

A local-to-global multi-regional input-output database for Austria and its federal states consistent with official accounts

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Abstract

Austria's climate research community is calling for databases to assess subnational carbon footprints (CFs) and trade-induced greenhouse gas emissions to facilitate evidence-based debates on regional interdependencies in national decarbonization efforts. Although national-to-global multi-regional input–output (MRIO) databases are well established for national CF assessments, consistently linking such global models to the subnational scale remains an important area of research. Moreover, the misalignment between MRIO databases and official statistics from national statistical institutions has slowed the adoption of MRIO-based insights in policymaking. We address these challenges by presenting a local-to-global MRIO database for Austria and its nine federal states, which is aligned with the official environmental–economic accounts of Austria, thereby fostering the uptake of the results for ongoing climate policy processes. The first version of the MRIO model is in a product-by-product format and covers 57 regions (the nine federal states of Austria plus 48 countries and world regions) from 2010 to 2022 in a heterogeneous sector classification (74 products for Austria and 200 products for the rest of the world), including energy and process-related emissions of CO₂, CH₄, and N₂O. This study provides an overview of the database compilation, structure of the local-to-global MRIO model, and a comparison with existing CF estimates for Austria to highlight deviations.

1. Background

Austria's economy requires deep and accelerated decarbonization to meet the internationally negotiated and nationally committed 2030 climate targets ^{1,2}. Similar to other European countries, Austria has a federal political system with nine federal states. Political competencies for implementing climate policies are partly located at the federal level but remain rather unexploited ³. There is an ongoing debate on how to allocate Austria's national greenhouse gas (GHG) budget to the federal state level, which would enable federal state authorities and industry stakeholders to plan their GHG reduction measures with more certainty ⁴.

Austria's climate change research community is increasingly calling for data on the Carbon Footprint (CF) of federal states to monitor trade-induced GHG emissions and related regional dependencies, which would provide empirical grounds for informed discussion. Traditional production-based emission accounts (PBA), which are the basis of emission reporting under the UNFCCC, allocate emissions to the region where GHGs are physically emitted. National PBAs are routinely issued by national statistical institutions (NSI). Under this reporting scheme, regions can reduce their emissions accounts by outsourcing emission-intensive industries, thereby indirectly increasing the emissions embodied in their imports. Such a “burden shifting” ⁵ can occur internationally between countries as well as within countries, for example, between federal states. As pointed out by Steininger and colleagues ⁴, the determination of federal states' GHG budgets based solely on PBAs is neither meaningful nor reasonable.

The CF, which is a consumption-based approach to GHG emission accounting (CBA), attributes embodied GHGs to the regions driving emissions through their demand for goods and services⁶. The CF quantifies the total upstream GHG emissions that are due to a region's final demand (e.g., household expenditures, government consumption, or capital formation) regardless of where in the world emissions are emitted. CF assessments have greatly contributed to a more holistic understanding of trade-induced climate impacts and related consumption drivers^{7–10}.

The most widely used method for assessing economy-wide CFs is environmentally-extended multi-regional input-output (EE-MRIO) analysis^{11–13}. The core tables of EE-MRIO models are monetary input-output (IO) tables, which are balanced monetary accounts of production, consumption and trade. Monetary MRIO tables provide a holistic systems perspective on inter-industry commodity flows between economic sectors and markets, considering the specific economic structures of each region¹⁴. Extending such monetary MRIO tables with environmental satellite accounts depicting PBAs of GHG emissions enables the calculation of CF indicators¹⁵. Most EE-MRIO models are designed for the national-to-global scale, which is an established methodology for investigating internationally fragmented production-consumption networks and associated embodied GHG emissions^{16–18}.

Over the past decade, several MRIO databases have been constructed that integrate national-to-global MRIO databases with subnational local-to-national MRIO models thereby spanning the local-to-global scale^{19–22}. For instance, recent research on China illustrates a coupled subnational–international MRIO model that connects provinces to the global economy (Hou et al., 2025). These models enable the depiction of economic heterogeneity across subnational regions, which is important for addressing policies related to structural economic change, supply-chain-transmitted shocks and risks^{23,24}.

The general misalignment between EE-MRIO databases and official statistics from NSIs has been identified as a major obstacle to the policy uptake of derived CF accounts²⁵. EE-MRIO models are generally underdetermined systems; that is, not all table elements are known or explicitly informed by primary data. EE-MRIO models are built from official statistics sourced from a range of national and international statistical authorities; however, these statistics are often significantly altered during model compilation through balancing algorithms that are necessary to reconcile conflicting data sources. To alleviate this shortcoming, EE-MRIO models tailored to a specific country of interest have been developed, which represent the official data of this country with much higher accuracy (Edens et al., 2015; Hambj e et al., 2018; Wilting, 2012).

One of the first country-specific national-to-global MRIO models was constructed for the UK²⁶. The CF from the UK-MRIO became part of the annual reporting scheme of the official national statistics and was used to facilitate the UK emissions reduction policy²⁷. This achievement is also attributed to the existence of a customized EE-MRIO database²⁸. For Austria, the Institute of Economic Research (WIFO) has compiled regionalized MRIO models for economic assessments, but these have not been used for carbon footprints, nor are they peer-reviewed, openly available to the public, or globally-nested²⁹.

So far, CF accounts for Austria's federal states covering all final demand categories (including final consumption of households, government, and capital) have not been compiled. MRIO-based national-level CFs analyses of Austria's total final demand have been conducted^{30,31} but most CF assessments for Austria have focused on household demand. National CFs of household consumption have been investigated in more detail, for example, along their time-use patterns³² and in the context of urban and rural divides as well as income groups³³. Windsperger³⁴ used life cycle assessment (LCA) to assess household CFs with more product details than those in previous studies. A combination of IO and LCA was used to assess the CFs of the Austrian health sector³⁵. The most recent CF assessment conducted by Dorninger³⁶ combines a national-to-global MRIO (EXIOBASE 3.8.2) with household budget surveys of Austria to analyze the CFs of federal states' household demand in terms of income groups in a time series from 2000 to 2020. However, Dorninger and colleagues did not regionalize other final demand categories (e.g., gross fixed capital formation) and could not account for existing heterogeneities in the economic structures and supply chain patterns of federal states.

