The construction of an environmentally extended multi-scale MRSUT: the case of Indonesia

Rum, I.A.; Koning, A. de; Tukker, A.; Yusuf, A.A.

Economic Systems Research

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/cesr20

The construction of an environmentally extended multi-scale MRSUT: the case of Indonesia

Irlan A. Rum, Arjan de Koning, Arnold Tukker & Arief A. Yusuf

To cite this article: Irlan A. Rum, Arjan de Koning, Arnold Tukker & Arief A. Yusuf (2024) The construction of an environmentally extended multi-scale MRSUT: the case of Indonesia, Economic Systems Research, 36:3, 378-403, DOI: 10.1080/09535314.2023.2280888

To link to this article: https://doi.org/10.1080/09535314.2023.2280888

ECONOMIC SYSTEMS RESEARCH
2024, VOL. 36, NO. 3, 378–403
https://doi.org/10.1080/09535314.2023.2280888

The construction of an environmentally extended multi-scale MRSUT: the case of Indonesia

Irlan A. Rum [a,b], Arjan de Koning [a], Arnold Tukker [a,c,d] and Arief A. Yusuf [b]

[a]Institute of Environmental Science (CML), Leiden University, Leiden, Netherlands; [b]Department of Economics, Universitas Padjadjaran, Bandung, Indonesia; [c]Netherlands Organisation for Applied Scientific Research (TNO), den Haag, Netherlands; [d]Paris Institute of Advanced Study, Paris, France

ABSTRACT

This article presents the construction of an environmentally extended multi-scale multi-region supply and use table (MRSUT) combining the global MRSUT from EXIOBASE with a national MRSUT at the provincial level for Indonesia using TERM database (called INDOTERM). The multi-scale MRSUT covers 2010 and 2016, reflecting comprehensive information on the transactions of 80 products among 80 different industries across 34 Indonesian provinces, 43 countries, and 5 remaining continents. To ensure the consistency of Indonesian provincial data in the multi-scale MRSUT, we use a (sub)national accounts consistent approach. Extensions are created in the MRSUT, providing valuable information regarding GHG emissions, land use, and job creation. As an illustrative example of the practical utility of this multi-scale MRSUT, a case study is used to demonstrate how changes in global consumption can have differential economic and environmental impacts on specific provinces within Indonesia.

ARTICLE HISTORY
Received 23 January 2022
In final form 2 November 2023

KEYWORDS
Environmentally extended MRSUT; multi-scale assessment; Indonesia; global demand shocks

1. Introduction

A national Supply-Use Table (SUT) provides average information on the supply and use structure by industry and by product of a country. Such economic structures, particularly in large countries, can differ across subnational regions (illustrated by subnational per capita GDP in four countries, as shown in Supplementary Information (SI), Figure SI.1–2). Compared to national SUT, region-specific SUTs often do not exist or are constructed under the assumption that supply and use structures by industry and product at the subnational level are similar to those at the national level. This is often due to the lack of hard data at the subnational level, both for industry supply and use, and inter-regional trade. However, subnational-level data have become more widely available in several countries, and they have been used to create national multi-region SUT (MRSUT) in the United States, Belgium, Brazil, Canada, Australia, China, Germany, Italy, and Indonesia, among others

CONTACT Irlan A. Rum i.a.rum@cml.leidenuniv.nl Institute of Environmental Science (CML), Leiden University, Leiden, Netherlands

Supplemental data for this article can be accessed online at https://doi.org/10.1080/09535314.2023.2280888.

(de Souza et al., 2010; Faturay et al., 2020; Oosterhaven & Többen, 2017; Paniccia & Rosignoli, 2018; Stofberg, 2016; Towa et al., 2021; Wittwer & Horridge, 2010; Wu & Liu, 2016; Yusuf et al., 2018).

The added value of such a national MRSUT is that it accounts for differences in the economic structure between subnational regions. Indonesia is a clear example in which GDP by province is driven by different sectors. Riau Province on the island of Sumatra relies mainly on the agriculture and mining sectors (56.49% share of total GDP in 2010 and 47.4% in 2019), East Kalimantan on Borneo Island relies mainly on the mining sector (47.4% in 2010 and 45.5% in 2019), and West Java on Java Island relies on manufacturing (37.8% in 2010 and 41.6% in 2019) (BPS, 2014, 2020). We refer to the detailed production structure by province for Indonesia in Figure SI.2. The existence of a national MRSUT allows for an analysis of the implications of changes in subnational final demand and international trade at the subnational level (e.g. Lenzen et al., 2017; Wittwer, 2021; Wittwer & Horridge, 2010; Yuan et al., 2018; Yusuf et al., 2018).

The global economy has become increasingly integrated over time. According to OECD data, global gross exports increased threefold between 1995 and 2018, from 1848 billion USD to 8549 billion USD. For OECD countries, the share of foreign content (i.e. the value of imported (intermediate) products) in gross exports increased from 3.4% in 1995 to 8.4% in 2018. During the same period, for non-OECD countries, the share of domestic content in gross exports increased from 87.3% to 90.2%. The volume of domestic value-added (VA) embodied in exports has increased fivefold in non-OECD countries. This shift has led them to grow their domestic share of global VA in gross exports from 45.8% in 1995 to 50.7% in 2018 (OECD, 2021b).

Global trade has contributed a significant impact on environmental impacts, such as CO_2 emissions from both consumption and production perspectives. Using the ICIO database, OECD calculated CO_2 emissions embodied in international trade and domestic final demand (OECD, 2016). Between 2005 and 2015, OECD countries reduced both production- and consumption-based CO_2 emissions by 9.1% (to 12.2 Gt) and 11.4% (13.7 Gt), respectively. During the same period, non-OECD countries increased their production- and consumption-based CO_2 emissions by 47.1% (to 20 Gt) and 60.7% (18.4 Gt), respectively. Non-OECD countries have increased CO_2 emissions, in contrast to OECD countries that have reduced CO_2 emissions, due to the growth in their domestic VA in exports.

To gain insight into how international trade can impact an economy at the provincial level, having a national MRSUT discerning provinces within a country is not sufficient. It lacks an interconnection with the global economy. What we call a global-subnational multi-scale MRSUT is required. Such a multi-scale MRSUT would combine a global MRSUT with a national MRSUT that discerns sub-country regions. A national MRSUT is defined as a multi-region SUT composed of subnational SUTs, whereas a global MRSUT is composed of national SUTs. A multi-scale MRSUT can be used to explain how consumption in one country can affect production activities and the environmental pressures thereof, such as GHG emissions and resource extraction in subnational regions.

In this article, we aim to develop the first global-subnational multi-scale MRSUT with environmental extensions for Indonesia. In Section 2, we review previous studies on multi-scale MRSUTs. Section 3 outlines the methodology and data sources used to integrate the global MRSUT with the national MRSUT and validate the results. In Section 4, we present a case study using multi-scale MRSUT to illustrate how different changes in global consumption affect provincial economies in Indonesia. Finally, Section 5 provides conclusions and potential directions for future work.

2. Literature review

By now, approximately five or six initiatives have been undertaken to develop global MRSUT/IOT databases (Tukker & Dietzenbacher, 2013). Notable examples are GTAP-MRIO (Aguiar et al., 2019; Walmsley et al., 2012), EXIOBASE (Dietzenbacher et al., 2013; Lenzen et al., 2013; OECD, 2018; Stadler et al., 2018; Tukker et al., 2009; Tukker & Dietzenbacher, 2013). A global MRSUT/IOT links several national SUT/IOTs via international trade. This approach has been widely and successfully used to analyze international trade in relation to the creation of VA and a wide variety of environmental and social footprints (Giljum et al., 2015; Kobayakawa, 2022; Steen-Olsen et al., 2014; Többen et al., 2018; Wiebe et al., 2018). However, as indicated, a global MRSUT/IOT cannot capture the heterogeneity across regions within a country.

The introduction already indicated that the national MRSUT/IOTs have been developed for various countries. However, such national MRSUT/IOTs are typically not linked to global MRSUT/IOT, and only provide total product exports from and imports to the country or province, with no information on the destination country or sector. Until now, only a few authors have combined global MRSUT/IOTs with a national MRSUT/IOT into a multi-scale MRSUT/IOT (see Table 1). From this literature, we see that the authors used multi-scale MRSUT/IOT for different purposes and approaches in the integration process, as explained below.

(a) Purpose of the analysis. A multi-scale MRSUT/IOT can be used for different purposes. First, it can be used to conduct static global-subnational multiplier analyses (e.g. Wang et al., 2017). Second, it can be used as a basis for analyses with a Computable General Equilibrium (CGE) model (e.g. using a national MRSUT/IOT, Wittwer, 2012).
(b) Aligning industry and product classifications. Global and national MRSUT/IOTs are often classified into different industries or products. There are two options for aligning such classifications. First, we can aggregate global and national tables into one common classification. The common classification will have equal or lesser amounts of industries and products as the most aggregated classification (e.g. Meng et al., 2018). Second, we can split certain industries or products into one classification such that they match the industries or products in the other classification. In this case, the common classification will have an equal or higher number of industries or products as present in the most aggregated classification (e.g. Bachmann et al., 2015).
(c) Allocating international trade to the sub-national (province/state) level. There are two options for allocating international trade at the sub-national level. Often, we have information about how a specific country trades specific products with all other countries, but not about the contributions of subnational regions to such imports or exports. When additional data are not available, imports and exports by industry/product and province/state are usually assumed to be proportional to the total use and supply by industry/product. Each industry/product and province/state are assumed to have the same ratio of domestic and foreign inputs and outputs (Wang

Table 1. Previous studies that developed a global-subnational multi-scale MRSUT/IOT.

