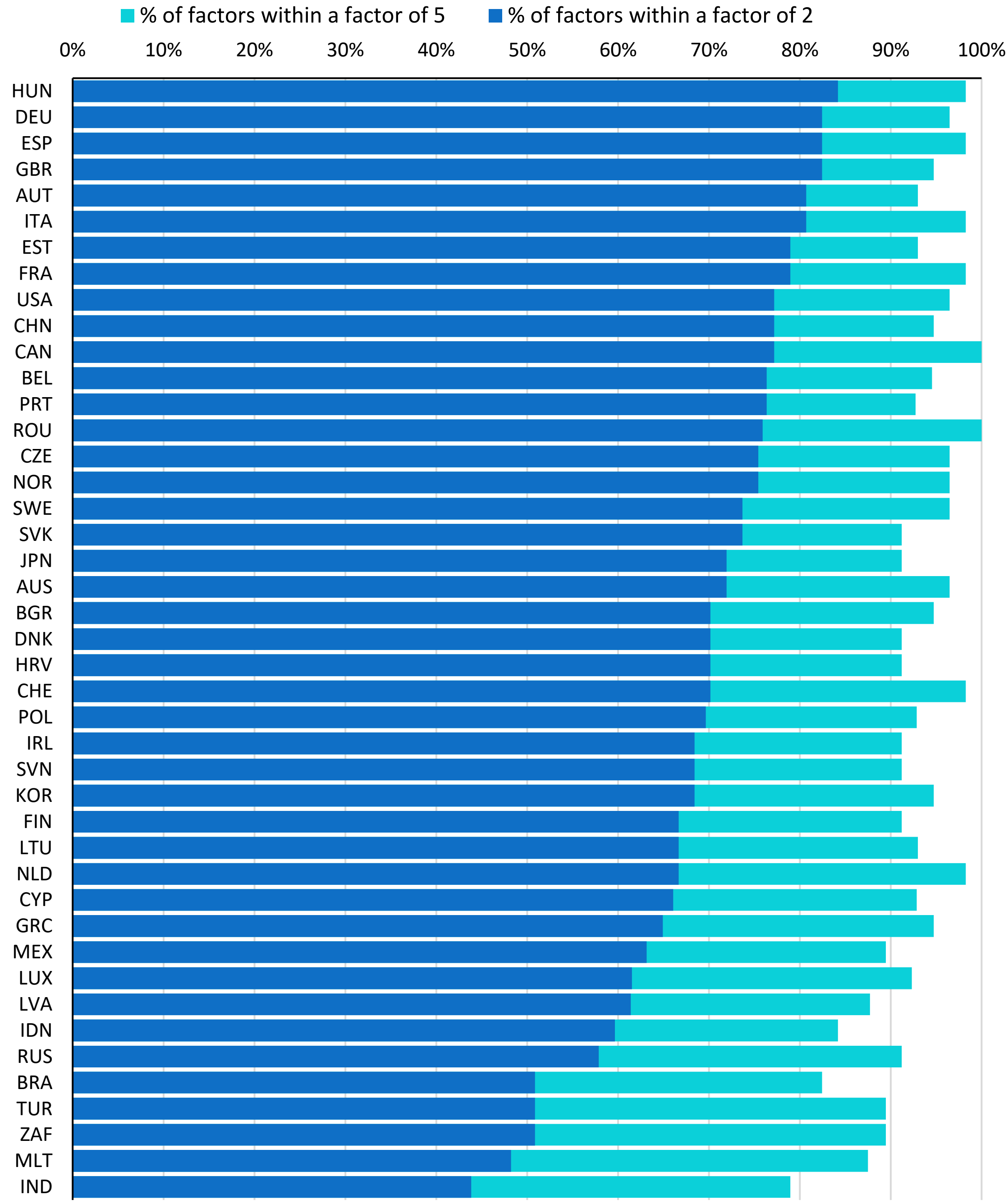

Figure 2: The percentage of sectors in each country where the emissions factors from both the SWC MRIO and EXIOBASE models agree within factors of 2 and 5. See Appendix D for a full list of country codes.