The present work addresses the above-mentioned policy needs and overcomes current data limitations by presenting an open-access environmentally-extended local-to-global MRIO database for Austria that is consistent with official accounts, linking federal states to 48 countries and world regions, thereby enabling the CF assessment of federal states from the subnational to the global scale. System boundaries and account definitions of the Austria MRIO follow the System of National Accounts³⁷ and System of Environmental Economic Accounting³⁸.

2. Methods

Overview of the MRIO compilation workflow

The compilation of the local-to-global MRIO was divided into two key steps, following similar procedures applied for Australia and China^{20,39}. The first step was to create a local-to-national EE-MRIO by downscaling Austria's national supply–use tables (SUT) and production-based GHG accounts to the federal state level, using various subnational data and appropriate proxies. To preserve alignment with official statistics, the database integrates official environmental–economic accounts sourced from Statistics Austria (StatA) and the Environmental Agency Austria (UBA). The second step was to nest the local-to-national MRIO into an existing national-to-global EE-MRIO, thereby linking the domestic supply chains of Austria's federal states to international supply chains. We used the latest version of the EXIOBASE MRIO (3.10.1). Figure 1 shows an overview of the MRIO construction workflow.

Both the construction of the local-to-national MRIO and its integration into the global MRIO employed a RAS-type balancing algorithm to align inconsistent data and balance the IO matrices. RAS-type balancing algorithms are essential for addressing missing, incomplete, and incompatible data in the construction of MRIO models⁴⁰. The RAS method, also sometimes referred to as iterative scaling technique, is extensively used to create balanced IOTs or SUTs by aligning matrices with specific constraints, such as

ensuring that sector inputs equal sector outputs. RAS necessitates an initial estimate of the target IO matrix, depicted as grey circles in Fig. 1, which should approximate the final IO table as closely as possible.

This study implemented the generalized RAS (GRAS) algorithm ⁴¹, which is an extension of the basic 'row-column balancing' RAS approach. GRAS enables the alignment of the MRIO matrix to specific subsets of matrix elements, including negative matrix elements, by incorporating them as additional data constraints (shown as blue cylinders in Fig. 1). Negatives may occur in the MRIO matrix elements that refer to subsidies, taxes, and changes in inventory. Subsets of MRIO matrix elements may refer to known values for certain inter-industry flows (e.g., federal states' household demand for food and energy products) or sub-regional blocks (e.g., sectoral value added of federal states). Beginning with an initial estimate and aligning it with key accounting identities (sector balances) and specific data constraints, GRAS offers a practical method for developing a complete and balanced model, even when data are incomplete and initially misaligned.

A highly detailed root classification for creating local-to-national Austria MRIOs

The development of the local-to-national MRIO model employs a virtual IO laboratory approach, utilizing modular data processing based on a highly detailed root classification and related proxy data to facilitate data integration ^{25,42,43}. All raw data used to compile the local-to-national MRIO database (see Table 1) was mapped to the root classification, allowing Austria's economy to be broken down into 2117 municipalities across 716 sectors, thus simplifying data reuse for future model construction. Data on employment, measured in full-time equivalents, from StatA's workplace survey for the years 2011 and 2021 was chosen as a proxy (Fig. 2). The root classification constitutes the most detailed sector and region classification that is possible for building local-to-national MRIO models in Austria.

Compiling initial estimates of the Austria MRIO

The initial estimate of the local-to-national Austria MRIO of federal states was created by downscaling national SUTs and sectoral GHG accounts using regional accounts from StatA, the Environmental Agency Austria (UBA), as well as root proxy data for situation where primary data was missing. Table 1 provides a summary of all the data used in the construction of the Austria MRIO, showing further details on classifications and whether the data were used for setting up the initial estimate only, or for formulating data constraints as well. Federal states' gross production, value added, and intermediate demand are approximated using the 525 sector-classed Structural Business Statistics (SBS) of StatA. Federal states' household expenditures was regionalized using StatA's household budget surveys. International imports and exports of federal states are downscaled using subnational-to-international trade accounts from StatA, which are also key for nesting the local-to-national MRIO into the national-to-global MRIO. Because the subnational-to-international trade accounts do not include trade in services, national imports and exports thereof were regionalized proportionally to federal states' share in the national gross production of the respective service sector (as reported by SBS). Following the approach

taken by ⁴⁴, domestic trade shares from the EUREGIO MRIO ⁴⁵ were used to create the initial estimate of inter-state trade between Austria's federal states. For each product and consuming state, the total (intermediate and final) product use is split across supplying states according to EUREGIO's NUTS2 trade shares. StatA's national production-based GHG accounts for sectors were downscaled using UBA's regional GHG inventories.

The second step of the local-to-global MRIO construction was to nest the resulting local-to-national Austrian MRIO into a national-to-global MRIO (EXIOBASE 3.10.1). The international trade accounts of federal states, which were already used to construct the local-to-national MRIO, were used again to create the initial estimate of the local-to-global MRIO and the associated constraints for the GRAS algorithm. Flows related to the local-to-national MRIO remain unchanged during GRAS, whereas the economic structure of Austria's direct trading partners is adjusted to maintain sector balances. Because Austria accounts for less than 2% of the global GDP, the adjustments of the GRAS algorithm to the rest-of-the-world (RoW) in the national-to-global MRIO are marginal.

Table 1
Summary of all datasets used for constructing the globally-nested Austria MRIO. StatA stands for Statistics Austria.