Authors	Data source	Type of database (MRSUT/ MRIOT)	Year	Number of regions and products/ industries	Satellite Accounts	Transaction between regions/ sub-regions	Integration method
Bachmann et al. (2015)	(a) Canadian MRIOT from Statistics Canada (13 provinces & territories, 25 industries, and 50 products); (b) Provincial foreign trade data from Statistics Canada; (c) Individual country IOT from OECD (48 countries, 37 industries); (d) bilateral trade data from OECD (33 OECD members and 14 non-OECD members)	Two scale (province, country) MRIOT	2005	(a) 60 regions (47 countries and 13 Canadian sub-regions); (b) 37 industries for 47 countries; (c) 25 industries and 50 products for 13 provinces	No extensions	Multiregional approach	The (sub)regional technical coefficients and trade coefficients are taken from the (sub)regional IO table. Region to sub-region trade flow coefficients is constructed using import and export coefficients. The proportion of exports from (imports to) a province only depends on the product type, regardless to destination (origin) country.
Wang et al. (2017)	(a) Chinese MRIOT (30 provinces, 30 sectors); (b) Chinese IOT (135 sectors); (c) Provincial foreign trade data from the Statistics China; (d) Global MRIOT from EORA (185 countries, 25–500 sectors)	Two scale (province, country) MRIOT	2007 as base year; Forecasted to 2011; backcasted from 1997	(a) 214 regions (184 countries and 30 Chinese provinces); (b) 30 economic sectors	CO_2e emission and sectoral income accounts for Chinese regions	Interregional approach	The intra- and interprovincial transactions are taken from the Chinese MRIOT. The intra- and intercountry transactions are taken from the EORA MRIOT. The international trade blocks are built using provincial foreign trade data and national trade-share coefficients from the EORA database. It assumes that the sectoral structure of provincial foreign trade is the same as the sectoral structure of China's foreign trade.
Meng et al. (2018)	(a) Chinese MRIOT from Statistics China (30 provinces, 30 sectors); (b) Global MRIOT from WIOD (41 countries, 35 sectors)	Two scale (province, country) MRIOT	2010	(a) 70 regions (40 countries and 30 provinces); (b) 20 economic sectors	Energy, water, and land use accounts for Chinese regions	Interregional approach	The intermediate and final flows among provinces in China and regions worldwide are built by splitting the total volume of regional sectoral trade using a matrix generated from trade relationships between China and other worldwide areas in the global MRIOT.

Jiang et al. (2019)	(a) Chinese MRIOT from Statistics China (30 provinces, 30 sectors) (b) additional resource extraction statistics to split up the Chinese MRIOT to 48 sectors; (c) Global EE MRIOT from EXIOBASE (49 countries, 163 industries); (d) specific customs data on imports and exports by sector and province	Two scale (province, country) MRIOT	2007, 2010	(a) 78 regions (48 countries and 30 Chinese provinces); (b) 48 economic sectors	Material extraction accounts for Chinese regions and rest of the world	Interregional approach	The Chinese province level MRIOT was disaggregated to 48 sectors. The IO relations of disaggregated sectors in province were assumed to be distributed in the same proportion as China's national level for those sectors. A harmonized sector classification is used between 2 MRIOs by aggregating EXIOBASE to 48 sectors. EXIOBASE imports and exports to and from China were imposed on the Chinese table. Province and sector-level customs data of China were used to disaggregate Chinese imports and exports by sector and province.
Fry et al. (2022)	(a) Australian EE MRIOT from the IElab (10 states and territories, 17 sectors); (b) Global MRIOT from IElab (27 countries and continents, 17 sectors).	Two scale (province, country) MRIOT	2009 as base year; forecasted to 2015	(a) 36 regions (26 countries and 10 Australian states and territories); (b) 17 economic sectors	Water account for Australian regions	Interregional approach	In the global MRIOT, Australia is replaced by its subnational multi-regional counterpart obtained from IElab. Trade blocks between each subnational region in Australia and trade partner countries are obtained by disaggregating all trade blocks via a proportionality assumption that each sector in each subnational region uses for each product a similar share of domestically produced and imported input. They use export and import weight matrix for splitting international trade flows into portions to subnational regions, following Wang et al. (2017).

Source: Authors compilation.

Abbreviation: (EE) MRIOT = (Environmentally Extended) Multi-Region Input–Output Table.

et al., 2017). However, if we have trade data by industry/product, province/state, and individual countries (such as custom data), we can build imports and exports by industry/product and province/state that are coherent in the multiscale MRSUT/IOT (e.g. Jiang et al., 2019).

(d) Integration process. Three options are available for the integration process. First, we can build a multi-scale MRSUT/IOT consistent with (sub)national accounts. In this approach, imports and exports according to the national MRSUT/IOT are imposed on the global MRSUT/IOT (compare Edens et al., 2015). Second, we can do the reverse: impose trade in the global MRSUT/IOT on the national MRSUT/IOT (Wang et al., 2017). Third, we can also build a multi-scale MRSUT/IOT that first combines the global and national MRSUT and balances them together at a multi-scale level. In all cases, a balancing procedure must be used to ensure that in the combined table supply equals use, such as RAS (e.g. Mi et al., 2018) or a Lagrangian balancing procedure (e.g. Edens et al., 2015).

(e) Estimation of transactions between countries. There are two options for estimating transactions between countries (Miller & Blair, 2022). The first option is an inter-regional model. It requires a complete set of intra- and inter-regional data for each national MRSUT/IOT (Wang et al., 2017). However, a complete inter-regional model is often difficult to implement because it requires a large amount of data. The second option is a multi-region model consisting of individual SUT/IOTs and shipment data between countries (e.g. Bachmann et al., 2015).

3. Building an Indonesian multi-scale environmentally extended MRSUT

3.1. Introduction: the approach in brief

The general approach is as follows: Two existing MRSUT datasets with subnational and global coverage are merged into one multiscale MRSUT. It links the MRSUT of Indonesian provinces, which provide inter- and intra-provincial transactions, with a global MRSUT that provides inter-country transactions. We impose Indonesian trade data from the national MRSUT on the global MRSUT, and rebalance the latter using the RAS technique. This leads to a multi-scale MRSUT that is consistent with Indonesian (sub)national accounts. Provincial foreign exports and imports by country are constructed from the national trade-share coefficients from the global MRSUT. It is assumed that the sectoral structure of provincial foreign trade is the same as that of national foreign trade.

For the global MRSUT, we use EXIOBASE version 3.3 for the year 2010 and version 3.6 for 2016. The construction of EXIOBASE has been described by Wood et al. (2015) and Stadler et al. (2018). This supply and use table covers 43 countries (of which 26 are EU countries) and 5 remaining continents. It includes 200 products, 163 industries, 6 types of labor, and environmental extensions with 34 different types of emissions and 14 different types of land use, in addition to the extraction of a few dozen biotic and abiotic resources next to water use. We select EXIOBASE over other global MRSUT due to its high consistent sector and product detail and the extensive coverage of environmental and labor extensions. EXIOBASE data is accessible at www.exiobase.eu.

For the national MRSUT, we utilize the Indonesia TERM (INDOTERM) database, which provides provincial accounts for Indonesia. We opt for INDOTERM over IndoLab (Faturay et al., 2017) because it allows full access to the database, whereas IndoLab is available on a protected online cloud-based platform that is not open access. INDOTERM belongs to the TERM family and is a framework for Computable General Equilibrium (CGE) modeling of multiple regions within a single country. TERM has been used in several countries (e.g. Horridge & Wittwer, 2006, 2008). In this study, we make use the 34-province INDOTERM database for 2010 and 2016, which is the latest year available. It covers 34 provinces and 185 products and industries but has neither environmental nor labor extensions. INDOTERM data can be accessed at www.copsmodels.com.

Before integration, it is necessary to transform INDOTERM into an MRSUT at because the MRSUT EXIOBASE is at basic price. We use the environmental and labor extensions already available in EXIOBASE for all countries except Indonesia. For Indonesia, we use a variety of national data sources to construct such extensions specific to sector and province. In Section 3.2, we discuss the mathematical approach, followed by Section 3.3, in which we explain practical data integration. Section 3.4 provides a brief assessment of the extent to which integration can change the structure of global economies. Section 3.5 shows final results and the ranges of potential application from this multi-scale MRSUT.

3.2. Mathematical elaboration

3.2.1. Transforming TERM into a national MRSUT at basic price

TERM has its own database structure and uses a different terminology than EXIOBASE or SUT/IOTs in general (Horridge, 2012). The structure of TERM and the list of variable names and parameters are provided in Supplementary Information (SI) Figure SI.3 and Table SI.1. Each variable consists of multiple parameters. For example, the variable *USE* at purchaser price in TERM, represented by $USE(p, s, u, d)$, contains four parameters: p for product, s for source (domestic, denoted as dom, and import, denoted as imp), u for user (intermediate and final users), and d for destination province. The variable *USE* shows the value of product p by source s, either domestically produced or imported, or later called $p(s)$, used by user u in destination province d (which can be both the province where the product is consumed or a province to which it is exported). Starting with this structure, two steps are required to transform the TERM database into an SUT structure at basic price.