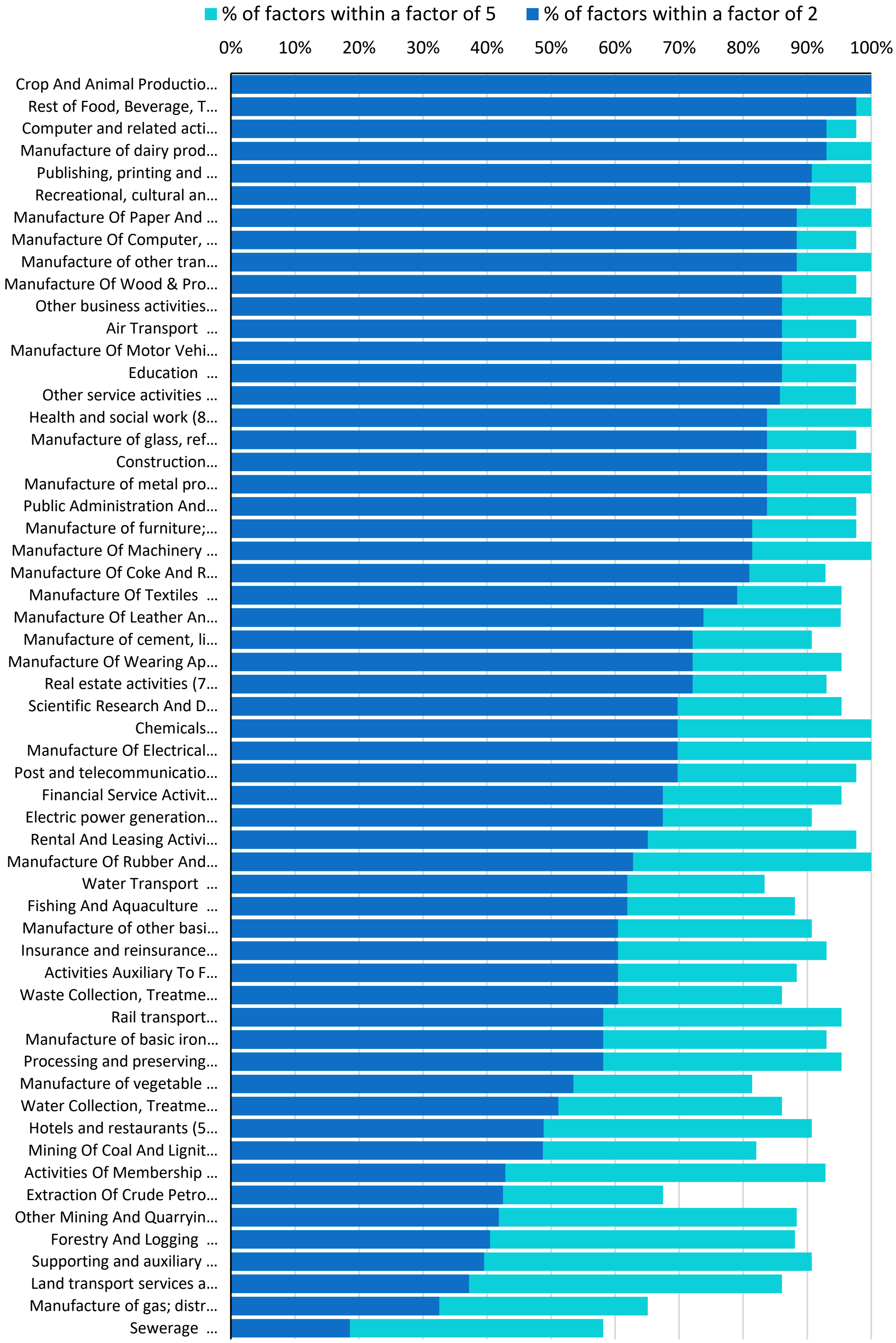

Figure 3: The percentage of countries in each sector where both the SWC MRIO and EXIOBASE models agree within factors of 2 and 5. See Table 1 for full sector names.

Comparison with the Eora Model

The Eora Model

Eora is an ongoing project funded by the Australia Research Council. It is constructed differently from other MRIO tables, due to the goal of leaving the source data as unaltered as possible instead of harmonising all countries into a common format. Eora covers 190 countries, representing around 98% of global GDP for the period of 1990-2018, which is further forecasted to 2022. However, for many of these countries data do not exist, so figures are estimated by modifying data from other countries using some known macroeconomic data. As the number of sectors is heterogenous, it is different for each country, ranging from 26 to 511 sectors. The total number of sectors is 15,909 which gives a simplistic average resolution of 84 sectors. Eora also publishes a harmonised 26-sector version of the model in a regular MRIO format. There are numerous satellite accounts published alongside the model including GHG emissions, labour inputs, air pollution, energy use, water requirements and land use [4][5].

Collection and Harmonisation of Data

In order to conduct a comparison, the relevant data from the Eora project were first collected. The latest version (v199.82) of the model, at basic prices for 2016, was chosen as the point of comparison, as this most closely relates to the approach and base year of the SWC MRIO model. 2018 data could unfortunately not be used due to limitations of the licensing. From this dataset, data on the direct GHG emissions for each country and sector in the model were collected in units of $kgCO_2e$. Due to the heterogenous nature of the Eora model, a like-for-like comparison of the accounts for each country would be laborious and ultimately remove the ability to assess the average accuracy of each sector. For this reason, data from only one country were selected, to give a sense of the level of agreement between models. The country selected was the Netherlands, primarily since Eora's sectoral format for this country was already close to the hybrid 61-sector format used in the comparison with EXIOBASE.

The SWC MRIO model differs from the Eora model on a couple of important inclusions which would affect the results of a comparison. The inclusions are Gross Fixed Capital Formation (GFCF) and a high-altitude radiative forcing factor for air transport. To conduct a more level comparison, a version of the SWC MRIO model without these two features was created. As with the EXIOBASE comparison, the sectoral classification system used by Eora is different to that used by the SWC MRIO. For the Netherlands, Eora's total number of sectors was 61, whereas there were 105 in the SWC MRIO. However, the hybrid set of 61 sectors initially developed for the EXIBOASE comparison could be reused here, to enable a 3-way comparison between the SWC MRIO, Eora, and EXIOBASE. This hybrid classification aimed to retain as many common sectors as possible, and only aggregate sectors when necessary, to provide the highest number of points of comparison.

Although the Eora dataset contained 61 sectors, which is the same number as the set of hybrid sectors detailed in Table 1, mapping was still required. Some sectors were aggregated or excluded in order to give a fair comparison with EXIOBASE and the SWC MRIO model. This meant that the final number of sectors used for the comparison between all three models was 51, and these sectors are listed in Figure 4. The original set of 61 Eora sectors for the Netherlands may be seen in Appendix C. Eora's emissions factors are given in units per US dollar, which was converted to Great British Pounds using the average exchange rate for 2018 [6].

Comparison of the Models

With the sectoral classification of all models aligned, their respective results could be compared. Again, this involved calculating the ratio of one model's results to another's, to gain a sense of how much they agree. Some sectors, predominantly retail, were excluded from the comparison due to differences in how margins are handled by the models. The "Households as Employers" sector was also excluded due to the high variability occurring within it. This arises due to the limitations of the data available for the sector. It should also be reiterated that this analysis is only for one country, the Netherlands, so overall trends in the models are difficult to discern. It is still useful, however, to gauge the overall level of agreement when considering that European countries such as the Netherlands often publish the kind of higher-quality data required in order to produce an IO model.

For the 51 sectors compared, the SWC MRIO model's emissions factors were lower than Eora's and EXIOBASE's for 13 sectors, in between the two for 22 sectors, and higher than both Eora and EXIOBASE for 16 sectors. There were some larger disagreements, not just between the SWC MRIO and the other leading models, but between Eora and EXIOBASE as well. For example, the SWC MRIO and EXIBOASE emissions factors for "Air Transport" and "Water Transport" agreed well (less than 20% difference) whilst the Eora figures for these sectors were over five times smaller. For the "Extraction of Crude Petroleum..." sector, the SWC MRIO's emissions factor was 1.75 times larger than Eora's, but around four times smaller than EXIOBASE's. Thus, the EXIOBASE figure was over seven times larger than Eora's for this sector. For the energy sector "Electric, gas, steam", the SWC MRIO model and EXIOBASE were in reasonable agreement, whilst Eora's figure was ten times smaller than EXIOBASE's. The latter two examples show the scale of disagreement among leading MRIO models, even when applied to a European country like the Netherlands which publishes high-quality data. The full results are depicted in Figure 4 as ratios relative to the SWC MRIO model. Positive values represent an emissions factor that is larger than the SWC MRIO model's result by a factor of the number displayed in the chart, whilst negative numbers represent a figure smaller than the MRIO result. At a glance, the SWC MRIO model's emissions factors appear to be fairly near the centre of the range, falling between those of Eora and EXIOBASE. The services industries towards the bottom of the list, however, may be slightly skewed towards the SWC MRIO model coming in lower when compared to Eora and EXIOBASE.