Item	Regions	Sectors	Years	Note	Used for Initial Estimate	Used as constraint in RAS
Official national supply use tables from StatA	1	74/78	2010–2022	Data in basic prices were used. Import matrices for final and intermediate products from the EU and the rest of the world.	yes	Yes
Employment (Full Time Equivalents) from StatA	2117	716	2011, 2021	Root proxy with the most detailed classification. It is used for gap-filling and data integration.	Yes	No
Gross VA; working time from StatA	9	58	2010–2022	Fully consistent with national IOT	Yes	Yes
Consumer survey from StatA	9	48	2010, 2015, 2020	Data in the Coicop classification. Bridge matrix to NACE sectors in the official supply–use tables.	Yes	Yes
Subnational to international trade accounts from StatA	9	99	2010–2022	Mainly manufactured products and food, and no services. 30 international trade partners.	Yes	Yes
Structural business statistics (SBS) from StatA	9	525	2010–2022	Data on production, intermediate use, and value-added. Detailed sector-level gap-filling using root proxy data is required.	Yes	No
EU-NUTS2 trade shares from EUREGIO MRIO	9	14	2010	EUREGIO trade flows were originally estimated using	Yes	No

Item	Regions	Sectors	Years	Note	Used for Initial Estimate	Used as constraint in RAS
				a transportation model.		
EXIOABSE MRIO	49	163/200	2010–2022	The global MRIO was used for nesting the national-to-local-scale MRIO of Austria.	Yes	No
Official emission accounts from StatA	1	71	2010–2022	Emissions of CO ₂ , CH ₄ and N ₂ O were selected for this study	Yes	Yes
GHG inventory for federal states from Umweltbundesamt	9	7	2010–2022	Household emissions are also included. The data follow the residence principle.	Yes	Yes

3. Data records

Version 1.0 of the database provides a time series from 2010 to 2022, covering 57 regions (of which nine refer to Austrian federal states), employing a heterogeneous sectoral classification of 74 products for Austria, and 200 for the rest of the world. Figure 3 provides an overview of the database system structure. The local-to-global Austria MRIO model is available in a product-by-product format. For each year in the time series, a zip folder containing a complete set of MRIO tables (including auxiliary tables with labels) can be downloaded from the website. The MRIO tables are in CSV format and are as follows: Z is the intermediate demand inter-industry matrix and L is the Leontief inverse, both of which have 10,266 rows and columns. Y is the final demand matrix, which differentiates between five categories: final consumption by households, the government, and non-profit institutions serving households, gross fixed capital formation, and changes in inventories and valuables (10,266 rows and 285 columns). x is the gross production vector, and v is the value-added vector, both of which have 10,266 elements. q is the environmental extension containing production-based GHG emissions (energy- and process-emissions of CO₂, CH₄, and N₂O) for production activities in a product classification. q_{hh} contains data for direct emissions from households. Monetary flows are in units of 1000 Euro, and GHG emissions are in kt CO₂e/yr based on GWP100 factors. The auxiliary file 'IOT_labels' contains a unique list of regions (including region groups and acronyms), as well as sector codes and labels for the inter-industry and final demand matrices.

4. Data overview

We present two summary figures of Austria's local-to-national MRIO data for 2010, the base year of the database compilation with the best data quality. Figure 4 shows a heatmap of the monetary inter-industry transactions in the local-to-national MRIO table (product-by-product format). The nine federal states in a 74-sector classification yield an intermediate demand matrix comprising 666 rows and columns (see the dark-colored section of the Z matrix in Fig. 3). In terms of regional distribution, more than 80% of Austria's (monetary) inter-industry transactions are situated within federal states (the diagonal block), with Vienna's domestic inter-industry transactions alone (region 9) accounting for approximately 31% of the national total.

Figure 5 provides an overview of Austria's subnational production-based GHG emissions. It illustrates the sectoral and regional distribution of emissions in the subnational GHG extension across 74 industries and households. At the national level, emissions from the top five sectors (households, energy, basic metals, agriculture, and paper) account for approximately 69% of Austria's total production-based GHGs (see the white dots in the top left of Fig. 5). The contributions of the three major industrial regions in Austria to these top five sectors (Upper Austria, Lower Austria, and Styria) account for more than 48% of the total national production-based GHG emissions.

5. Technical validation

Diagnostics for initial estimates and GRAS balancing runs

Using subnational data and proxies to regionalize Austria's national IO table yields an initial estimate of the local-to-national MRSUT, which largely aligns with the available national and subnational data, but violates subnational IO sector balances. The GRAS balancing algorithm then adjusts the initial estimate to ensure that both the national and subnational constraints and the IO sector balances of industries and product markets are respected. Figure 6a shows the subnational IO sector balances of the initial estimate of the local-to-national MRSUT before the GRAS balancing run commenced. It depicts a total of 1,332 sectors (nine regions, each with 74 industries and 74 product markets). Roughly 55% of federal states' sectors have imbalances of more than $\pm 25\%$. As shown in Figs. 7a–7e, GRAS requires approximately 50 iterations to find an estimate of the local-to-national MRSUT that fulfils the data constraints and the subnational sector balances. The GRAS balancing run for the subnational GHG extensions required fewer iterations (approximately 25) to reach reasonable convergence for all constraints (Fig. 7f).

When creating the initial estimate of the globally-nested MRIO model, the EXIOBASE data relating to Austria's inter-industry flows (including international imports and exports) were replaced with Austria's local-to-national MRIO table. This eventually results in violations of the global sector balances of Austria's trading partners. The purpose of GRAS in the nesting exercise is to adjust the data of Austria's direct trading partners such that global sector balances are respected while maintaining the local-to-national Austria MRIO data as is. Figure 6b illustrates the discrepancy between the monetary data for

Austria in EXIOBASE and the official national accounts of Statistics Austria. To enable a one-to-one comparison of sectoral data from EXIOBASE and the official accounts, the local-to-national MRIO table was re-aggregated to the national level, and the sectors were grouped into a common classification comprising 53 products. Figure 6b shows that most data points (more than 88%) fall outside the $\pm 25\%$ equality range, as indicated by dashed lines. However, as Austria's economy is relatively small compared to other countries (approximately 1.5% of the global GDP), the GRAS balancing algorithm achieves global sector balances after approximately ten iterations (see Fig. 7h).

Comparing Carbon Footprints from the Austria MRIO with other sources

Four peer-reviewed studies provide CF estimates for Austria within the timeframe of the globally-nested Austria MRIO (2010–2022), of which three are derived from MRIO models^{30,31,36} and one from a bottom-up LCA approach³⁴. Figure 8a shows a comparison of the national CFs for the total final demand, also showing the CF results from both the original EXIOBASE 3.10.1^{17,46} and the most recent GLORIA MRIO (release 060)^{47,48}. GLORIA provides two greenhouse gas (GHG) extensions, one based on OECD data⁴⁹ and the other on the EDGAR database⁵⁰. We found that the CFs of the Austria MRIO are most similar to those of EXIOBASE 3.10.1 and GLORIA-EDGAR (with discrepancies of no more than approximately $\pm 5\%$ for the years prior to 2020), with larger discrepancies found only for 2021 and, to a lesser extent, 2022 (in the range of approximately ± 5 to 15%). The Austria MRIO is the only source that shows a relatively strong increase after the COVID-19 pandemic outbreak. The CFs of GLORIA-OECD and the other three peer-reviewed studies are always smaller than those of the Austria MRIO.