First, we introduce variable $USET(p, s, r, d)$, which represents the value of a (traded) product by source $p(s)$ from origin province r and be used in destination province d at purchaser price. Based on the TERM structure shown in Figure SI.3, we can define *USET* as

$$USET(p, s, r, d) = TRADE(p, s, r, d) + \sum_{m} TRADMAR(p, s, m, r, d) \quad (1)$$

where variables *TRADE* and *TRADMAR* are available in TERM. The variable $TRADE(p, s, r, d)$ represents the value of product $p(s)$ traded from origin province$r$ to destination province d at basic price. The variable $TRADMAR(p, s, m, r, d)$ shows the value of margin m required to trade product $p(s)$ from origin province r to destination province d. We verify that the sum of *USET* over origin is equal to the sum of *USE* over users, or we express it as $\sum_r USET = \sum_u USE$.

We use variable *USET* to derive a variable called $USEM(p, s, u, r, d)$ that shows the value of product $p(s)$ from origin province r used by user u in destination province d at purchaser price, such that

$$USEM(p, s, u, r, d) = SHRUSE(p, s, u, d) \times USET(p, s, r, d) \tag{2}$$

where $\times$ is a scalar multiplication. The variable $SHRUSE(p, s, u, d)$ represents the share of product $p(s)$ by user u in destination province d, which is derived from

$$SHRUSE(p, s, u, d) = \frac{USE(p, s, u, d)}{\sum_u USE(p, s, u, d)} \tag{3}$$

We verify that the sum of *USEM* over users is equal to the *USET*, or we write it as $\sum_u USEM = USET$. Next, we assume that variable *TRADMAR* has the same user share as in *USE*. Using the same use share variable we defined earlier, we can derive another variable, $TRADMARM(p, s, u, m, r, d)$, which shows the trade margin with an additional dimension of user u called which shows the value of margin m required to trade product $p(s)$ from origin province r to user u in destination province d, as

$$TRADMARM(p, s, u, m, r, d) = SHRUSE(p, s, u, d) \times TRADMAR(p, s, m, r, d) \tag{4}$$

We verify that the sum of *TRADMARM* over users is equal to *TRADMAR*, which can be expressed as $\sum_u TRADMARM = TRADMAR$. Next, we generate variable $USEB(p, s, u, r, d)$ which shows the value of product $p(s)$ from origin province r used by user u in destination province d at basic price as

$$USEB(p, s, u, r, d) = SHRUSE(p, s, u, d) \times TRADE \tag{5}$$

$$USEB(m, \mathrm{dom}, u, r, d) = USEB(m, \mathrm{dom}, u, r, d) + \sum_s \sum_p TRADMARM(p, s, u, m, r, d) \tag{6}$$

$$USEB(p, \mathrm{dom}, \mathrm{stocks}, d, d) = STOCKS(p, d) \tag{7}$$

In generating variable *USEB*, we assume that *TRADE* has the same user share as in the *USE*. We use the variables *SHRUSE* and *TRADE* at basic price (Equation 5). At this point, the total use of the margin products may not equal to its total supply. Margin product that is traded from origin to destination province does not contain the overall use of margin product, some parts are allocated for domestic margin supply. Thus, we add the use of margin product from the trade margin of all products from the origin to destination province (Equation 6). This adjustment ensures that the total use of the margin products is equal to the total supply. We also account for stock changes for each domestic product in each destination province from the variable stocks, $STOCKS(p, d)$.

We define variable $SUPPLY(p, i, d, d)$ as the value of product p supplied by industry i in destination province d at basic price. Based on the TERM structure illustrated in Figure SI.3, we can derive *SUPPLY* as

$$\begin{aligned} SUPPLY(p, i, r, d) &= 0 \\ SUPPLY(p, i, d, d) &= MAKE(p, i, d) + STOCKS(i, d) \end{aligned} \tag{8}$$

The variables *MAKE* and *STOCKS* are available in TERM. The variable $MAKE(p, i, d)$ shows the value of product p produced by industry i in destination province d. Lastly, we define variable $FACTOR(f, i, d)$ as the value of factor input f used by industry i in destination province d.

Second, we construct supply and use tables at basic price using the SUT structure, as depicted in Figure 1. In the supply table, we use variable *SUPPLY*. We calculate the total output per industry i and destination d and the total supply of product p in destination d by using

$$\begin{aligned} OUTPUT(i,d) &= \sum_p SUPPLY(p,i,d,d) \\ SUPPLY(p,d) &= \sum_i SUPPLY(p,i,d,d) \end{aligned} \tag{9}$$

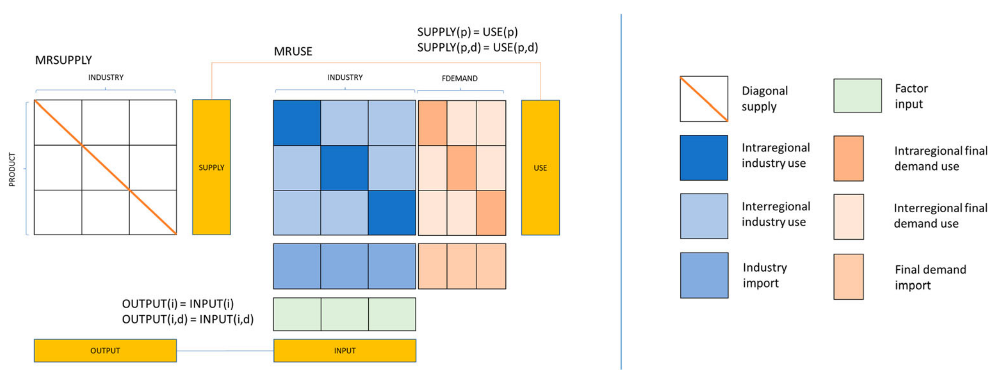
In the use table, we use variables *USEB* and *FACTOR*. We calculate the total input and total use by using

$$\begin{aligned} INPUT(i,d) &= \sum_r \sum_s \sum_p USEB(p,s,i,r,d) + \sum_f FACTOR(f,i,d) \\ USE(p,d) &= \sum_r \sum_u USEB(p,\text{dom},u,d,r) \end{aligned} \tag{10}$$

We verify that the total supply is equal to the total use, and that the total output is equal to the total input for each product p and destination province d, or we write it as $SUPPLY(p,d) = USE(p,d)$ and $OUTPUT(i,d) = INPUT(i,d)$.

Before integrating the national MRSUT into the global MRSUT, we need to transform these three variables into two-dimensional matrices: *SUPPLY*, *USEB* and *FACTOR*. We generate (1) a supply matrix $\mathbf{S}^{\text{nat}}$ that contains the diagonal values of $SUPPLY(p, i, r, d)$, (2) a domestic use matrix $\mathbf{U}^{\text{nat}}$ that contains the $USEB(p, \text{dom}, u, r, d)$ values, (3) an import use matrix $\mathbf{IMP}^{\text{nat}}$ that contains the $USEB(p, \text{imp}, u, r, d)$ and (4) a factor input matrix $\mathbf{F}^{\text{nat}}$ that contains the $FACTOR(f, i, d)$. These two-dimensional matrices are illustrated in Figure 1. From this point, we have complete supply and use tables that generate the national MRSUT at basic price.

Figure 1. SUT structure of TERM at basic price.



Source: Authors.

3.2.2. Integrating national MRSUT into the global MRSUT

We begin with the national MRSUT at basic price, as derived in the previous section. In this section, we explain the integration of the national MRSUT into the global MRSUT, forming a multi-scale MRSUT. To distinguish between national and global parameters, we use the notation 1 for national MRSUT and 2 for global MRSUT.