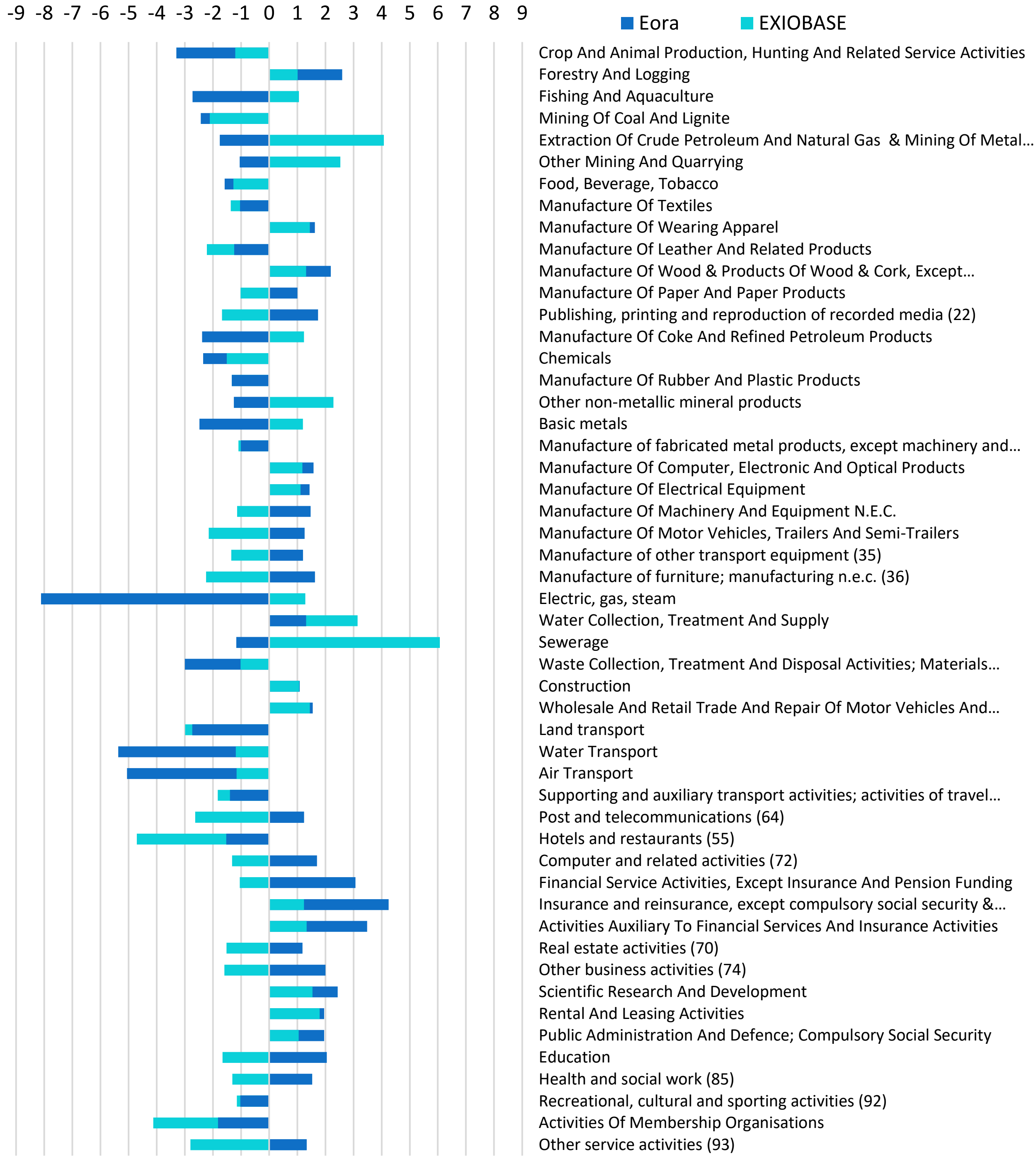

Figure 4: The relative differences between emissions factors from Eora, EXIOBASE, and the SWC MRIO for each sector. The Eora and EXIOBASE data points in the above chart represent the factor by which they differ from the SWC MRIO figures. For example, a value of 2.1 for Eora would mean Eora's emissions factor is 2.1 times larger than the SWC MRIO figure. Conversely, -2.1 would mean 2.1 times smaller. Note that the bars are overlaid and not stacked.

Comparison with the UKMRIO Model

The UKMRIO Model

The UKMRIO model is constructed by the University of Leeds each year, to assess the consumption-based emissions of the UK. The model was developed in place of using other available global MRIO models due to the consumption-based accounts being designated a "National Statistic". This means that the model must implement data from the Office for National Statistics (ONS) in such a way as to minimise any deviation from the original source data, to ensure consistency [7][8][9]. The use of non-publicly available ONS data imposes a sectoral resolution of 110 sectors on the model. The database contains 8 countries including the UK, the USA, the BRICS countries, and Japan, plus 7 other ROW regions. As the ONS only provides data for the UK, EXIOBASE has been used to fill the gaps for the other regions after mapping EXIOBASE's sectors onto the 110 sectors of the UKMRIO model.

Collection and Harmonisation of Data

The results from the UKMRIO model are published annually via the Department for Environment, Food & Rural Affairs (Defra) [9], meaning that collecting the data is simple. The input data for the model, and consequently the results, are on a three-year lag. This means that for the 2022 edition emissions factors, or multipliers as they are referred to in the database, data are available for years up to 2019. The factors for 2018 were selected from the latest release and were aggregated from 110 sectors down to 105 sectors in order to match the SWC MRIO. As the UKMRIO model and the SWC MRIO model use the same underlying sector classification system, it is not necessary to develop a hybrid set of common sectors, and only a handful of UKMRIO's sectors needed to be aggregated.

It is important to note that as the UKMRIO was developed to assess the UK's consumption-based emissions, only emission factors for the UK are published. Therefore, only data for the UK from the SWC MRIO are used for this comparison. The SWC MRIO model differs from the UKMRIO model on a couple of important inclusions which would affect the results of a comparison. The inclusions are Gross Fixed Capital Formation (GFCF) and a high-altitude radiative forcing factor for air transport. To conduct a more level comparison, a version of the SWC MRIO model without these two features was created. Another important difference in the UKMRIO data is that the emissions factors published are consumption-based, and therefore represent an average emissions factor for a given sector based on the UK's consumption of the products, both domestic and imported, within that sector. The comparisons conducted thus far have only dealt with production-based emissions factors, which are based on the produced output of the UK sector. To provide a fair comparison, the SWC MRIO model was hence used to calculate consumption-based factors alongside the production-based figures. It is the consumption-based emissions factors from the SWC MRIO model which are used in this comparison.

Comparison of the Models

Again, ratios were calculated by dividing the SWC MRIO total emissions factors for each sector in the UK by Leeds' UKMRIO total emissions factors. This gives a rough sense of how closely the results of each model align. It was found that the models agree relatively well, with just over half the emissions factors agreeing to within a factor of 1.35 and the vast majority agreeing within a factor of 2. There were a few outliers, with agreement beyond a factor of 2, but these were largely limited to small sectors with known boundary or data issues. Combining this analysis with data from the ONS on emissions from each sector [10] shows that around 84% of UK emissions are represented by sectors which agree within a factor of 1.5, rising to 95% agreeing within a factor of 2. Figure 5 shows the full distribution of the results of calculating the total emissions factor ratios between the models. The median of the ratios was found to be 1.51, whilst calculating a weighted mean of the ratios, using sector emissions as the weights, yielded an average of 1.14. Thus, on average, the SWC MRIO model's emissions factors were slightly larger than those from Leeds' UKMRIO model. This is also reflected by the distribution in Figure 5, below.

