Comparing CEDA, GLORIA and EXIOBASE for greenhouse gas (GHG) emissions embodied in imports by USEEIO model

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Abstract

The U.S. Environmentally Extended Input-Output (USEEIO) model, one of the most widely used input-output data for greenhouse gas (GHG) accounting, is a single-region model that employs domestic import technology assumption. Estimating GHG emissions embodied in imports using domestic technology, however, runs the risk of mischaracterizing the magnitude of Scope 3 emissions as well as the opportunities to reduce them under today's global supply chain. This study compares the implications of using three multi-regional input-output (MRIO) databases—CEDA, EXIOBASE, and GLORIA—when integrated into the USEEIO framework for estimating GHG emissions embodied in imports, referred to as import factors. The results reveal notable variations in import factors across the databases. The main drivers of variation identified include sectoral detail, geographic coverage, and assumptions used. Weighted by economic output of each sector, import factors are found to be 44% higher (CEDA), 16% higher (EXIOBASE), and 8% lower (GLORIA) than domestic factors – on average, import factors are 17% higher than domestic factors. This indicates relying solely on domestic GHG emission factors for Scope 3 calculations is likely to result in underestimation of supply chain impacts, especially for organizations with substantial expenditures in sectors characterized by large discrepancies between import and domestic emission factors.

1. Introduction

1.1 Background and Motivation

In recent years, global supply chains have become increasingly complex, resulting in a growing need for robust tools to assess the embodied GHG emissions of goods and services across national boundaries. The Environmentally Extended Input-Output (EEIO) models have emerged as indispensable frameworks for evaluating the environmental footprints of economies by linking economic transactions with environmental pressures. Among these, the U.S. Environmentally Extended Input-Output (USEEIO) model has been widely adopted for both national and corporate-level environmental assessment, serving as a critical tool for policymakers, researchers, and businesses.

A central challenge in applying the USEEIO model to modern supply chains stems from the accurate representation of imported goods and services. Given that a substantial portion of U.S. consumption is fulfilled by products manufactured abroad, the GHG emissions embodied in these imports—referred to as "import emission factors"—must be rigorously quantified. These import factors play a pivotal role in understanding the true environmental consequences of domestic consumption and are essential for credible greenhouse gas (GHG) inventories and sustainability reporting.

1.2 The Role of MRIO Databases in EEIO Modeling

Import emission factors are derived from multi-regional Input-Output (MRIO) databases, which enable the tracing of environmental flows across multiple countries and sectors. MRIO databases provide the necessary data infrastructure to capture the upstream GHG emissions of international trade, making them integral to both national-level modeling and corporate carbon accounting. Among the most prominent MRIO databases available today are CEDA (Suh, 2005), EXIOBASE (Stadler et al., 2018), and GLORIA (Lenzen et al., 2024), each offering unique strengths in terms of sectoral detail, regional coverage, and methodological approach.

1.3 Research Gap and Objectives

While the importance of MRIO databases in estimating import emission factors is well recognized, their variations in structure and content can significantly influence the outcomes of environmental modeling, especially in sectors highly exposed to international trade. There is currently limited systematic understanding of how the choice among CEDA, EXIOBASE, and GLORIA affects the estimation of import factors within the USEEIO framework, and what this implies for the accuracy and reliability of both national and corporate carbon accounting.

The primary research question addressed in this study is: **How does the choice of MRIO databases (tested here were CEDA, EXIOBASE, and GLORIA) affect the GHG emissions factors of USEEIO?** To address this, we analyze and compare import factors derived from integrating these MRIO databases with the USEEIO framework, offering insights for researchers, policymakers, and practitioners in the field of international trade and GHG accounting.

2. Method and Data

2.1 Overview of the USEEIO Model

The USEEIO model is a robust framework developed by the U.S. Environmental Protection Agency to estimate the environmental impacts associated with U.S. economic activity, taking into account both domestic production and imports (Ingwersen et al., 2022). It builds on the foundational structure of input-output analysis by extending it to include environmental flows such as GHG emissions, resource use, and pollutant releases. The model is structured by economic sectors, enabling granular analysis of the impacts tied to specific industries and products.