We define the matrices $\mathbf{S}^{\text{nat}}$, $\mathbf{U}^{\text{nat}}$, $\mathbf{IMP}^{\text{nat}}$, and $\mathbf{F}^{\text{nat}}$, which are represented as

$$\mathbf{S}^{\text{nat}}_{r\times d} = \begin{pmatrix} \mathbf{S}_{11} & \cdots & \mathbf{O} \\ \vdots & \ddots & \vdots \\ \mathbf{O} & \cdots & \mathbf{S}_{rd} \end{pmatrix};\ \mathbf{S}_{ii} = \mathbf{S}_{p_1\times n_1} \tag{11}$$

$$\mathbf{U}^{\text{nat}}_{r\times d} = \begin{pmatrix} \mathbf{U}_{11} & \cdots & \mathbf{U}_{1d} \\ \vdots & \ddots & \vdots \\ \mathbf{U}_{r1} & \cdots & \mathbf{U}_{rd} \end{pmatrix};\ \mathbf{U}_{ij} = \mathbf{U}_{p_1\times(n_1+m_1)} \tag{12}$$

$$\mathbf{IMP}^{\text{nat}}_{1\times d} = \begin{pmatrix} \mathbf{M}_{11} & \cdots & \mathbf{M}_{1d} \end{pmatrix};\ \mathbf{M}_{1j} = \mathbf{M}_{p_1\times(n_1+m_1)} \tag{13}$$

$$\mathbf{F}^{\text{nat}}_{1\times d} = \begin{pmatrix} \mathbf{F}_{11} & \cdots & \mathbf{F}_{1d} \end{pmatrix};\ \mathbf{F}_{1j} = \mathbf{F}_{f_1\times n_1} \tag{14}$$

where $\mathbf{S}^{\text{nat}}_{r\times d}$ is a national multi-region supply (mrSupply) matrix with dimension $r \times d$ submatrices and consists of diagonal provincial supply submatrices $\mathbf{S}_{ii}$ (supply product p_1 by industry n_1 in province i). Parameters p_1 and n_1 refer to the products and industries used in the national MRSUT. The $\mathbf{U}^{\text{nat}}_{r\times d}$ is a national domestic multi-region use (mrUse) matrix with dimension $r \times d$ submatrices and consists of interprovincial domestic use submatrices $\mathbf{U}_{ij}$ (use domestic product p_1 from province i by industry n_1 and final demand m_1 in province j). The $\mathbf{IMP}^{\text{nat}}_{1\times d}$ is a national multi-region import (mrImport) matrix, with dimension $1 \times d$ submatrices and consists of provincial import use submatrices $\mathbf{M}_{1j}$ (use import product p_1 from province i by industry n_1 and final demand m_1 in province j). The $\mathbf{F}^{\text{nat}}_{1\times d}$ is a national multi-region factor input (mrFactor) matrix, with dimension $1 \times d$ submatrices, and consists of provincial factor input submatrices $\mathbf{F}_{1j}$ (use factor input f_1 by industry n_1 in province j).

Next, we examine the global MRSUT. We define the symbols $\mathbf{S}^{\text{global}}$, $\mathbf{U}^{\text{global}}$ and $\mathbf{F}^{\text{global}}$ as matrices, which can be written as:

$$\mathbf{S}^{\text{global}}_{s\times t} = \begin{pmatrix} \mathbf{S}_{11} & \cdots & \mathbf{O} \\ \vdots & \ddots & \vdots \\ \mathbf{O} & \cdots & \mathbf{S}_{st} \end{pmatrix};\ \mathbf{S}_{ii} = \mathbf{S}_{p_2\times n_2} \tag{15}$$

$$\mathbf{U}^{\text{global}}_{s\times t} = \begin{pmatrix} \mathbf{U}_{11} & \cdots & \mathbf{U}_{1t} \\ \vdots & \ddots & \vdots \\ \mathbf{U}_{s1} & \cdots & \mathbf{U}_{st} \end{pmatrix};\ \mathbf{U}_{ij} = \mathbf{U}_{p_2\times(n_2+m_2)} \tag{16}$$

$$\mathbf{F}^{\text{global}}_{1\times t} = \begin{pmatrix} \mathbf{F}_{11} & \cdots & \mathbf{F}_{1t} \end{pmatrix};\ \mathbf{F}_{1j} = \mathbf{F}_{f_2\times n_2} \tag{17}$$

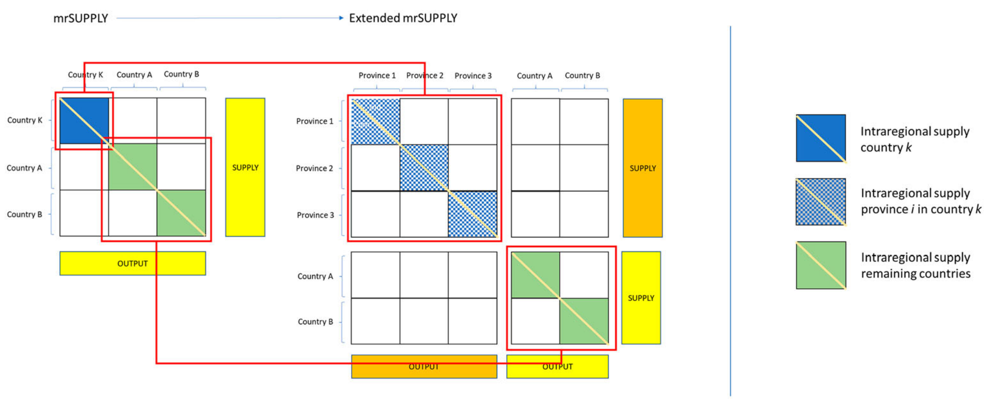
where $\mathbf{S}^{\text{global}}_{s\times t}$ is a global mrSupply matrix with dimension $s \times t$ submatrices and consists of diagonal national supply submatrices $\mathbf{S}_{ii}$ (supply product p_2 by industry n_2 in country i). Parameters p_2 and n_2 refer to products and industries in the global MRSUT. The $\mathbf{U}^{\text{global}}_{s\times t}$

is a global mrUse matrix with dimensions $s \times t$ submatrices and consists of national use submatrices $\mathbf{U}_{ij}$ (use product p_2 from country i by industry n_2 and final demand m_2 in country j). The $\mathbf{F}^{\text{global}}_{1\times t}$ is a global mrFactor input matrix with dimension $1 \times t$ submatrices and consists of national factor input submatrices $\mathbf{F}_{1j}$ (use factor input f_2 by industry n_2 in country j).

In our case, the national MRSUT uses a different product, industry, and factor input classification compared to global MRSUT. To enable the integration of the national MRSUT with the global MRSUT, we must harmonize these classifications. We chose to create a common classification by aggregating the products, industries, and factor inputs in both SUTs. While this method results in loss of data resolution with this approach, it eliminates the need for the relatively time-consuming work of splitting up products, industries, or factor inputs in both databases and avoids the danger that they may be differently defined at this more detailed level.

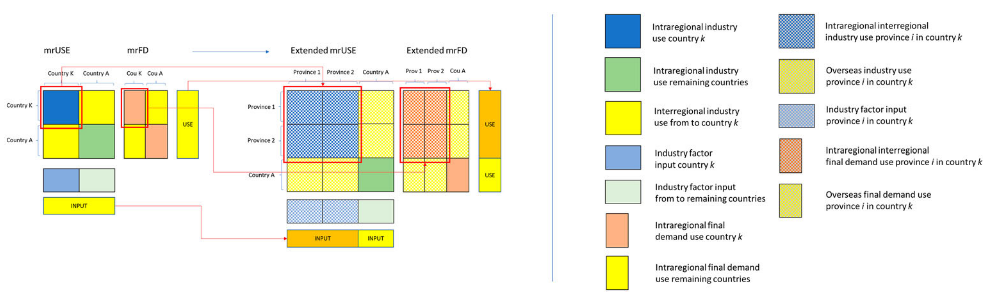
We correspond p_1 products, n_1 industries, m_1 final demands, and f_1 factor inputs from the national MRSUT to p_2 products, n_2 industries, m_2 final demands, and f_2 factor inputs from the global MRSUT to generate common p products, n industries, m final demands, and f factor inputs using a concordance matrix. For the national MRSUT, we create a

Figure 2. Integrating mrSupply matrices.



Source: Authors.

Figure 3. Integrating mrUse matrices.



Source: Authors.

concordance matrix $\mathbf{C}_{p_1\times p}$, $\mathbf{C}_{n_1\times n}$ and $\mathbf{C}_{m_1\times m}$ to aggregate the $\mathbf{U}^{\text{nat}}$ matrix from p_1 to p products, n_1 to n industries, and from m_1 to m final demands, respectively. For the $\mathbf{F}^{\text{nat}}$ matrix, we create a concordance matrix $\mathbf{C}_{f_1\times f}$ to aggregate from f_1 to f factor inputs. Thus, we can generate new submatrices with common classifications as

$$\begin{aligned}\mathbf{U}_{p\times n} &= (\mathbf{C}_{p_1\times p})^{\mathrm{T}}\cdot\mathbf{U}_{p_1\times n_1}\cdot\mathbf{C}_{n_1\times n}\ \forall\ \mathbf{U}_{ij}\\ \mathbf{U}_{p\times m} &= (\mathbf{C}_{p_1\times p})^{\mathrm{T}}\cdot\mathbf{U}_{p_1\times m_1}\cdot\mathbf{C}_{m_1\times m}\ \forall\ \mathbf{U}_{ij}\\ \mathbf{F}_{f\times n} &= (\mathbf{C}_{f_1\times f})^{\mathrm{T}}\cdot\mathbf{F}_{f_1\times n_1}\cdot\mathbf{C}_{n_1\times n}\ \forall\ \mathbf{F}_{1j}\end{aligned}\tag{18}$$

where T is a transpose operation, and · is a dot product. The same concordance matrix was used to aggregate the $\mathbf{S}^{\text{nat}}$ and $\mathbf{IMP}^{\text{nat}}$ matrices.

We use the same approach as described above for the global MRSUT. We create concordance matrices $\mathbf{C}_{p_2\times p}$, $\mathbf{C}_{n_2\times n}$ and $\mathbf{C}_{m_2\times m}$ to aggregate $\mathbf{S}^{\text{global}}$ and $\mathbf{U}^{\text{global}}$ matrices from p_2 to p products, n_2 to n industries, and from m_2 to m final demands, respectively. Additionally, we use a concordance matrix $\mathbf{C}_{f_2\times f}$ to aggregate $\mathbf{F}^{\text{global}}$ from f_2 to f factor inputs. From here on, we have all the matrices we need to integrate the national MRSUT with the global MRSUT at basic price.