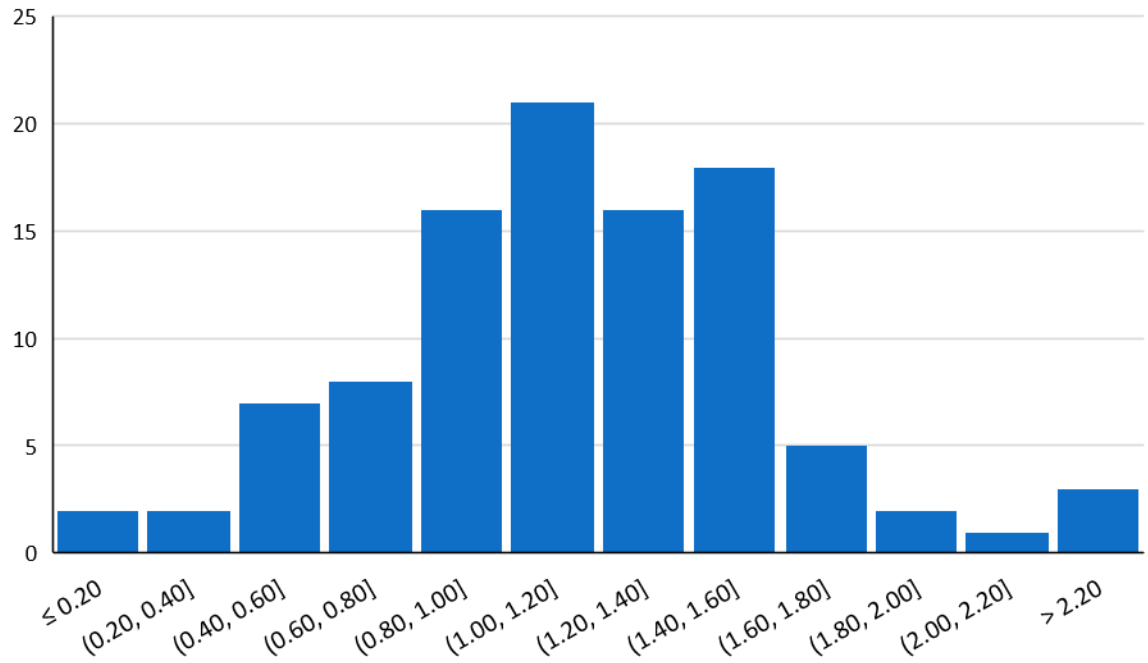

Figure 5: The distribution of the ratios calculated by dividing the SWC MRIO's total emissions factors by Leeds UKMRIO's total emissions factors for each sector.

Validation Against Electricity Emissions Factors

Estimating the Electricity Emissions Factors

A key issue with MRIO modelling is the lack of a “ground truth” by which to measure the relative success of different models. One area where this may be somewhat possible is the electricity production sector since data are available both for the carbon intensity of different countries’ electricity grids and for the price of their produced electricity. Using those data points, a direct emissions factor may be calculated; however, this does not cover the full upstream emissions of the sector, instead representing only its “Scope 1” emissions. The primary models being tested in this validation and comparison exercise were EXIOBASE and the SWC MRIO model. EXIOBASE breaks down the electricity sector into smaller sectors of generation, providing different emissions factors depending on how the electricity was generated. To obtain a grid average, these smaller sectors were thus aggregated by calculating a weighted average, with the monetary output of each sector being used as the weighting basis. The averaged EXIOBASE sector was thus comparable with the corresponding electricity sector from the SWC MRIO model.

To obtain as many points of comparison as possible, electricity emissions factors for all countries common to both the EXIOBASE and SWC MRIO models were estimated, using data on grid intensities and prices. The data for the emissions intensity of electricity grids in different countries were taken from a compiled set of factors produced by carbonfootprint.com [11]. These factors were compiled from either official sources or other compiled sets of factors whose source is ultimately trustworthy, such as the International Energy Agency (IEA). The price of electricity for each country was taken from a compiled database of prices published by globalpetrolprices.com, which provides estimated price data for many fuels as well as electricity [12]. This company compiles the price by surveying the largest electricity providers within each country and conducting a weighted average based on the market share of each provider. Prices paid by businesses and households are reported separately and include all final taxes and fees. Since EXIOBASE reports emissions factors in basic prices rather than purchasers’ prices (inclusive of taxes and distributors’ margins), the electricity prices were converted to basic prices to provide a level comparison. This was estimated using a country- and sector-specific factor estimated from each country’s supply and use tables. These tables detail the total supply from the electricity sector in monetary units, in both basic and purchasers’ prices. The grid intensities from carbonfootprint.com were in units of $kgCO_{2e}$/kWh, whilst the electricity prices from globalpetrolprices.com were in units of £GBP/kWh. Therefore, to estimate an average direct emissions factor for electricity production in each country, the former was divided by the latter. This estimate, in units of $kgCO_{2e}$/£GBP, could then be compared against EXIOBASE and the SWC MRIO.

Comparison of the Models

Taking the newly estimated values for the direct electricity emissions factors as an approximate ground truth, the EXIOBASE and SWC MRIO models were compared. This was conducted by, again, calculating ratios by dividing the models' estimates by the "true" values. From this, simple summary statistics were produced and analysed. It was found that the results varied dramatically depending on the model and country being compared. Out of the 41 countries in the comparison, EXIOBASE was closer to the "true" value for 7 countries whilst the SWC MRIO was closer for 34 countries. Taking averages gives the SWC MRIO estimates a mean ratio of 1.06 and a median ratio of 0.97 when compared to the "true" values. For EXIOBASE, the mean was 0.94; however, the median came in at 0.46 demonstrating the larger variability of EXIOBASE's results. This is also shown by the fact that EXIOBASE's factors were within a factor of 2 of the "true" value for only 15 out of the 41 countries. In comparison, the SWC MRIO was within a factor of 2 for 29 countries.

The largest outliers, which differed from the "true" value by more than a factor of 10, were all EXIOBASE factors and included 9 countries. The biggest difference was for Slovenia: EXIOBASE's direct electricity emissions factor for this country came in at nearly 140 times lower than the estimated "true" value, whereas the SWC MRIO emissions factor was only 4% higher. The largest outlier for the SWC MRIO model was Luxembourg which was 6.65 times lower than the "true" value, although interestingly EXIOBASE's factor was 6.83 times lower, meaning that the models agreed with each other but disagreed with the estimated "true" value. This could suggest that the data used to estimate Luxembourg's electricity factor may not be accurate, or it could also simply be coincidence. Among EXIOBASE's large outliers are two economically and environmentally significant countries: Brazil and Russia. This is important to note, since electricity is extensively involved in the production of most goods and services within an economy, meaning that its associated emissions factor has a knock-on effect on the emissions factors for all sectors within a country. Since Brazil and Russia are sizeable trading partners, the emissions factors for their electricity sectors can in turn have a knock-on effect on the emissions factors of sectors which consume their goods and services.