Figure 8: Comparison of CFs from the globally-nested Austria MRIO with results from other peer-reviewed studies. Subfigure a) compares the total CFs for the full final demand of Austria. Subfigure b) depicts the per-capita household footprints for 2020. The databases and versions underlying the calculations of peer-reviewed results are shown in brackets. GLORIA MRIO comes with two different GHG extensions sourced from the OECD and the EDGAR database. The results of Dorninger (2025) were calculated using a customized version of EXIOBASE 3.8.2, which incorporates household survey data and emissions data from the Environmental Agency Austria.

Figure 8b shows a comparison of the per-capita household CFs of federal states, which are only available from Dorninger³⁶. Dorninger used a customized version of EXIOBASE 3.8.2, incorporating Austria's household budget survey data and production-based emission accounts from the Austrian Environmental Agency (UBA). While both datasets identified Vienna as the federal state with the smallest per capita household CF (approximately 7 tCO₂ e/cap/yr), the regional rankings differed considerably sometimes, with significant variations observed for Lower Austria (over 2 tCO₂e/cap/yr), Styria, and Upper Austria (approximately 1 tCO₂e/cap/yr).

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Conflict of interest statement

The authors declare no conflict of interest

Data availability statement

The MRIO database will be made available for download once the data descriptor has been accepted for publication following peer review.

Code availability statement

The code used to create the MRIO database is not publicly available.

Author contribution statements

HPW conceived the study, designed the methodology, curated the data, performed the modelling and analyses, and led the writing of the manuscript. CD contributed to study design, assisted with data work, and provided feedback on the manuscript. DW contributed to study design and provided feedback on the manuscript. JT helped to implement the methodology and provided feedback on the manuscript.

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Figures

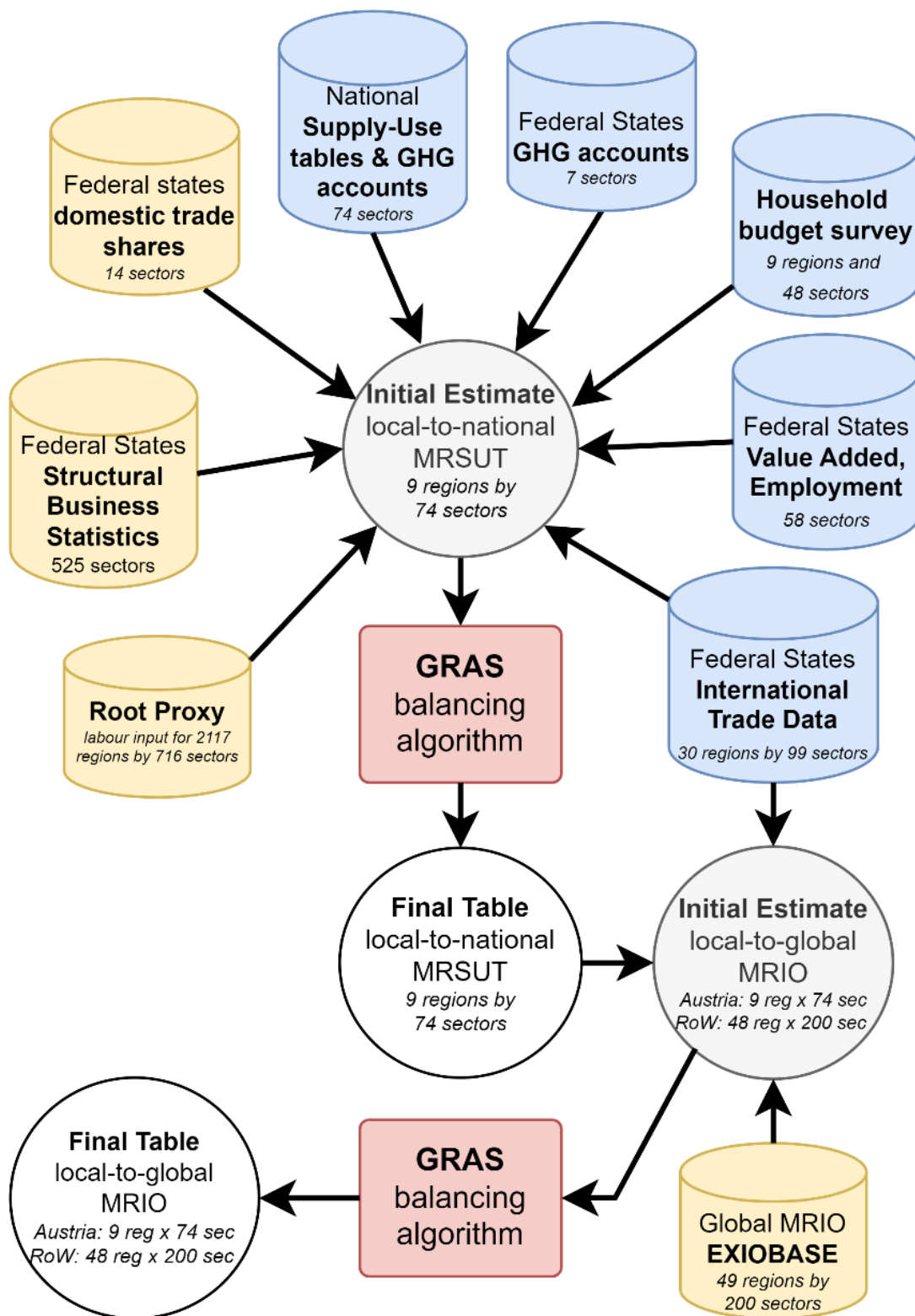


Figure 1

Overview of the MRIO compilation workflow. The cylinders represent data sources, where the blue cylinders represent datasets used to create the initial estimate and define the constraints for the RAS balancing algorithm. The data sources shown in yellow were used only to create the initial estimates of the MRIO tables.