We begin by integrating the mrSupply matrices using the structure shown in Figure 2. A multi-scale mrSupply matrix, denoted as $\mathbf{S}_{N\times N}$, can be defined as

$$\mathbf{S}_{N\times N} = \begin{pmatrix}\mathbf{S}^{\text{nat}}_{r\times d} & \mathbf{O}_{r\times(t-1)}\\ \mathbf{O}_{(s-1)\times d} & \mathbf{S}^{\text{global}}_{(s-1)\times(t-1)}\end{pmatrix};\ \mathbf{S}_{ii} = \mathbf{S}_{n\times n}\tag{19}$$

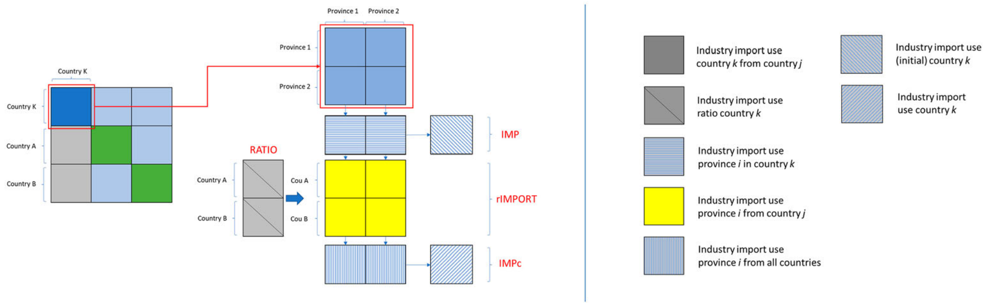
where the $\mathbf{S}^{\text{nat}}_{r\times d}$ and $\mathbf{S}^{\text{global}}_{(s-1)\times(t-1)}$ are previously defined submatrices, and $\mathbf{O}$ is a null submatrix. The upper diagonal submatrix is filled by the national mrSupply matrix $\mathbf{S}^{\text{nat}}_{r\times d}$ and the lower diagonal submatrix is filled by the global mrSupply matrix $\mathbf{S}^{\text{global}}_{(s-1)\times(t-1)}$. We delete the supply submatrix of country k (Indonesia in this case) from the original global mrSupply matrix $\mathbf{S}^{\text{global}}_{s\times t}$. We then replace the national Supply matrix with the national mrSupply matrix $\mathbf{S}^{\text{nat}}_{r\times d}$. From these three submatrices $\mathbf{S}^{\text{nat}}$, $\mathbf{S}^{\text{global}}$, and $\mathbf{O}$, we generate the multi-scale mrSupply matrix $\mathbf{S}$, with dimension $N\times N$ submatrices with $N = r + (s-1)$.

Next, we integrate the mrUse matrices using the structure presented in Figure 3. Let us define a multi-scale mrUse matrix, denoted as $\mathbf{U}_{N\times N}$, as

$$\mathbf{U}_{N\times N} = \begin{pmatrix}\mathbf{U}^{\text{nat}}_{r\times d} & \mathbf{impU}^{\text{global}}_{r\times(t-1)}\\ \mathbf{impU}^{\text{nat}}_{(s-1)\times d} & \mathbf{U}^{\text{global}}_{(s-1)\times(t-1)}\end{pmatrix};\ \mathbf{U}_{ij} = \mathbf{U}_{p\times(n+m)}\tag{20}$$

where the $\mathbf{U}^{\text{nat}}_{r\times d}$ and $\mathbf{U}^{\text{global}}_{(s-1)\times(s-1)}$ are previously defined submatrices. We delete submatrices related to country k in the original global mrUse matrix $\mathbf{U}^{\text{global}}_{s\times t}$. The national Use matrix of country k is replaced by its national mrUse matrix. The $\mathbf{impU}^{\text{nat}}_{(s-1)\times d}$ is a national import mrUse submatrix with dimension $(s-1)\times d$ submatrices and consists of provincial import use submatrices $\mathbf{U}_{ij}$. The $\mathbf{impU}^{\text{global}}_{r\times(s-1)}$ is a national export mrUse submatrix (a.k.a., global import) with dimension $r\times(s-1)$ submatrices and consists of global import use submatrices $\mathbf{U}_{ij}$. The construction of $\mathbf{impU}^{\text{nat}}$ and $\mathbf{impU}^{\text{global}}$ occurs in the following steps.

Figure 4. Creating impU^{nat} matrix.



Source: Authors.

When integrating the national MRSUT into the global MRSUT, discrepancies arise in the export and import values between the two. These disparities can be attributed to variations in data compilation practices, classifications, exchange rate conversion, etc. Therefore, the global MRSUT need to be adapted while the national MRSUT remains fixed following the System of National Accounts Consistent (SNAC) approach developed by Edens et al. (2015). This ensure that the total provincial exports and imports by product and industry in the integrated Use table align with those in the national MRSUT.

We construct the national import matrix $\mathbf{impU}^{\text{nat}}$ following the structure shown in Figure 4. The $\mathbf{impU}^{\text{nat}}$ matrix is expressed as

$$\mathbf{impU}^{\text{nat}}_{(s-1)\times d} = \begin{pmatrix} \mathbf{M}_{11} & \cdots & \mathbf{M}_{1d} & \mathbf{M}_{(s-1)1} \\ \mathbf{M}_{21} & \cdots & \mathbf{M}_{2d} & \cdots \\ \vdots & \ddots & \vdots & \mathbf{M}_{(s-1)d} \end{pmatrix};\ \mathbf{M}_{ij} = \mathbf{M}_{p\times(n+m)} \tag{21}$$

where $\mathbf{impU}^{\text{nat}}_{(s-1)\times d}$ is a previously defined submatrix. As part of $\mathbf{U}$ matrix, we have $\mathbf{U}_{ij} = \mathbf{M}_{ij}$, showing the value of imported product p used by industry n and the final demand m of province j in country k from country i. We derive $\mathbf{M}_{ij}$ from the total provincial imports using the national import coefficient of country k from country i as

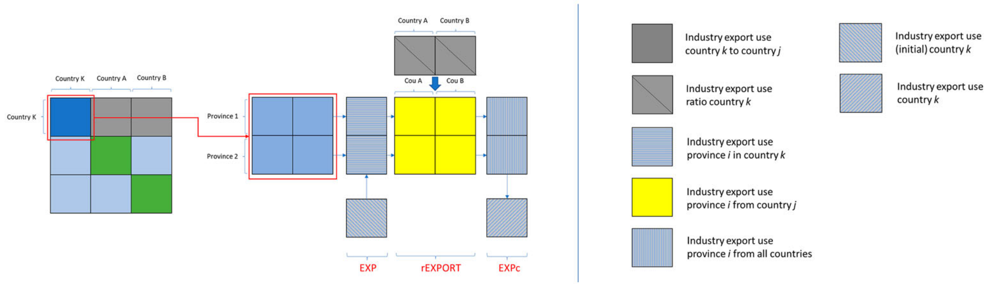
$$\mathbf{M}_{ij} = \mathbf{sM}_{ik}\ circ\ \mathbf{M}_{kj} \tag{22}$$

where $\circ$ is a Hadamard or element-wise product. The $\mathbf{M}_{kj}$ is an $p \times (n+m)$ matrix showing the total imports of province j in country k, taken from the national MRSUT. The $\mathbf{sM}_{ik}$ is also $p \times (n+m)$ matrix and indicates the import coefficient of country k from country i, derived from

$$\mathbf{U}_{ik} = \mathbf{sM}_{ik} \circ \sum_{i=1, i\neq k}^{n_2} \mathbf{U}_{ik} \tag{23}$$

where $\mathbf{U}_{ik}$ is a $p \times (n+m)$ matrix of imports of country k from country i, taken from the global MRSUT.

Figure 5. Creating impU$^{\text{global}}$ matrix.



Source: Authors.