Overall, both EXIOBASE and the SWC MRIO more often than not underestimated the direct electricity emissions factor in comparison with the estimated "true" value. This could potentially indicate a slight systematic error in the estimation of the "true" value. This would, however, be unlikely to have a dramatic effect on the overall result, due to the large differences involved in the EXIOBASE results. The full results for every country can be seen in Figure 6 and Figure 7, which show the relative differences between the SWC MRIO, EXIOBASE and the estimated "true" value. Each bar shows the factor by which each model differs from the "true" value, with negative values representing a factor that is smaller by that amount. Note that the results have been split out in order to produce figures with different scales, for improved clarity.

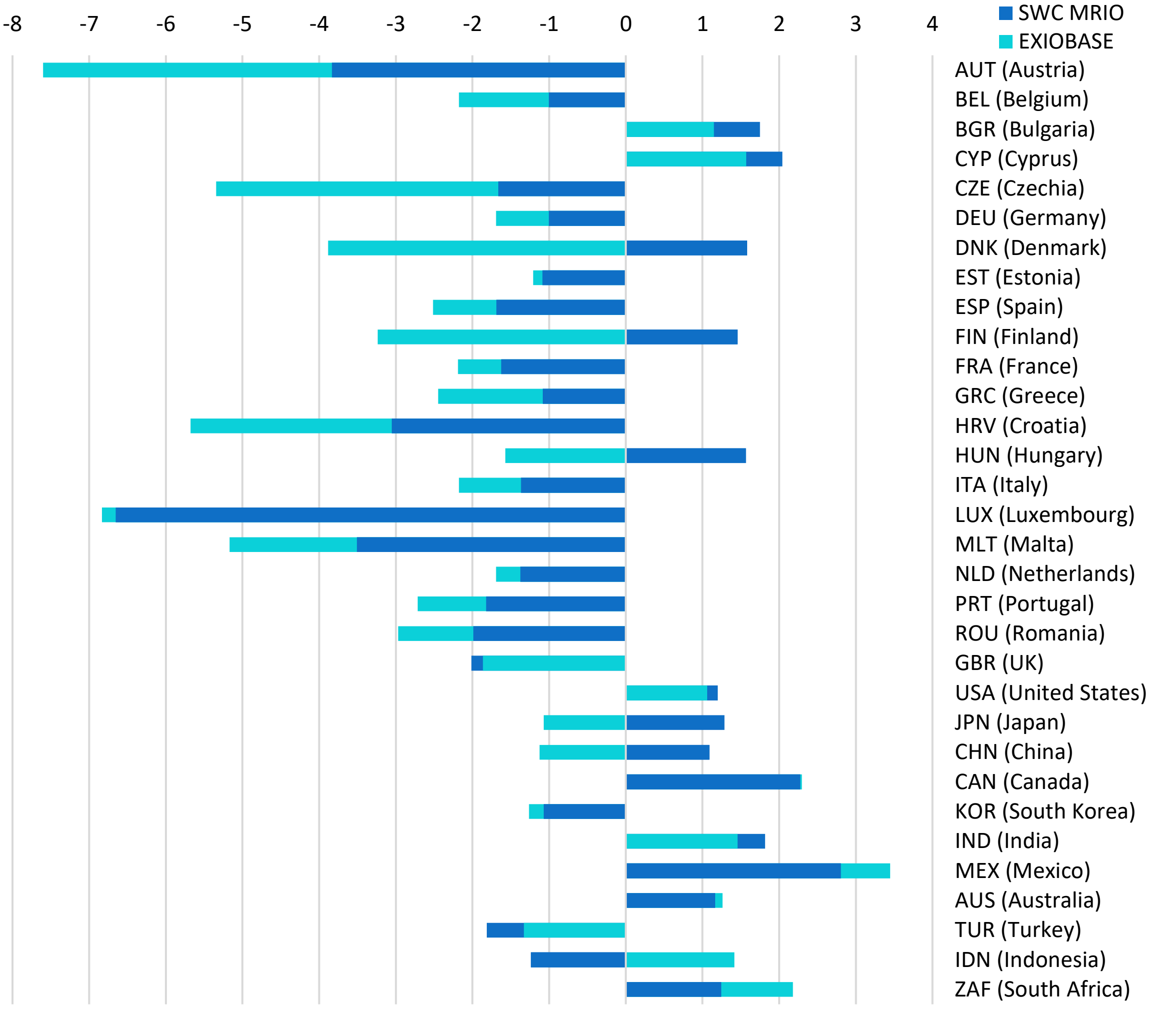

Figure 6: The relative differences between direct emissions factors for electricity in different countries, as modelled by EXIOBASE and the SWC MRIO relative to the estimated "true" value. The data points represent the factor by which they differ from the estimated "true" value. Negative values signal that they are smaller by that factor.

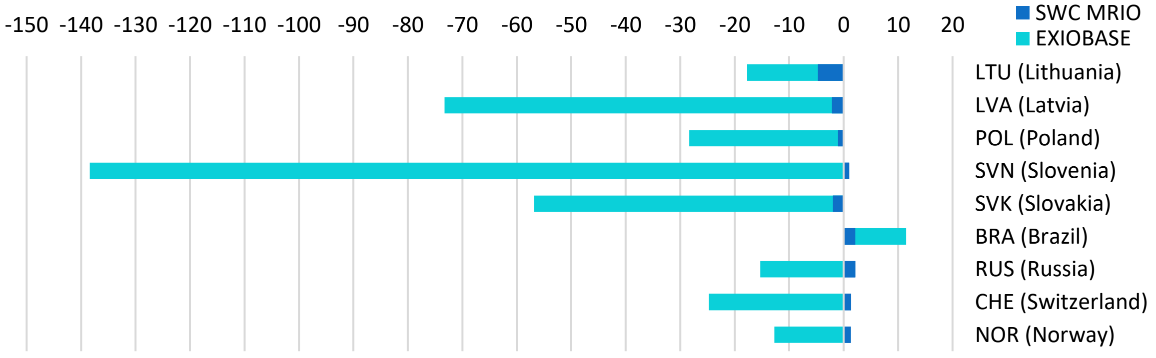

Figure 7: The relative differences between direct emissions factors for electricity in different countries, as modelled by EXIOBASE and the SWC MRIO relative to the estimated "true" value. The data points represent the factor by which they differ from the estimated "true" value. Shown separately from Figure 6 due to differences in scale.