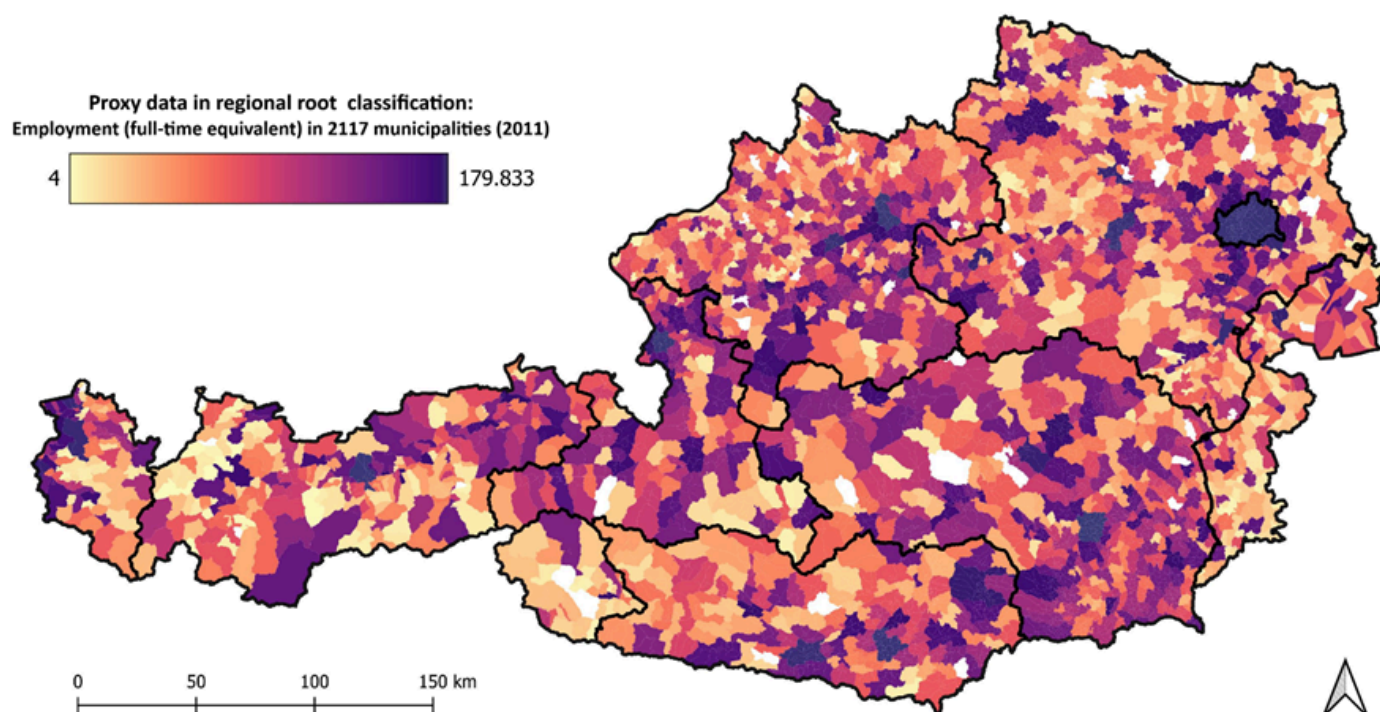


Figure 2

The regional root classification underlying the construction of the local-to-national MRIO model of Austrian federal states. The heatmap shows root proxy data for 2011, i.e., employment inputs (in full-time equivalents) in 2117 municipalities aggregated across 716 sectors.