Next, we construct a global import matrix $\mathbf{impU}^{\text{global}}$ following the structure shown in Figure 5. The $\mathbf{impU}^{\text{global}}$ matrix is expressed as

$$\mathbf{impU}^{\text{global}}_{r\times(t-1)} = \begin{pmatrix} \mathbf{X}_{11} & \mathbf{X}_{12} & \cdots & \mathbf{X}_{1(t-1)} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{X}_{r1} & \mathbf{X}_{r2} & \cdots & \mathbf{X}_{r(t-1)} \end{pmatrix};\ \mathbf{X}_{ij} = \mathbf{X}_{p\times(n+m)} \tag{24}$$

where $\mathbf{impU}^{\text{global}}_{r\times(s-1)}$ is a previously defined submatrix. As part of $\mathbf{U}$ matrix, we have $\mathbf{U}_{ij} = \mathbf{X}_{ij}$, showing the value of imported product p used by industry n and the final demand m of country j from province i in country k. We derive $\mathbf{X}_{ij}$ from the total provincial exports using the national export coefficient of country k to country i as

$$\mathbf{X}_{ij} = \text{s}\mathbf{X}_{kj} \circ \mathbf{X}_{ik} \tag{25}$$

where $\mathbf{X}_{ik}$ is a $p \times (n+m)$ matrix of the total exports of province i in country k, taken from the national MRSUT. The matrix $\mathbf{sX}_{kj}$ is a $p \times (n+m)$ matrix of the export coefficient of country k from country j, derived from

$$\mathbf{U}_{kj} = \mathbf{sX}_{kj} \circ \sum_{j=1,j\neq k}^{n_2} \mathbf{U}_{kj} \tag{26}$$

where $\mathbf{U}_{kj}$ is an $p \times (n+m)$ matrix of exports of country k from country j, taken from the global MRSUT. We generate matrix $\mathbf{X}_{ik}$ from

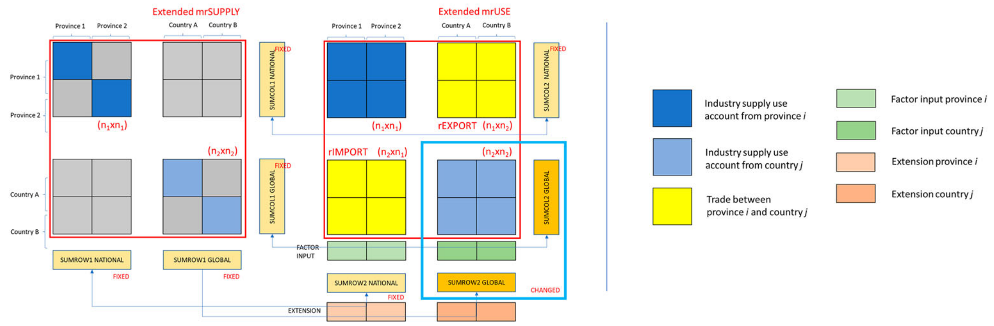
$$\mathbf{X}_{ik} = \mathbf{rX} \circ \mathbf{x}_i \tag{27}$$

where $\mathbf{rX}$ is a $p \times (n+m)$ matrix of the national export ratio by the user of country k taken from the global MRSUT. The $\mathbf{x}_i$ is a $p \times 1$ vector and represents the total exports of province i in country k, taken from the national MRSUT.

We integrate the mrFactor matrices following the structure shown in Figure 6. The multi-scale mrFactor matrix, denoted as $\mathbf{F}_{1\times N}$, can be defined as

$$\mathbf{F}_{1\times N} = \begin{pmatrix} \mathbf{F}^{\text{nat}}_{1\times d} & \mathbf{F}^{\text{global}}_{1\times(s-1)} \end{pmatrix};\ \mathbf{F}_{1j} = \mathbf{F}_{f\times n} \tag{28}$$

Figure 6. Combining SUT with provincial accounts consistent.



Source: Authors.

where the $\mathbf{F}^{\text{nat}}_{1\times d}$ and $\mathbf{F}^{\text{global}}_{1\times(s-1)}$ are the previously defined submatrices. We delete the national factor input submatrix of country k in the original global mrFactor matrix $\mathbf{F}^{\text{global}}_{1\times s}$. The national factor input matrix of country k is replaced by its national mrFactor matrix.

We proceed to integrate the $\mathbf{S}$, $\mathbf{U}$, and $\mathbf{F}$ matrices. The mrSupply matrix $\mathbf{S}$ and mrFactor matrix $\mathbf{F}$ are submatrices that originate from the national and global MRSUT. However, this is not the case for the mrUse matrix, $\mathbf{U}$. Because we integrate provincial account consistent data into global accounts and change the import use matrices between Indonesia and other countries in the world, we have an unbalanced mrUse matrix in the submatrix of $\mathbf{U}^{\text{global}}_{(s-1)\times(s-1)}$, as depicted in Figure 6. This part of the mrUse matrix must be rebalanced while keeping the total product use and industry input as fixed constraints. The algorithm used to balance $\mathbf{U}^{\text{global}}_{(s-1)\times(s-1)}$ is the Generalized RAS procedure (Temurshoev et al., 2013). This procedure is a bi-proportional balancing algorithm that correctly handles negatives and assumes that all values in the matrix have equal relative errors. Using RAS procedure, a new $\hat{\mathbf{U}}^{\text{global}}_{(s-1)\times(s-1)}$ submatrix is generated such that the integrated MRSUT total industry input is equal to the industry output for each industry sector and the total product supply is equal to the total product use for each product, thereby complying with the balance condition. This results in $\mathbf{S}_{N\times N}$, new $\hat{\mathbf{U}}_{N\times N}$, and $\mathbf{F}_{1\times N}$ matrices that constitute a balanced multi-scale MRSUT that combines global and subnational accounts.

3.2.3. Adding environmental and labor extensions to the multi-scale MRSUT

Suppose we have environmental extensions (e.g. greenhouse gas (GHG) emissions) for national and global MRSUT with different emission classifications. We define the $\mathbf{E}^{\text{nat}}$ and $\mathbf{E}^{\text{global}}$ matrices as

$$\mathbf{E}^{\text{nat}}_{1\times d} = \begin{pmatrix} \mathbf{E}_{11} & \cdots & \mathbf{E}_{1d} \end{pmatrix};\ \mathbf{E}_{1j} = \mathbf{E}_{e_1\times(n_1+m_1)} \tag{29}$$

$$\mathbf{E}^{\text{global}}_{1\times t} = \begin{pmatrix} \mathbf{E}_{11} & \cdots & \mathbf{E}_{1t} \end{pmatrix};\ \mathbf{E}_{1j} = \mathbf{E}_{e_2\times(n_2+m_2)} \tag{30}$$

where $\mathbf{E}^{\text{nat}}_{1\times d}$ represents a national mrEmission matrix with dimension $1 \times d$ submatrices and consists of the provincial GHG emissions submatrix $\mathbf{E}_{1j}$ (emission e_1 created by industry n_1 and final demand m_1 in province j). The $\mathbf{E}^{\text{global}}_{1\times t}$ is a global mrEmission matrix with dimension $1 \times t$ submatrices and consists of the national GHG emission submatrix $\mathbf{E}_{1j}$ (emission e_2 created by industry n_2 and final demand m_2 in country j).

Before integrating the GHG emission accounts in the national MRSUT to the global MRSUT, we correspond e_1 emissions from a national MRSUT with e_2 emissions from a global MRSUT. For the national MRSUT, we create a concordance matrix $\mathbf{C}_{e_1 \times e}$ to aggregate $\mathbf{E}^{\text{nat}}$ matrix from e_1 to e emissions, such that

$$\begin{aligned} \mathbf{E}_{e \times n} &= (\mathbf{C}_{e_1 \times e})^{\mathrm{T}} \cdot \mathbf{U}_{e_1 \times n_1} \cdot \mathbf{C}_{n_1 \times n} \; \forall \; \mathbf{E}_{1j} \\ \mathbf{E}_{e \times m} &= (\mathbf{C}_{e_1 \times e})^{\mathrm{T}} \cdot \mathbf{U}_{e_1 \times m_1} \cdot \mathbf{C}_{m_1 \times m} \; \forall \; \mathbf{E}_{1j} \end{aligned} \tag{31}$$

where $\mathbf{C}_{n_1 \times n}$ and $\mathbf{C}_{m_1 \times m}$ are previously defined concordance matrices. We use the same approach to aggregate GHG emissions from the global MRSUT. We create a concordance matrix $\mathbf{C}_{e_2 \times e}$ to aggregate $\mathbf{E}^{\text{global}}$ matrix from e_2 to e emissions.

We integrate the multi-region Emission (mrEmission) matrices using the structure shown in Figure 6. A multi-scale mrEmission matrix $\mathbf{E}_{1 \times N}$ can be defined as.

$$\mathbf{E}_{1 \times N} = \begin{pmatrix} \mathbf{E}^{\text{nat}}_{1 \times d} & \mathbf{E}^{\text{global}}_{1 \times (t-1)} \end{pmatrix}; \; \mathbf{E}_{1j} = \mathbf{E}_{e \times n} \tag{32}$$

where $\mathbf{E}^{\text{nat}}_{1 \times d}$ and $\mathbf{E}^{\text{global}}_{1 \times (t-1)}$ are submatrices previously defined. We delete the GHG emission submatrix of country k in the original global mrEmission matrix $\mathbf{E}^{\text{global}}_{1 \times t}$. We then replace the national emission matrix with the national mrEmission matrix, $\mathbf{E}^{\text{nat}}_{1 \times d}$.

For labor extensions, such as jobs per skill type, a similar procedure can be followed. Suppose we have the number of jobs per skill by industry, for both the national and global MRSUT with different skill classifications. We define the matrices $\mathbf{P}^{\text{nat}}$ and $\mathbf{P}^{\text{global}}$ as

$$\mathbf{P}^{\text{nat}}_{1 \times d} = \begin{pmatrix} \mathbf{P}_{11} & \cdots & \mathbf{P}_{1d} \end{pmatrix}; \; \mathbf{P}_{1j} = \mathbf{P}_{p_1 \times n_1} \tag{33}$$

$$\mathbf{P}^{\text{global}}_{1 \times t} = \begin{pmatrix} \mathbf{P}_{11} & \cdots & \mathbf{P}_{1t} \end{pmatrix}; \; \mathbf{P}_{1j} = \mathbf{P}_{p_2 \times n_2} \tag{34}$$

where $\mathbf{P}^{\text{nat}}_{1 \times d}$ represents a national multi-region labor (mrLabor) matrix with dimension $1 \times d$ submatrices and consists of the provincial labor submatrix $\mathbf{P}_{1j}$ (jobs p_1 needed by industry n_1 in province j). The $\mathbf{P}^{\text{global}}_{1 \times s}$ is a global mrLabor matrix with dimension $1 \times t$ submatrices and consists of the national labor submatrix $\mathbf{P}_{1j}$ (jobs p_2 needed by industry n_2 in country j).