A critical feature of the latest USEEIO v2.5 model (Young and Ingwersen, 2025) is its reliance on accurate import emission factors to represent the GHG emissions embodied in goods and services produced abroad but consumed domestically. This requires integrating external MRIO data into the USEEIO structure, necessitating a harmonization process to ensure consistency in sectoral and regional classifications.

2.2 Description of MRIO Databases

CEDA is an MRIO database that provides data representing 95% of the world's GDP across 148 countries and regions at 400 sector-resolution. It emphasizes resolution for key economic sectors and GHG emission categories, facilitating both national and international supply chain data. EXIOBASE is an MRIO database designed for the comprehensive analysis of environmental impacts associated with global economic activity. It provides a time series of global environmental extensions, allowing assessments of both European and non-European countries. GLORIA adopts an approach by offering a homogenous multi-regional supply-use table (MR-SUT) structure. This structure features harmonized sector labels for both industry and commodity sectors. GLORIA provides data on sector-specific transactions for resource flow analysis and the derivation of import emission factors.

Table 1 shows the variations in geographical and sectoral resolution across the three MRIO databases. CEDA has the broadest sectoral detail with 400 sectors and 148 countries plus one Rest of World (ROW) region. GLORIA covers the most countries at 160 plus 4 ROW regions but has the fewest sectors with 120. EXIOBASE falls in between 160 sectors and 44 countries plus 5 ROW regions. Figure 1 visually presents the geographical coverage and regional aggregation schemes of each database, highlighting differences in country-specific representations and ROW aggregations, which affect import emission factor estimations. CEDA uses a single ROW region, while EXIOBASE and GLORIA employ multiple region-specific aggregations.

Table 1. Geographic and sectoral resolution of MRIO databases. The table summarizes the number of countries (plus aggregated Rest of World [ROW] regions) and the number of economic sectors represented in each MRIO database: CEDA, EXIOBASE, and GLORIA. Higher numbers indicate greater geographic or sectoral detail, which can influence the accuracy and specificity of import emission factor estimates within the USEEIO modeling framework.

	Number of Countries	Number of Sectors per country/region
CEDA	148 + 1 ROW region	400
EXIOBASE	44 + 5 ROW regions	160
GLORIA	160 + 4 ROW regions	120