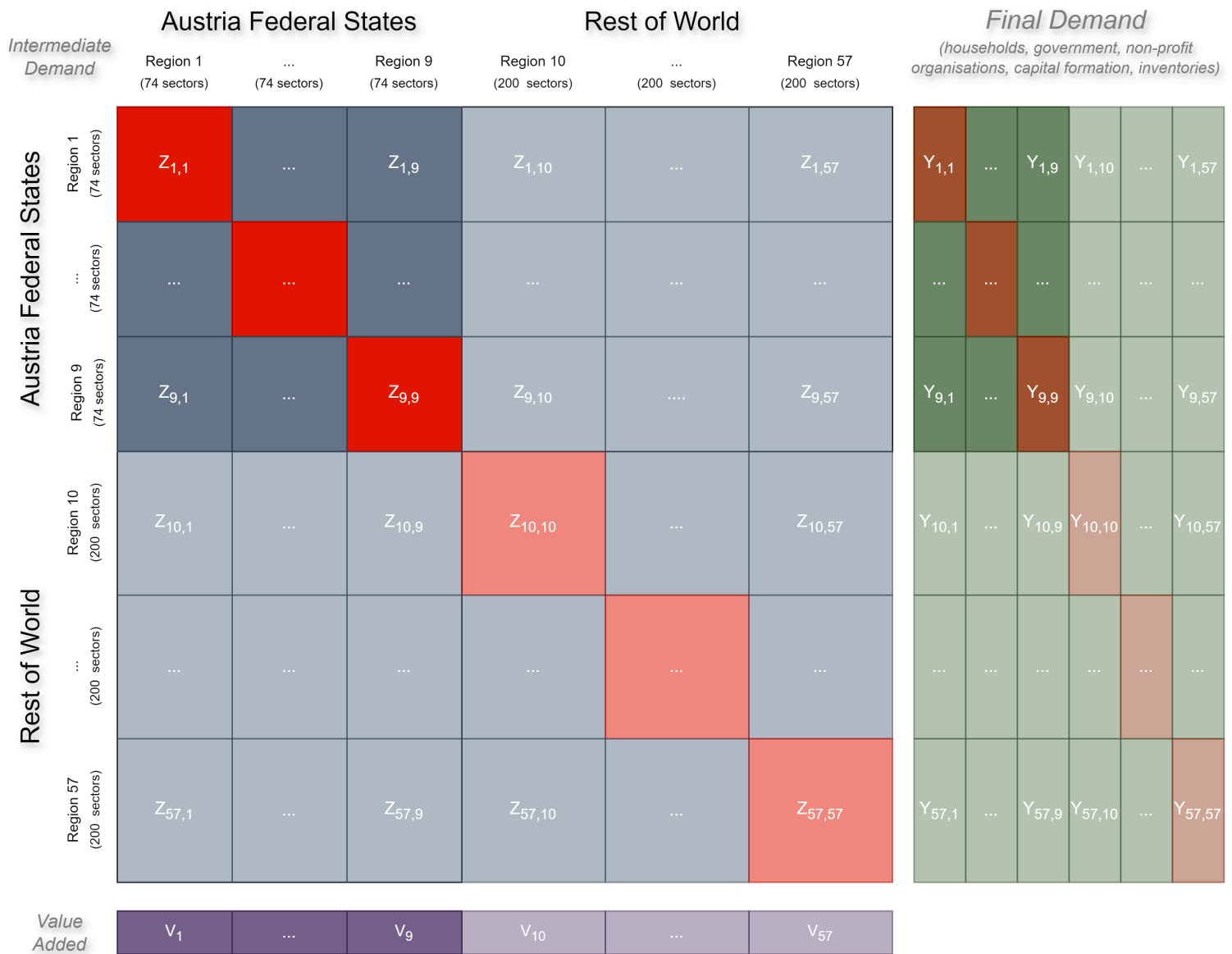


Figure 3

Overall system structure of the local-to-global MRIO model for Austria. The red sections depict domestic inter-industry flows in each region. Brown stands for regional final demand for domestically produced final products. Grey and dark green signify the trades of intermediate and final products, respectively. Value added is shown in purple at the bottom. Dark colors highlight monetary flows within Austria (including inter-state trade), whereas light colors signify international flows. Note the heterogeneous sector classification with 74 products for Austria and 200 products for the Rest of the World.



Figure 4

A heatmap showing all monetary flows situated within Austria (2010), corresponding to the dark-colored sections in the overall system structure depicted in Figure 3.

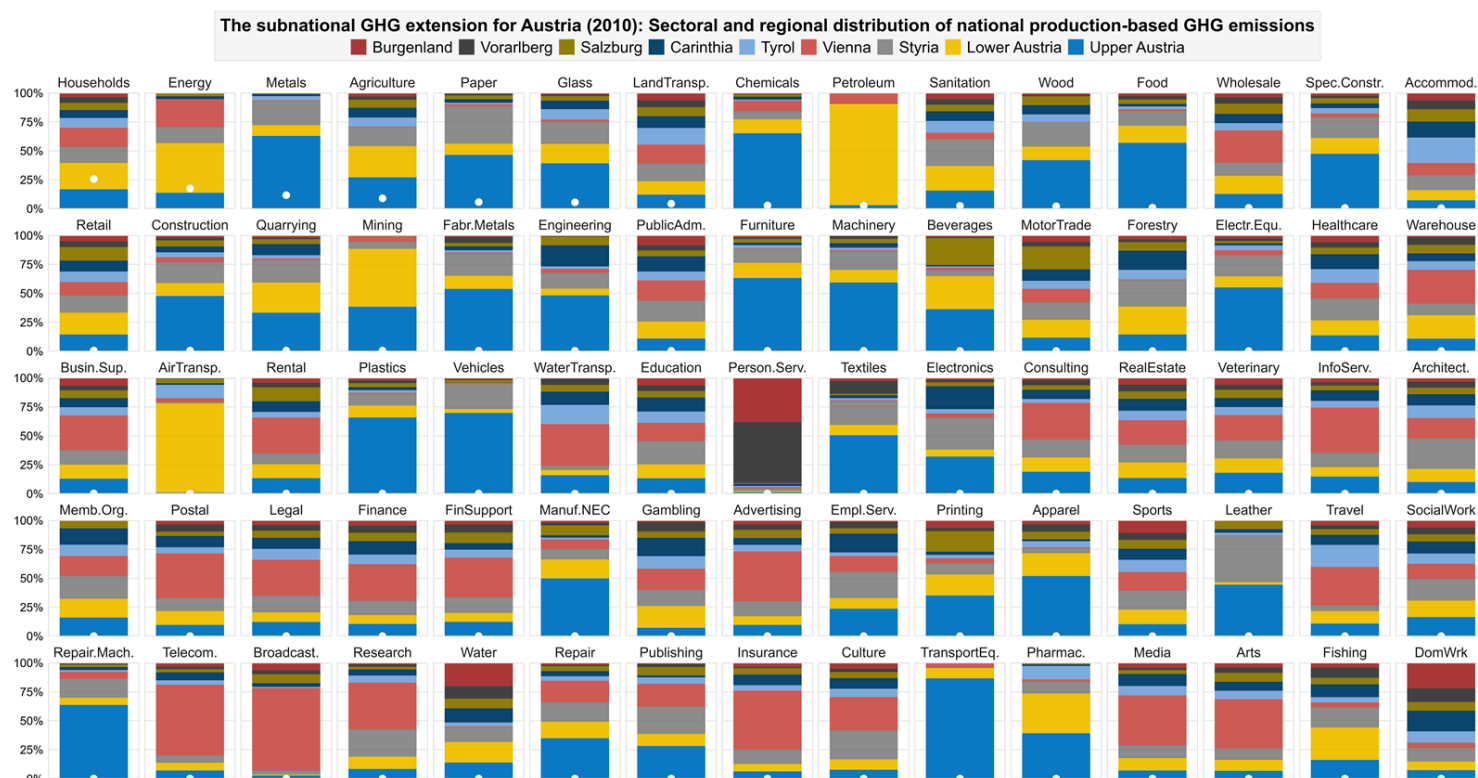


Figure 5

Summary of the GHG extension for Austrian federal states, that is, the subnational sectoral production-based GHG emissions inventory (CO₂, CH₄, and N₂O). The distribution of production-based emissions of 74 NACE sectors plus direct household emissions is shown in decreasing order of total national emissions from the top left (largest emitter) to the bottom right (smallest). The white dots depict the relative contribution of each sector to the total national GHG emissions in Austria. The colors signify the federal state shares in the national emissions of the sector.