Discussion

Factors Influencing the Results

Models may disagree on an emissions factor for a given region and sector for many different reasons. Some differences between their results can be extremely difficult to explain, due to the many contributing factors, some of which are not easily discernible without considerable effort, if at all. Some of these contributing factors include the use of different data sources with differing reliability, alternative balancing algorithms for joining data, varying regional resolution and coverage, varying sectoral resolution and classification, and a myriad of small assumptions which may not be included in a full methodological breakdown. This last point is especially true for the process of estimating the direct emissions of each sector for countries which do not publish such data.

One contributing factor which is easier to understand includes the use of different Global Warming Potential (GWP) factors for converting other gases into units of CO_2 equivalent. The SWC MRIO uses the most up-to-date figures from the IPCC, whilst the other models use the somewhat outdated but more widely used 2007 figures. Although the effect this has on the models' results is easier to quantify, it does not necessarily contribute greatly to explaining the differences between the models. This is due to its effect being rather limited, and ultimately smaller than other contributing factors. Another broad factor which may contribute towards the models' differing results is the way in which the SWC MRIO model employs upscaling. The primary modelling and data consist of 45 sectors, whilst the final results are upscaled to 105 sectors with the aim of improving overall accuracy. Consequently, the sectors that are split out in this upscaling process may be less accurate than if the model had contained 105 sectors to begin with. The issue is that the source data are not really of sufficient quality to ensure this level of sectoral resolution throughout the model. Therefore, one has to decide between using auxiliary data and a set of assumptions to disaggregate the source data to create a 105-sector model or, conversely, using auxiliary data and a set of assumptions to upscale the 45-sector model. The latter option is employed by the SWC MRIO model, and the results to date suggest that this may be a reasonable approximation and is at least better than simply using the original 45-sector version.

Although it is difficult – for the reasons outlined above – to quantify the effects of different models' methods and assumptions on their results, some factors are worth pointing out. The following text will set out some of these reasons for each model.

The EXIOBASE Model

Overall, the results from the SWC MRIO model and the EXIOBASE model agree within a reasonable level for most regions and sectors, when expressed in a common 61-sector format.

That is to say, around 70% of emissions factors agree within a factor of 2. Generally speaking, the results from the SWC MRIO model were slightly higher than from EXIOBASE, and there was least agreement for the mining and waste sectors, among others. A study comparing EXIOBASE's results to the "ecoinvent" LCA database found that the mining and waste sectors were the most erratic. It also found that the results overall were lower than expected: usually one would expect EEIO-derived emissions factors to be higher than LCA-derived ones due to truncation error [13]. The original EXIOBASE data series ends in 2011 and since then auxiliary economic data has been used to update the model through to the present day. This does mean, however, that the core data itself are not as current as in other models, including the SWC MRIO model which has a base year of 2018. EXIOBASE's approach of disaggregating the source data in order to build a model of 163 sectors is creditable, but there is potential for errors to creep in and become compounded during the process of stretching out sparse source data in conjunction with several auxiliary datasets, each with their own uncertainties.

Specifically looking at the direct emissions factors relating to electricity, some of EXIOBASE's results depart greatly from the expected values estimated using other data sources. Even when considering that the price data may not be wholly free from volatility, it is surprising to see direct emissions factors for countries like Russia and Brazil differing from the expected values by more than a factor of 10. This is especially the case when the SWC MRIO model produces direct emissions factors many times closer to the expected value. Since comparing EXIOBASE's electricity emissions factors required taking a weighted average of several subsectors (split out by type of generation), this may not best represent the EXIOBASE data. It may be the case that some types of generation are better represented than others. However, when analysing EXIOBASE's direct emissions data (in absolute terms, not direct emissions factors) it can be seen that the total quantity of emissions from within the electricity sectors is clearly not accurate for some countries. This supports the results obtained by comparing the weighted average of the direct electricity emissions factors. One of the possible reasons for this appears to be a misallocation of electricity emissions to the steam sector, due to the higher prevalence in some countries of Combined Heat and Power (CHP) plants. These plants produce both electricity and steam when fuels are burnt, which means that apportioning the resulting emissions into separate sectors is no simple task. The fact that many of the countries featured in Figure 7, including Russia, Latvia, Lithuania, Poland, and Slovakia, operate more CHP plants than other countries indicates that there may be an issue with allocating CHP emissions.

The Eora Model

The differences between Eora and EXIOBASE for the Netherlands have shown to what extent the leading models can disagree, even for countries with relatively good data. A key factor which helps to explain differences in the results is that the primary data source for Eora's environmental accounts is PRIMAP. These data do not have sufficiently high sectoral resolution to map to some countries in the Eora model that have a greater number of sectors. The fact that emissions are mapped using the monetary output of each sector only compounds this problem. The net result of these issues is a set of emissions accounts unsuitable for micro-scale analyses such as company footprinting. It is also worth noting that Eora's extensive country coverage is not all based on real data. For many of the smaller countries absent from other models, data have been estimated by starting with a proxy dataset and modifying it to match the small amount of data obtained for the original country.

The UKMRIO Model

Since the results of the UKMRIO model and the SWC MRIO model agree fairly well and both employ some similar UK data sources, there is less to discuss here. One factor which may affect the UKMRIO results is that EXIOBASE is used for the international component of the emissions factors. Office for National Statistics (ONS) data constitute the primary source, which is then embedded in a modified EXIOBASE model in order to account for international imports. One potential problem with this is that EXIOBASE and the ONS do not use the same sectoral classification system, and so mapping is required which may introduce inaccuracies. Overall, the use of EXIOBASE data means that any potentially erroneous EXIOBASE figures may affect the UK emissions factors, although the effect of this is likely to be somewhat smaller.

Conclusion

The analysis so far has shown that the SWC MRIO model passes sense checks and comparisons at least as well as other leading models do, and, in many cases surpasses them. A detailed exploration of the methodology for upscaling the number of sectors from 45 to 105 and the validity of the approach has been carried out, and we expect to publish this early in 2024. However, the analysis described in this document has suggested that the process delivers net benefit, and no immediate reason to dismiss the assumption was identified. The variability between the results from Eora and EXIOBASE makes it difficult to compare the SWC MRIO results against a consensus value, since consensus is largely absent. However, a consensus value still would not fully validate the final emissions factors and thus – as has been carried out here with direct electricity emissions factors – other key commodities could be compared against the MRIO models in an attempt to ground truth them. This would require a commodity which a) adequately represents the sector encompassing it and b) has good region-specific data available on the emissions required to produce it, and on its price. Commodities like steel may be good candidates for this ground truthing exercise, which would help with achieving a much-needed understanding of the true accuracy of each MRIO model.