The concordance matrices $\mathbf{C}_{p_1 \times p}$ and $\mathbf{C}_{p_2 \times p}$ are used to aggregate p_1 and p_2 job skills from the national and global MRSUT to obtain p common job skills. Following Equation 31, we can create each submatrix $\mathbf{P}_{1j} = \mathbf{P}_{p \times n}$. We integrate the mrLabor matrices using the structure shown in Figure 6. A multi-scale mrLabor matrix $\mathbf{P}_{1 \times N}$ can be defined as

$$\mathbf{P}_{1 \times N} = \begin{pmatrix} \mathbf{P}^{\text{nat}}_{1 \times d} & \mathbf{P}^{\text{global}}_{1 \times (t-1)} \end{pmatrix}; \; \mathbf{P}_{1j} = \mathbf{P}_{p \times n} \tag{35}$$

where $\mathbf{P}^{\text{nat}}_{1 \times d}$ and $\mathbf{P}^{\text{global}}_{1 \times (t-1)}$ are as defined above. We delete the national labor submatrix of country k from the original global mrLabor matrix $\mathbf{P}^{\text{global}}_{1 \times t}$. We then replace the national labor matrix with the national mrLabor matrix, $\mathbf{P}^{\text{nat}}_{1 \times d}$. This completes the integration of environmental and labor extension to the multi-scale MRSUT presented above.

3.3. Practical data integration steps

3.3.1. Creating the Indonesian multi-scale MRSUT

We employ the method explained above to create a multi-scale MRSUT for Indonesia. To begin, we generate a national MRSUT at basic price from the INDOTERM, following the procedure explained in Section 3.2. This process yields the $\mathbf{S}^{nat}$, $\mathbf{U}^{nat}$, $\mathbf{IMP}^{nat}$, and $\mathbf{F}^{nat}$ matrices for 2010 and 2016. Next, we acquire the $\mathbf{S}^{global}$, $\mathbf{U}^{global}$ and $\mathbf{F}^{global}$ matrices from EXIOBASE for the same year, which are directly available and do not require any transformations. At this point, the national and global MRSUT are still classified differently, as described in Section 3.1. To address this, we adopt a common classification for products and industries, into which both INDOTERM and EXIOBASE are aggregated, following Equation 18. The detailed concordance matrices and lists of industry names are provided in Tables SI.2–SI.5. Since INDOTERM is valued in Indonesian Rupiah (IDR) and EXIOBASE in European Euro (EUR), we convert the values into European Euro (EUR) using the OECD exchange rate in 2010 and 2016 (OECD, 2021a).

We integrate the data for the 34 provinces from INDOTERM and the 43 countries and 5 remaining continents from EXIOBASE. We compile matrix $\mathbf{S}$ from $\mathbf{S}^{nat}$ and $\mathbf{S}^{global}$ and matrix $\mathbf{F}$ from $\mathbf{F}^{nat}$ and $\mathbf{F}^{global}$. We construct matrix $\mathbf{U}$ from $\mathbf{U}^{nat}$, $\mathbf{impU}^{nat}$, $\mathbf{impU}^{global}$ and $\mathbf{U}^{global}$. We generate $\mathbf{impU}^{nat}$ from the total import matrix by province given by INDOTERM and the import share matrix of Indonesia by country calculated from EXIOBASE. We come up with 48×34 submatrices in the national mrImport matrix, as illustrated in Figure 4. Next, we generate a matrix $\mathbf{impU}^{global}$ from the export column by province given by INDOTERM, and use the national export matrix ratio by user by country calculated from EXIOBASE. We end up with 34×48 submatrices in the global mrImport matrix, as illustrated in Figure 5. For some products, we face the problem that INDOTERM shows imports and exports, whereas EXIOBASE shows zero trade. In such cases, we impose INDOTERM imports and exports on EXIOBASE. In some cases, we assume that the countries and sectors to and from which export/imports occur can be proxied using the ratio from the Asia Pacific region in EXIOBASE.

Then, we integrate all the submatrices to form the $\mathbf{S}$, $\mathbf{U}$, and $\mathbf{F}$ matrices, as illustrated in Figure 6. It consists of 80 products and industries, five final demands, and five factor inputs for 82 regions (34 provinces, 48 countries, and 5 remaining continents). Since we impose Indonesian imports and exports on all other countries, we have an unbalanced global mrUse matrix $\mathbf{U}^{global}$ in the multi-scale MRSUT. Before the RAS procedure, the difference between total supply and use is 12.4 billion EUR (about 0.0129% of total supply) in 2010 and 13.9 billion EUR (0.0101%) in 2016. The difference between total input and output is 25.1 billion EUR (0.0261% of total input) in 2010 and 21.8 billion EUR (0.0159%) in 2016.

In the last step, we implement the Generalized RAS procedure to the global mrUse matrix $\mathbf{U}^{global}$ while Indonesia's total exports and imports by product and industry remained the same as in the original INDOTERM data. The intra-regional and inter-regional accounts of the remaining countries are adjusted to reflect Indonesia's export and import data. Finally, we have the $\mathbf{S}$, $\hat{\mathbf{U}}$ and $\mathbf{F}$ matrices that provide a balanced multi-scale MRSUT. After the RAS procedure, the difference between total supply and use is 13.3 million EUR (about 1.38 e-05% of total supply) in 2010 and 3.17 million EUR (0.23 e-05%) in 2016. The difference between total input and output is 19.1 billion EUR (0.0199% of total input) in 2010 and 14.3 billion EUR (0.0104%). Finally, we can transform this multi-scale MRSUT into a multi-scale MRIOT using industry technology assumptions (United Nations, 2018).

3.3.2. Adding environmental extensions for Indonesia

EXIOBASE already includes environmental extensions for all countries, including Indonesia. However, INDOTERM lack detailed provincial-level environmental data, such as information on land use or GHG emissions. Thus, we develop new extensions for Indonesia at the provincial level. We construct two environmental extensions for Indonesia, focusing on GHG emissions and land use. Similar to import and export data in the national MRSUT, we prefer using Indonesian data on extensions over those available in a global database, such as EXIOBASE.

In this study, we utilize Indonesia's GHG emission data from SIGN-SMART, a database platform developed by the Indonesian Ministry of Environment and Forestry (MoEF) for monitoring national and provincial GHG emissions (MoEF, 2015). The SIGN-SMART emission data encompass three types of emitted substances from five sectors based on the Intergovernmental Panel on Climate Change (IPCC) guidelines. We use national GHG emission data available for the years 2010 and 2016. These 75 activities are categorized within five IPCC sectors: energy (10 activities), Industrial Process and Product Use, or IPPU (32), agriculture (11), forestry (17), and waste (5). We correspond the national emissions of 75 activities with 80 industries and five final demands for each year. Detailed mapping is shown in Table SI.6. The emissions by province are derived from national emissions using output shares. Once we have emission accounts by province and industry, we aggregate the 19 GHG-related emission categories from EXIOBASE into three types of emitted substances available in SIGN-SMART: CO_2, CH_4, and N_20. This mapping is presented in Table SI.7.

Next, we incorporate Indonesia's land use data from two data sources. We initially utilize data from the national monitoring system on forest and land cover (SIMONTANA) developed by MoEF (2020). We access land cover data for the years 2009 and 2015, the closest to 2010 and 2016, but data for these years are not available in SIMONTANA. It discerns 20 land use categories, ranging from primary dryland forests to settlement areas in 34 provinces (North Kalimantan was included in East Kalimantan before 2012). However, there are only three categories for crop land: estate crop plantations, dryland agriculture, and rice fields. To align these categories with the detailed agriculture production data in the multi-scale MRSUT, we utilize provincial crop land data from the Spatial Production Allocation Model (SPAM) database for the year 2010 (IFPRI, 2019). Because the SPAM database is not available for 2016, we apply the proportion of land use categories provided in 2010.

SPAM provides information on both physical area and harvest area per crop (which can be larger than the physical area if more than one harvest per year takes place). We use this physical area for land use extension. This database further divides land use per crop according to the production system, which is based on variety, pesticide, fertilizer, water use, mechanization, and market. We take into account crops from all technologies, ranging from irrigation to rainfed agriculture, as provided by SPAM. By mapping and scaling to SIMONTANA in this way, we obtain a land use accounts by province in 57 land use categories. We correspond 57 categories of land use with the 80 industries and final demand (most notably households). The total provincial land use adds up to the total national land use. To ensure that land extensions are in the same classification as in other countries, we aggregate these categories into 12 land use categories used by EXIOBASE. This mapping can be found in Tables SI.8–9.