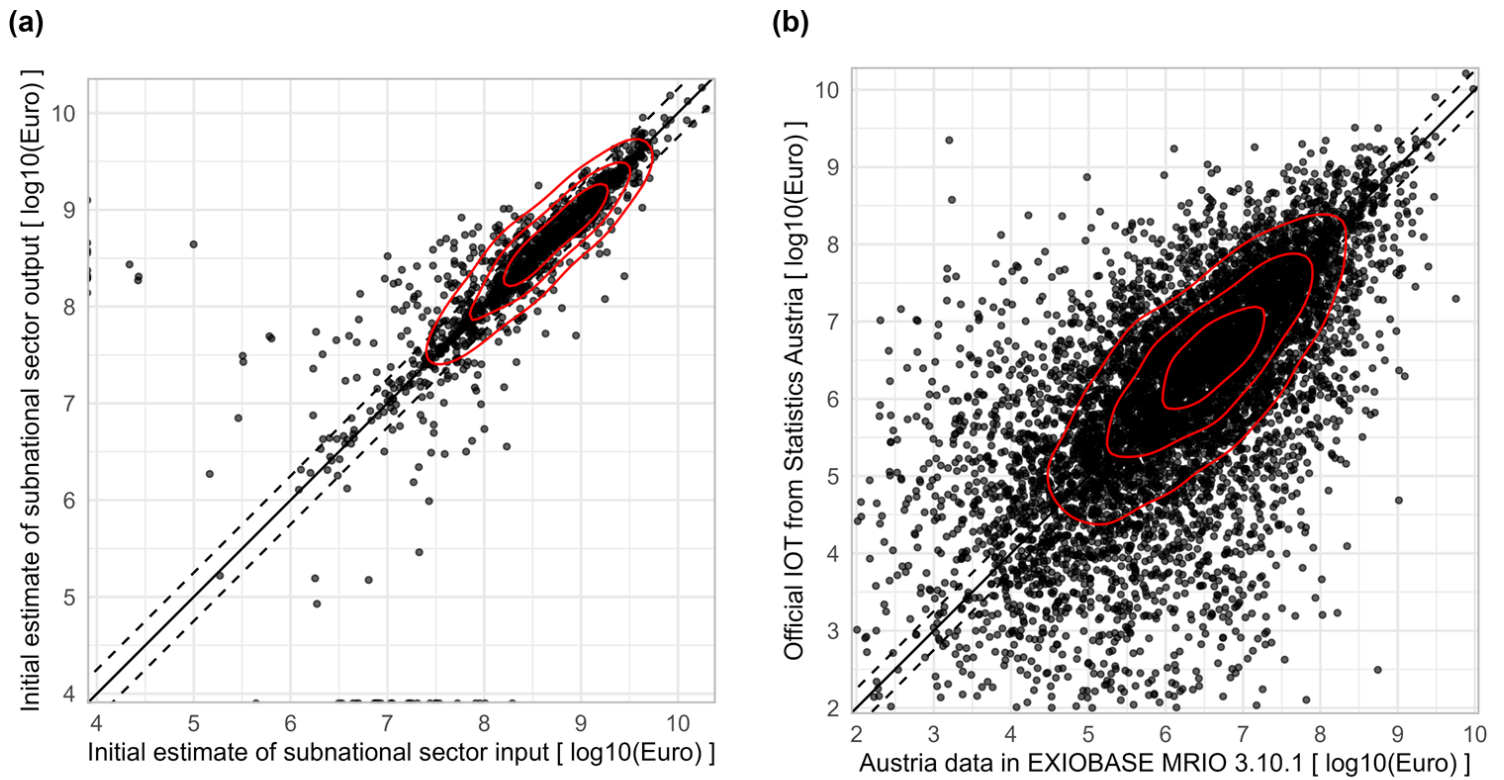


Figure 6

Part (a) on the left shows the sector balances of federal states in the initial estimate of the local-to-national MRIO. Part (b) on the right shows a comparison of the monetary IO data of Austria, as reported by Statistics Austria, versus its EXIOBASE MRIO 3.10.1 counterpart, using a common classification of 53 sectors. The solid 45-degree line signifies equality. Dashed lines indicate the +/- 25% range. Density plots with red circles highlight areas of over-plotting, where the inner circle marks 25%, the middle circle 50%, and the outer circle 75% of all the data points. The numbers refer to the 2010 data and are presented on a logarithmic scale.