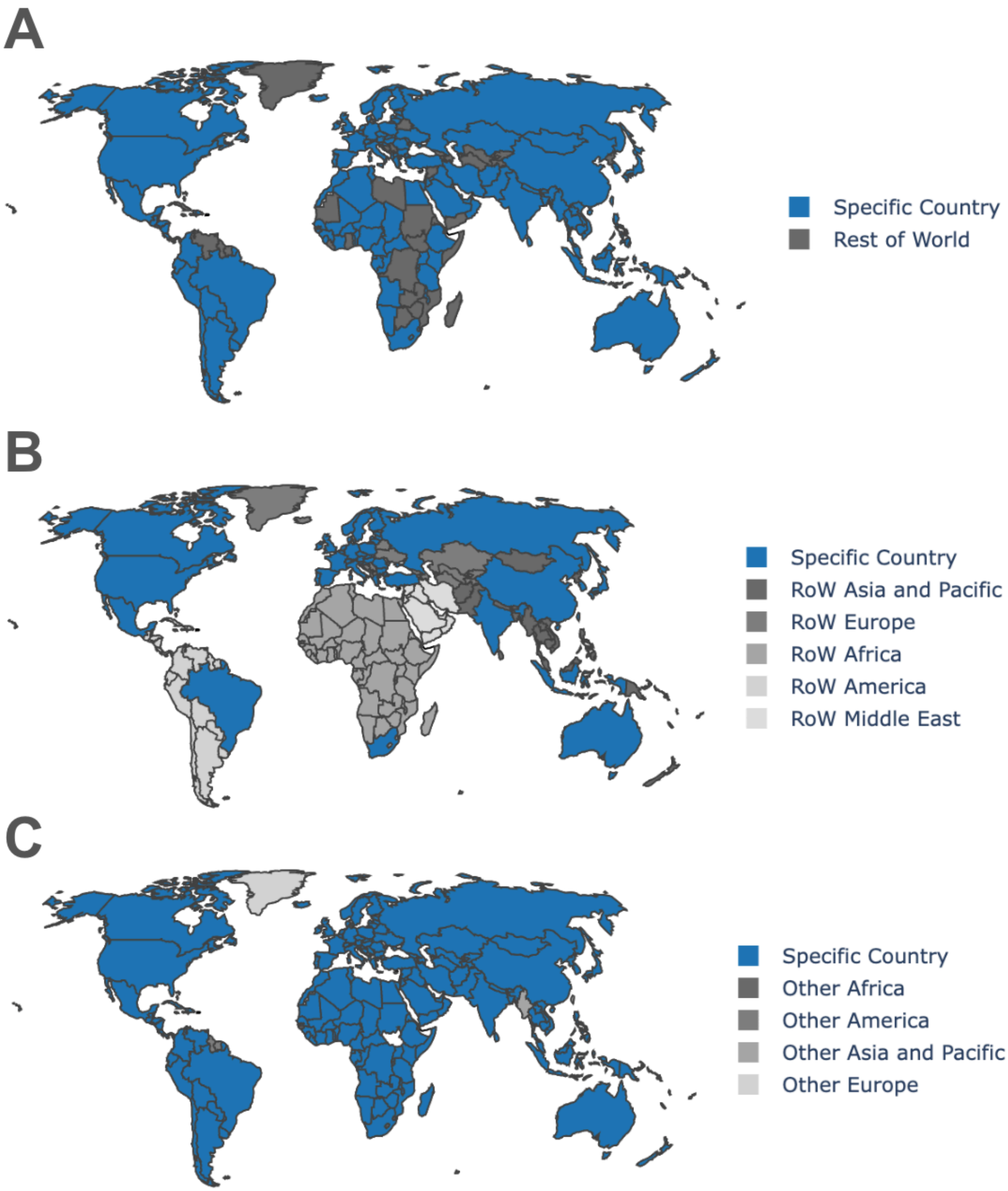

Figure 1. Geographic coverage and regional aggregation schemes of MRIO databases. (A) Country and region representation in CEDA, which distinguishes between specific countries (blue) and aggregates the remainder as "Rest of World" (gray). (B) EXIOBASE's regional aggregation, showing specific countries (blue) and multiple "Rest of World" (RoW) regions for Asia and Pacific, Europe, Africa, America, and Middle East (varying gray tones). (C) GLORIA's

representation, with specific countries (blue) and "Other" aggregated regions for Africa, America, Asia and Pacific, and Europe (gray tones). These maps illustrate differences in regional detail and aggregation approaches among the MRIO databases, which can influence the estimation of import emission factors.

2.3 Data Harmonization and Integration Procedures

To ensure comparability across MRIO databases, a harmonization process was implemented to align sectoral and regional classifications with those used in USEEIO. This involved aggregating or disaggregating sectors as needed to match the USEEIO classification. For each MRIO database, GHG emission data was collected and organized based on the harmonized sectoral classification. This harmonization is essential to ensure comparability while retaining the unique characteristics of each dataset.

Import emission factors were then generated by applying each harmonized MRIO database to the USEEIO framework for all USEEIO sectors. The process involved extracting environmental extensions and trade flow data from each MRIO, then calculating the emissions embodied in imports for each sector. The methodology followed standard input-output procedures, with equations linking sectoral imports to upstream emissions based on MRIO data.