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Appendix A: SWC MRIO 105-Sector Classification

SIC Code	Sector Description
01	Crop and Animal Production, Hunting and Related Service Activities
02	Forestry and Logging
03	Fishing and Aquaculture
05	Mining of Coal and Lignite
06 & 07	Extraction of Crude Petroleum and Natural Gas & Mining of Metal Ores
08	Other Mining and Quarrying
09	Mining Support Service Activities
10.1	Processing and Preserving of Meat and Production of Meat Products
10.2-3	Processing and Preserving of Fish, Crustaceans, Molluscs, Fruit and Vegetables
10.4	Manufacture of Vegetable and Animal Oils and Fats
10.5	Manufacture of Dairy Products
10.6	Manufacture of Grain Mill Products, Starches and Starch Products
10.7	Manufacture of Bakery and Farinaceous Products
10.8	Manufacture of Other Food Products
10.9	Manufacture of Prepared Animal Feeds
11.01-6 & 12	Manufacture of Alcoholic Beverages & Tobacco Products
11.07	Manufacture of Soft Drinks; Production of Mineral Waters and Other Bottled Waters
13	Manufacture of Textiles
14	Manufacture of Wearing Apparel
15	Manufacture of Leather and Related Products
16	Manufacture of Wood & Products of Wood & Cork, Except Furniture; Manuf. of Articles of Straw
17	Manufacture of Paper and Paper Products
18	Printing and Reproduction of Recorded Media
19	Manufacture of Coke and Refined Petroleum Products
20.3	Manufacture of Paints, Varnishes and Similar Coatings, Printing Ink and Mastics
20.4	Manufacture of Soap & Detergents, Cleaning & Polishing, Perfumes & Toilet Preparations
20.5	Manufacture of Other Chemical Products
20A	Manufacture of Industrial Gases, Inorganics and Fertilisers (Inorganic Chemicals) - 20.11/13/15
20B	Manufacture of Petrochemicals - 20.14/16/17/60
20C	Manufacture of Dyestuffs, Agro-Chemicals - 20.12/20
21	Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations
22	Manufacture of Rubber and Plastic Products
23.5-6	Manufacture of Cement, Lime, Plaster and Articles of Concrete, Cement and Plaster
23OTHER	Manufacture of Glass, Refractory, Clay, Porcelain, Ceramic, Stone Products - 23.1-4/7-9
24.1-3	Manufacture of Basic Iron and Steel
24.4-5	Manufacture of Other Basic Metals and Casting
25.4	Manufacture of Weapons and Ammunition
25OTHER	Manufacture of Fabricated Metal Products, Excluding Weapons & Ammunition - 25.1-3/5-9
26	Manufacture of Computer, Electronic and Optical Products
27	Manufacture of Electrical Equipment
28	Manufacture of Machinery and Equipment N.E.C.
29	Manufacture of Motor Vehicles, Trailers and Semi-Trailers
30.1	Building of Ships and Boats
30.3	Manufacture of Air and Spacecraft and Related Machinery
30OTHER	Manufacture of Other Transport Equipment - 30.2/4/9
31	Manufacture of Furniture

32	Other Manufacturing
33.15	Repair and Maintenance of Ships and Boats
33.16	Repair and Maintenance of Aircraft and Spacecraft
33OTHER	Rest of Repair; Installation - 33.11-14/17/19/20
35.1	Electric Power Generation, Transmission and Distribution
35.2-3	Manufacture of Gas; Distribution of Gaseous Fuels Through Mains; Steam and Aircon Supply
36	Water Collection, Treatment and Supply
37	Sewerage
38	Waste Collection, Treatment and Disposal Activities; Materials Recovery
39	Remediation Activities and Other Waste Management Services
41, 42 & 43	Construction
45	Wholesale and Retail Trade and Repair of Motor Vehicles and Motorcycles
46	Wholesale Trade, Except of Motor Vehicles and Motorcycles
47	Retail Trade, Except of Motor Vehicles and Motorcycles
49.1-2	Rail Transport
49.3-5	Land Transport Services and Transport Services Via Pipelines, Excluding Rail Transport
50	Water Transport
51	Air Transport
52	Warehousing and Support Activities for Transportation
53	Postal and Courier Activities
55	Accommodation
56	Food and Beverage Service Activities
58	Publishing Activities
59 & 60	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming and Broadcasting Activities
61	Telecommunications
62	Computer Programming, Consultancy and Related Activities
63	Information Service Activities
64	Financial Service Activities, Except Insurance and Pension Funding
65.1-2 & 65.3	Insurance and Reinsurance, Except Compulsory Social Security & Pension Funding
66	Activities Auxiliary to Financial Services and Insurance Activities
68.1-2	Buying and Selling, Renting and Operating of Own or Leased Real Estate, Excluding Imputed Rent
68.2IMP	Owner-Occupiers' Housing
68.3	Real Estate Activities on a Fee or Contract Basis
69.1	Legal Activities
69.2	Accounting, Bookkeeping and Auditing Activities; Tax Consultancy
70	Activities of Head Offices; Management Consultancy Activities
71	Architectural and Engineering Activities; Technical Testing and Analysis
72	Scientific Research and Development
73	Advertising and Market Research
74	Other Professional, Scientific and Technical Activities
75	Veterinary Activities
77	Rental and Leasing Activities
78	Employment Activities
79	Travel Agency, Tour Operator and Other Reservation Service and Related Activities
80	Security and Investigation Activities
81	Services to Buildings and Landscape Activities
82	Office Administrative, Office Support and Other Business Support Activities
84	Public Administration and Defence; Compulsory Social Security
85	Education

86	Human Health Activities
87 & 88	Residential Care & Social Work Activities
90	Creative, Arts and Entertainment Activities
91	Libraries, Archives, Museums and Other Cultural Activities
92	Gambling and Betting Activities
93	Sports Activities and Amusement and Recreation Activities
94	Activities of Membership Organisations
95	Repair of Computers and Personal and Household Goods
96	Other Personal Service Activities
97	Activities of Households as Employers of Domestic Personnel

Table 2: The full list of the sectoral classification scheme employed by the SWC MRIO model. The total number of sectors is 105.

Appendix B: EXIOBASE 163-Sector Classification

Sector Description
Cultivation of paddy rice
Cultivation of wheat
Cultivation of cereal grains nec
Cultivation of vegetables, fruit, nuts
Cultivation of oil seeds
Cultivation of sugar cane, sugar beet
Cultivation of plant-based fibers
Cultivation of crops nec
Cattle farming
Pigs farming
Poultry farming
Meat animals nec
Animal products nec
Raw milk
Wool, silk-worm cocoons
Manure treatment (conventional), storage and land application
Manure treatment (biogas), storage and land application
Forestry, logging and related service activities (02)
Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)
Mining of coal and lignite; extraction of peat (10)
Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
Extraction of natural gas and services related to natural gas extraction, excluding surveying
Extraction, liquefaction, and regasification of other petroleum and gaseous materials
Mining of uranium and thorium ores (12)
Mining of iron ores
Mining of copper ores and concentrates
Mining of nickel ores and concentrates
Mining of aluminium ores and concentrates
Mining of precious metal ores and concentrates
Mining of lead, zinc and tin ores and concentrates
Mining of other non-ferrous metal ores and concentrates
Quarrying of stone
Quarrying of sand and clay
Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.
Processing of meat cattle
Processing of meat pigs
Processing of meat poultry
Production of meat products nec
Processing vegetable oils and fats
Processing of dairy products
Processed rice
Sugar refining
Processing of Food products nec
Manufacture of beverages
Manufacture of fish products
Manufacture of tobacco products (16)