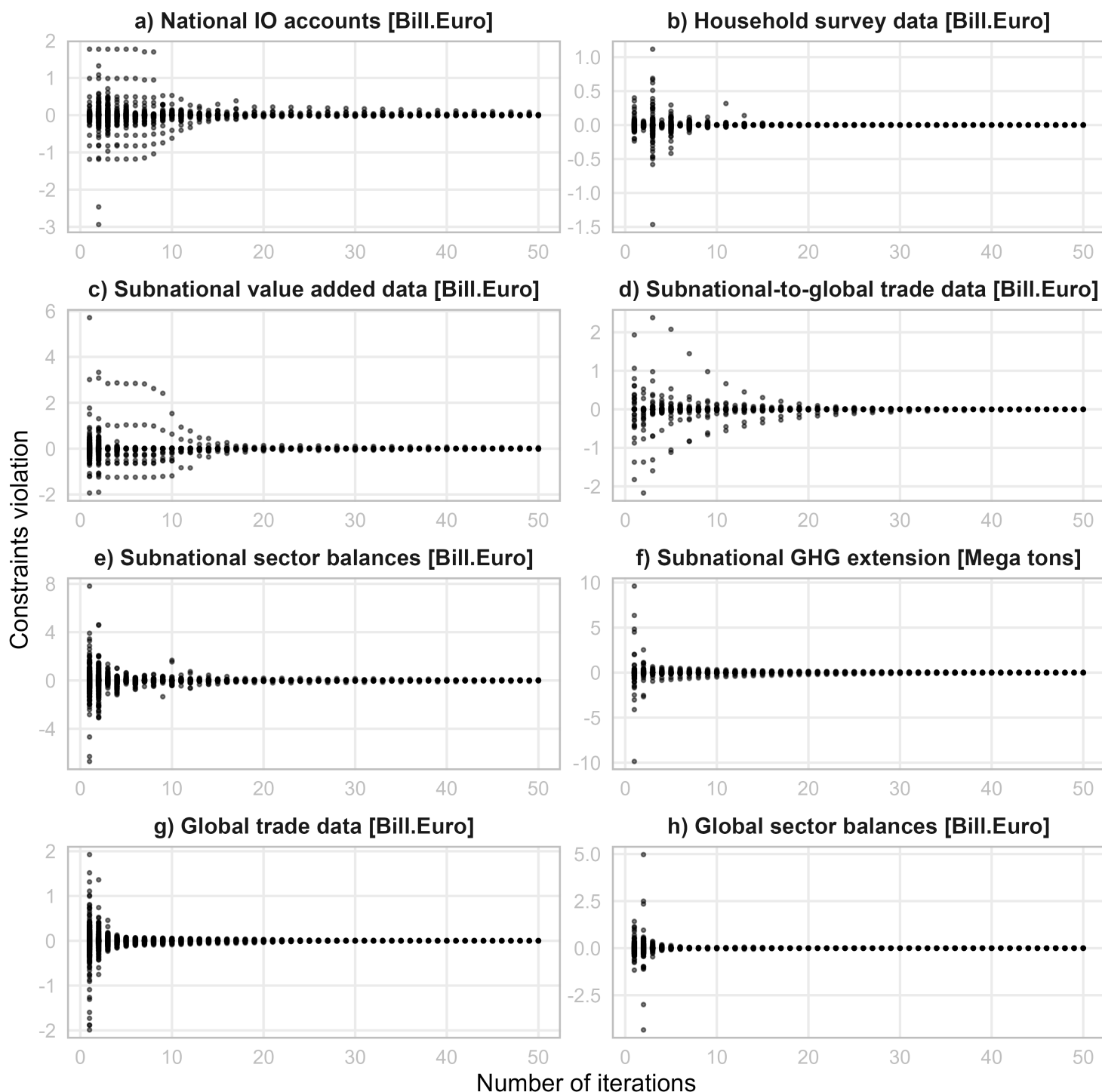


Figure 7

Summary of the evolution of constraint violations in the GRAS balancing runs. Sub-figures a) to e) show the constraints on the monetary data of the local-to-national MRSUT. Subfigure f) shows the evolution of the constraint violation for the local-to-national GHG extension. Sub-figures g) and h) show the constraint violations when nesting the local-to-national MRIO into the global MRIO EXIOBASE. The number of iterations is shown on the x-axis, and the violations are shown on the y-axis. The results refer to the model used in 2010.

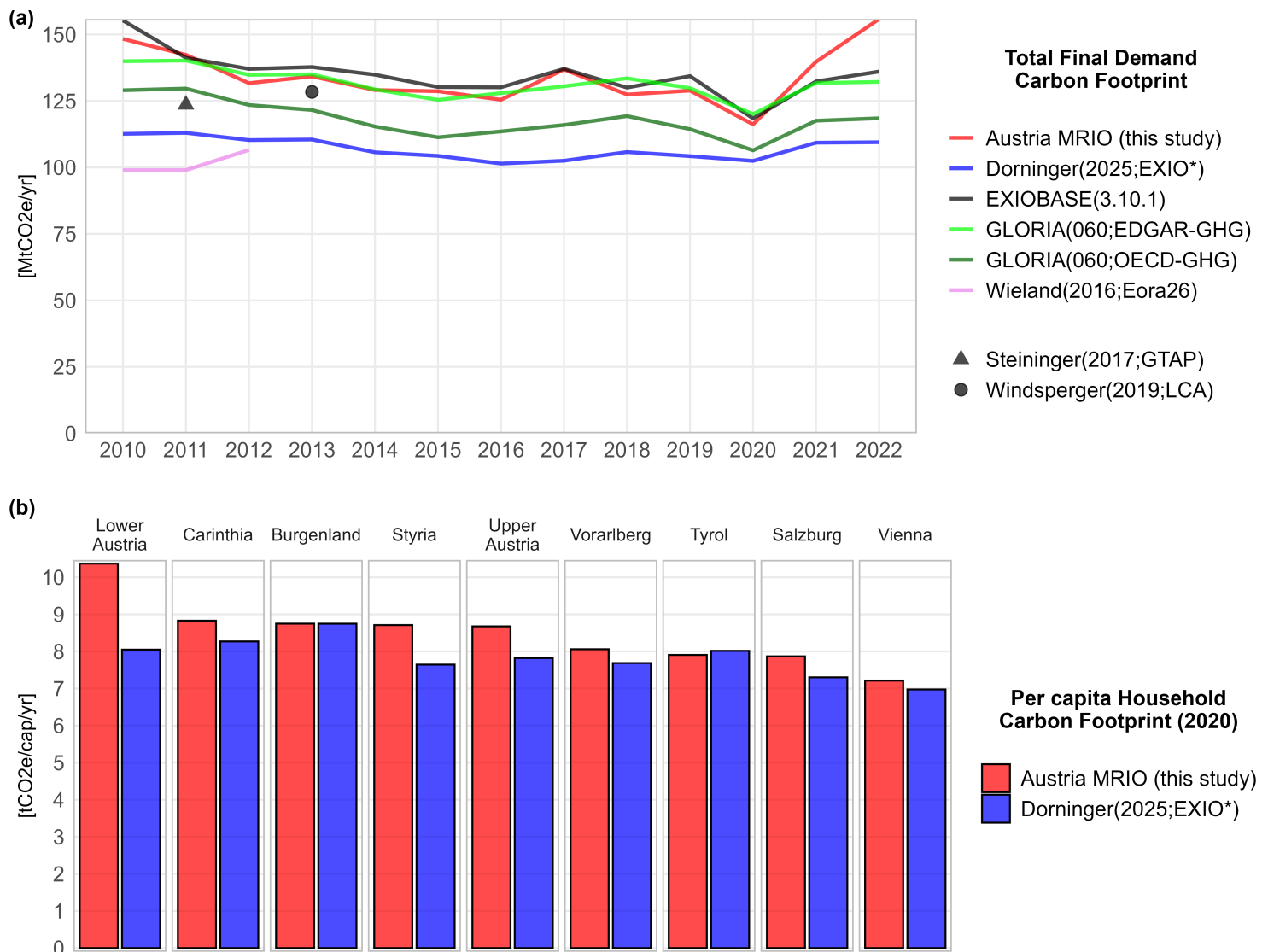


Figure 8

Comparison of CFs from the globally-nested Austria MRIO with results from other peer-reviewed studies. Subfigure a) compares the total CFs for the full final demand of Austria. Subfigure b) depicts the per-capita household footprints for 2020. The databases and versions underlying the calculations of peer-reviewed results are shown in brackets. GLORIA MRIO comes with two different GHG extensions sourced from the OECD and the EDGAR database. The results of Dorninger (2025) were calculated using a customized version of EXIOBASE 3.8.2, which incorporates household survey data and emissions data from the Environmental Agency Austria.