2.4 Analytical Approach

The comparative analysis focused on the sectoral, regional, and aggregate levels. We compared the import emission factors across the three MRIO databases by calculating the percentage change in emission factors, EF_j, due to the use of MRIO i (equation 1). The results provide insights into the sensitivity of GHG emission factors to the choice of MRIO data.

$$(EF_{i,j} - EF_{domestic,j}) / EF_{domestic,j} * 100\% \quad (1)$$

3. Results

Our analysis revealed notable differences in emission factors across the databases, which are attributed to variations in their sectoral detail, geographic resolution, and data assumptions. Weighted by economic output of each sector and compared to domestic factors, CEDA-derived import factors are 44% higher, EXIOBASE-derived factors are 16% higher, and GLORIA-derived factors are 8% lower. On average, using MRIO models leads to 17% higher GHG emission factors.

Figure 2 shows the distribution of percent differences between import emission factors—derived from the CEDA, EXIOBASE, and GLORIA MRIO databases—and the corresponding domestic emission factors across agriculture, manufacturing, and service sectors. For agriculture, the distributions are relatively narrow and centered near zero for all three databases, indicating that import emission factors are generally comparable to domestic factors with limited deviations across most countries and regions. In contrast, the manufacturing and service sectors exhibit much broader distributions, with percent differences ranging widely in both positive and negative directions. This suggests that, for these sectors, import emission factors can differ substantially from domestic factors, depending on the MRIO database used. Notably, GLORIA shows the greatest spread of values in manufacturing and service, reflecting higher heterogeneity or more pronounced regional differences in the emission profiles of imports. The central tendency (median) and interquartile range, as marked on the plots, further demonstrate the variability and asymmetry in these differences. By trimming the extreme 1% of values, the analysis focuses on the central 99% of observations, ensuring that the results are not unduly influenced by outliers. Overall, these findings underscore that the choice of MRIO database can significantly affect estimates of trade-related GHG emissions, particularly in sectors with complex and globally diverse supply chains.