Manufacture of textiles (17)
Manufacture of wearing apparel; dressing and dyeing of fur (18)
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)
Re-processing of secondary wood material into new wood material
Pulp
Re-processing of secondary paper into new pulp
Paper
Publishing, printing and reproduction of recorded media (22)
Manufacture of coke oven products
Petroleum Refinery
Processing of nuclear fuel
Plastics, basic
Re-processing of secondary plastic into new plastic
N-fertiliser
P- and other fertiliser
Chemicals nec
Manufacture of rubber and plastic products (25)
Manufacture of glass and glass products
Re-processing of secondary glass into new glass
Manufacture of ceramic goods
Manufacture of bricks, tiles and construction products, in baked clay
Manufacture of cement, lime and plaster
Re-processing of ash into clinker
Manufacture of other non-metallic mineral products n.e.c.
Manufacture of basic iron and steel and of ferro-alloys and first products thereof
Re-processing of secondary steel into new steel
Precious metals production
Re-processing of secondary precious metals into new precious metals
Aluminium production
Re-processing of secondary aluminium into new aluminium
Lead, zinc and tin production
Re-processing of secondary lead into new lead, zinc and tin
Copper production
Re-processing of secondary copper into new copper
Other non-ferrous metal production
Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
Casting of metals
Manufacture of fabricated metal products, except machinery and equipment (28)
Manufacture of machinery and equipment n.e.c. (29)
Manufacture of office machinery and computers (30)
Manufacture of electrical machinery and apparatus n.e.c. (31)
Manufacture of radio, television and communication equipment and apparatus (32)
Manufacture of medical, precision and optical instruments, watches and clocks (33)
Manufacture of motor vehicles, trailers and semi-trailers (34)
Manufacture of other transport equipment (35)
Manufacture of furniture; manufacturing n.e.c. (36)
Recycling of waste and scrap
Recycling of bottles by direct reuse

Production of electricity by coal
Production of electricity by gas
Production of electricity by nuclear
Production of electricity by hydro
Production of electricity by wind
Production of electricity by petroleum and other oil derivatives
Production of electricity by biomass and waste
Production of electricity by solar photovoltaic
Production of electricity by solar thermal
Production of electricity by tide, wave, ocean
Production of electricity by Geothermal
Production of electricity nec
Transmission of electricity
Distribution and trade of electricity
Manufacture of gas; distribution of gaseous fuels through mains
Steam and hot water supply
Collection, purification and distribution of water (41)
Construction (45)
Re-processing of secondary construction material into aggregates
Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
Retail sale of automotive fuel
Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)
Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)
Hotels and restaurants (55)
Transport via railways
Other land transport
Transport via pipelines
Sea and coastal water transport
Inland water transport
Air transport (62)
Supporting and auxiliary transport activities; activities of travel agencies (63)
Post and telecommunications (64)
Financial intermediation, except insurance and pension funding (65)
Insurance and pension funding, except compulsory social security (66)
Activities auxiliary to financial intermediation (67)
Real estate activities (70)
Renting of machinery and equipment without operator and of personal and household goods (71)
Computer and related activities (72)
Research and development (73)
Other business activities (74)
Public administration and defence; compulsory social security (75)
Education (80)
Health and social work (85)
Incineration of waste: Food
Incineration of waste: Paper
Incineration of waste: Plastic
Incineration of waste: Metals and Inert materials
Incineration of waste: Textiles
Incineration of waste: Wood

Incineration of waste: Oil/Hazardous waste
Biogasification of food waste, incl. land application
Biogasification of paper, incl. land application
Biogasification of sewage sludge, incl. land application
Composting of food waste, incl. land application
Composting of paper and wood, incl. land application
Waste water treatment, food
Waste water treatment, other
Landfill of waste: Food
Landfill of waste: Paper
Landfill of waste: Plastic
Landfill of waste: Inert/metal/hazardous
Landfill of waste: Textiles
Landfill of waste: Wood
Activities of membership organisation n.e.c. (91)
Recreational, cultural and sporting activities (92)
Other service activities (93)
Private households with employed persons (95)
Extra-territorial organizations and bodies

Table 3: The full list of sectors in the classification scheme employed by the EXIOBASE model. The total number of sectors is 163.

Appendix C: Eora 61-Sector Classification (Netherlands)

Sector Description
Products of agriculture, hunting and related services
Products of forestry, logging and related services
Fish and other fishing products; services incidental of fishing
Coal and lignite; peat
Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying
Uranium and thorium ores
Metal ores
Other mining and quarrying products
Food products and beverages
Tobacco products
Textiles
Wearing apparel; furs
Leather and leather products
Wood and products of wood and cork (except furniture); articles of straw and plaiting materials
Pulp, paper and paper products
Printed matter and recorded media
Coke, refined petroleum products and nuclear fuels
Chemicals, chemical products and man-made fibres
Rubber and plastic products
Other non-metallic mineral products
Basic metals
Fabricated metal products, except machinery and equipment
Machinery and equipment n.e.c.
Office machinery and computers
Electrical machinery and apparatus n.e.c.
Radio, television and communication equipment and apparatus
Medical, precision and optical instruments, watches and clocks
Motor vehicles, trailers and semi-trailers
Other transport equipment
Furniture; other manufactured goods n.e.c.
Secondary raw materials
Electrical energy, gas, steam and hot water
Collected and purified water, distribution services of water
Construction work
Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel
Wholesale trade and commission trade services, except of motor vehicles and motorcycles
Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods
Hotel and restaurant services
Land transport; transport via pipeline services
Water transport services
Air transport services
Supporting and auxiliary transport services; travel agency services
Post and telecommunication services
Financial intermediation services, except insurance and pension funding services
Insurance and pension funding services, except compulsory social security services

Services auxiliary to financial intermediation
Real estate services
Renting services of machinery and equipment without operator and of personal and household goods
Computer and related services
Research and development services
Other business services
Public administration and defence services; compulsory social security services
Education services
Health and social work services
Sewage and refuse disposal services, sanitation and similar services
Membership organisation services n.e.c.
Recreational, cultural and sporting services
Other services
Private households with employed persons
FISIM
Re-export

Table 4: The full list of sectors in the classification scheme employed by the Eora model specifically for the Netherlands. The total number of sectors is 61.

Appendix D: Regional Coverage of the SWC MRIO Model

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

Table 5: A table showing the full list of countries covered by the SWC MRIO model including the three-letter country codes. Highlighted countries are those common to the EXIOBASE model.