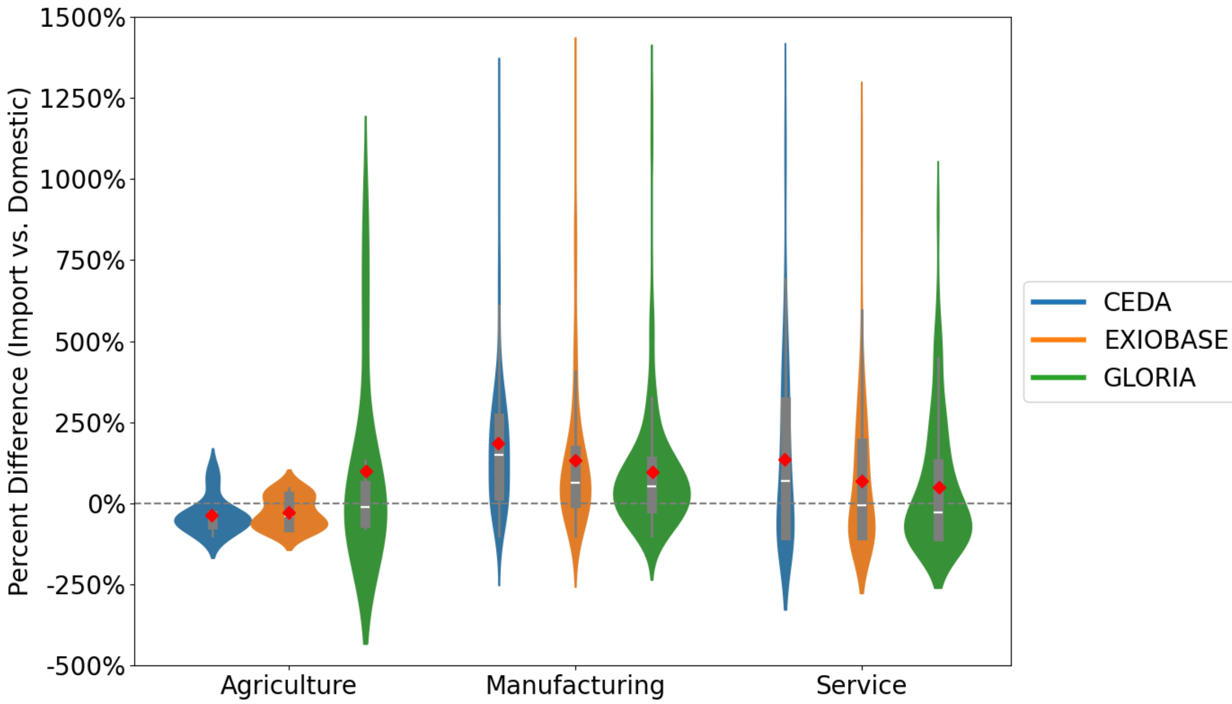

Figure 2. Distribution of percent differences between import and domestic emission factors. Violin plots show the distribution of percent differences in emission factors for imports relative to domestic production across three major sectors—agriculture, manufacturing, and service—using CEDA (blue), EXIOBASE (orange), and GLORIA (green) MRIO databases. The gray bars represent interquartile ranges for each distribution, the white lines represent median values, and the red diamonds indicate mean values. Distribution shows the central 99% of observations by excluding extreme outliers, i.e. the top 0.5% and bottom 0.5% of values. These results illustrate the variability in import emission factor estimates across sectors and databases, highlighting the influence of MRIO data source selection on modeled trade-related GHG emissions.

4. Discussion

Our results reveal that the import emission factors modeled using MRIO databases are, on average, 17% higher than the single-region input-output (SRIO) USEEIO model that employs domestic import technology assumption. This difference highlights a fundamental limitation in SR-based modeling of import emissions, which can lead to underestimation of corporate Scope 3 emissions. The magnitude of these differences is not uniform across sectors: for example, we observe that sectors such as manufacturing exhibit much larger percent differences compared to agriculture or services, reflecting the diverse international production practices and supply chain complexities captured by MRIOs.

Moreover, substantial variability exists among the three MRIO databases evaluated in this study—CEDA, EXIOBASE, and GLORIA. Each database yields different import emission factors for the same sector, with the variability most pronounced in sectors with complex or globally distributed supply chains. For instance, GLORIA tends to produce a broader spread in percent differences for manufacturing and service sectors, whereas EXIOBASE and CEDA display narrower or sector-specific patterns. These findings indicate that the choice of MRIO database can substantially influence modeled results, and by extension, the reported Scope 3 emissions of companies.

For users of the USEEIO model—particularly those in corporate sustainability and reporting—the implications are significant. Relying solely on SRIO-based emission factors for Scope 3 calculations is likely to result in underestimation of supply chain impacts, especially for organizations with substantial expenditures in sectors characterized by large discrepancies between import and domestic emission factors. Depending on a company's sectoral spend, the Scope 3 results may be 500% higher or 250% lower when MRIO-based factors are applied. These facts highlight the necessity for practitioners to exercise caution and awareness regarding the underlying data sources and methodologies used in their GHG accounting.

From a methodological perspective, our findings reinforce that SRIO-based emission factors are not sufficient for accurately modeling Scope 3 emissions in the context of today's globalized value chains. This limitation is particularly acute for manufacturing-intensive organizations, where import-related emissions are both significant and highly variable. While the US EPA's recent efforts to improve the USEEIO model with MRIO database integration helps mitigate this problem, the import factors would not be sufficient for companies that directly import goods or services, in which case the use of MRIO-based emission factors becomes necessary.

Finally, our study highlights the urgent need for harmonization among MRIO databases and for robust quantification of uncertainty ranges in MRIO-based emission factors. While the differences among MRIOs have been well documented in the literature, there has been little progress in closing these gaps or providing meaningful uncertainty estimates. Such efforts would be crucial for enabling users to make informed choices about which MRIO data to adopt for their Scope 3 reporting and supply chain management.

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