3.3.3. Adding labor extensions for Indonesia

In addition, we also incorporate labor extensions for Indonesia at the provincial level to complement data available at the country and industry levels that is available in EXIOBASE. We utilize Indonesia's labor data for both years, sourced from the National Labor Force Survey (SAKERNAS) published by the BPS (2010, 2016). SAKERNAS provides data for 14 labor types, 1099 industries, and 34 provinces. We align the 1099 industries in SAKERNAS 2010 and 9 industries in SAKERNAS 2016 with the 80 industries in the multi-scale MRSUT. We also consolidate the 14 labor types in SAKERNAS to the 6 labor types used in EXIOBASE, which can be categorized as low, middle, and high skilled worker, each divided into male and female. This mapping can be found in Tables SI.10–11.

3.4. Validation analysis

As explained, during the construction of the Indonesian multi-scale MRSUT, imports and exports in INDOTERM are imposed on all other countries in EXIOBASE. We compare how national exports and imports by product in INDOTERM differ from those in EXIOBASE. The total difference in Indonesian exports and imports between EXIOBASE and INDOTERM in 2010 are 12.1 billion EUR (9.7% of Indonesian exports in EXIOBASE), and 12.7 billion EUR (11.2% of Indonesian imports in EXIOBASE), respectively. For 2016, the total differences are 16.7 billion EUR (11.7% of EXIOBASE) and 17.7 billion EUR (12.9% of EXIOBASE) in Indonesian exports and imports between EXIOBASE and INDOTERM. Description in SI.1 Annex 2 shows in more detail the deviations in trade values by product and industry between INDOTERM and EXIOBASE. We further compare these findings with the export and import totals by product from UN COMTRADE and find that INDOTERM import and export data align best with COMTRADE. This supports our decision to apply INDOTERM trade data on EXIOBASE and to use Generalized RAS on EXIOBASE without Indonesia to rebalance the overall nested table.

To access the extent of structural changes introduced by the RAS procedure in this multi-scale MRSUT compared to EXIOBASE, we calculate the Mean Absolute Error (MAE) and Mean Absolute Deviation Percentage (MADP) between the national and global accounts from the multi-scale MRSUT. The calculations are conducted both at the national and global levels, and the results are detailed in Tables SI.12–13. The MAE and MADP of all product use, averaged across 48 countries are very small. For 2010, they are 1.9e-07 and 6.1e-08%, respectively. For 2016, these values decrease to 1.14e-15 and 2.59e-16%. When considering 34 provinces, the MAE and MADP are higher but still remain quite small at 6.1e-05 and 0.001% for 2010 and 1.89e-06 and 2.58e-05% for 2016. The MAE and MADP of all industry inputs, averaged across 48 countries are also relatively low, at 0.063 and 0.021% for 2010 and 0.053 and 0.012% for 2016. In the context of 34 provinces, these numbers are slightly higher at 0.001 and 0.021% in 2010 and 0.009 and 0.134% in 2016.

These results highlight that the MAE of all product uses is notably small across 48 countries and 34 provinces, with the values below 0.0001 for both years. Similarly, the MAE for all industry inputs in the 34 provinces is less than 0.01 for both years, and for the 48 countries, it remains under 0.06 in 2010 and 0.05 in 2016. In summary, these results indicate that the deviations we generated in the structure of the rest of the countries within the multi-scale MRSUT are very small.

3.5. Results

The environmentally extended multi-scale MRSUT/IOT for Indonesia for the years 2010 and 2016 shows the supply and use linkages of 80 products between 80 industries in 34 Indonesian provinces, as well as other 43 countries and 5 remaining continents. It includes extensions covering 3 GHG emissions, 12 land use and 6 job categories. In general, there are no significant structural changes at the national level between 2010 and 2016 in terms of national GDP by expenditure, value-added, industry and province. Tables SI.1–11 provides lists of products, industries, provinces, countries, emissions, land use, and job categories. Figure SI.1–4 offer detailed information about the regional heterogeneity and deviation of Indonesian trade between data.

This multi-scale MRSUT/IOT can be used for analyzing global-subnational trade related to Indonesia. It offers a range of potential applications, including:

- Assessing the impact of specific global consumption patterns on provincial land use and GHG emissions in Indonesia.
- Evaluating how specific provincial consumption impacts provincial and global GHG emissions.
- Examining the effects of national and global trade policies on provincial and global production and job creation.
- Analyzing how changes in global trade patterns impact regional economies in Asia and Indonesia.
- Examining how changes in the structure of provincial economies affect GHG emissions.

4. Illustrative application: how different changes in global consumption affect the provincial and regional economy in Indonesia

We utilize the Indonesian multi-scale MRIOT to understand how global consumption drives production in some Indonesian provinces. We simulate two different what-if scenarios, involving international final demand shocks. In these simulations, we choose China and the US as trade partners for Indonesia for mining and manufacturing products, respectively. Using the classic Leontief inverse approach, we assess the implication of doubling the import demand for these products in each importing country. We compare the results obtained from the global MRIOT and multi-scale MRIOT in 2016.

In the global MRIOT, China's mining imports account for around 32% of its total imports from Indonesia (worth 6.8 billion EUR). The US's imports of manufacturing products are around 63% of its total imports from Indonesia (9.4 billion EUR). A change in these imports will have different impacts on different regions of Indonesia. Our focus is on two regions that have different resources and geographical characteristics: Kalimantan, which drives its GDP from mining resources, and Java, primarily driven by industrial and service industries.

Figure 7 and 8 illustrate the change in VA and GHG emissions at the national and provincial levels as a result of China and the US' import demand shocks. The figures also provide the decomposition of VA and GHG emissions into two components: intra-regional (the effect from the own region) and inter-regional effects (the effect from other regions).

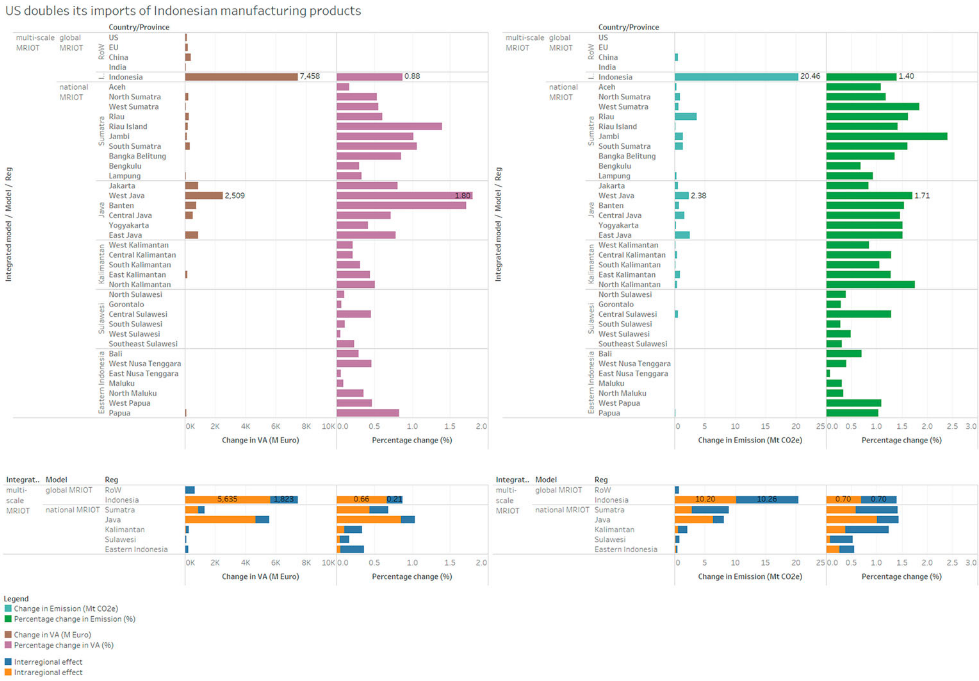
Our calculations show that if China doubles its imports of Indonesian mining products, Indonesia's VA will increase by 0.74%, equivalent to 6.31 billion EUR. National GHG emissions will increase by 0.36%, account to 5.26 million tonnes (Mt) CO_2e. In comparison, doubling US imports of Indonesian manufacturing products will result in an increase national VA by 0.88% or 7.45 billion EUR and GHG emissions by 1.4% or 20.46 Mt CO_2e.

The multi-scale MRIOT enables now a further assessment of implications at the regional and provincial levels. The demand shock of mining products from China will particularly affect the Kalimantan and Sumatra regions, especially in the East Kalimantan province, which produces large amounts of mining resources. We observe an increase in VA in East Kalimantan province of approximately 7.71% or 2.56 billion EUR. This increase is almost four times the increase in VA of South Kalimantan, the province with the second-highest increase in absolute terms. The GHG emissions in East Kalimantan increase by 1.58 Mt CO_2e or 2.19%. There are only small spillover effects in other regions, as shown in Figure 7. Java experiences a VA increase of 783 million EUR due to spillovers from other regions,

Figure 7. Change VA and GHG emissions in Indonesia due to a doubling of Chinese imports of Indonesian mining products in 2016. The two upper graphs show the change and percentage change of VA and GHG emissions in 34 provinces. The two lower graphs show the decomposition of VA and GHG emissions in 5 regions.

Source: Authors.

Figure 8. Change in VA and GHG emissions in Indonesia due to a doubling of US imports of Indonesian manufacturing products in 2016. The two upper graphs show the change and percentage change of VA and GHG emissions in 34 provinces. The two lower graphs show the decomposition in VA and GHG emissions in 5 regions.



Source: Authors.

especially Kalimantan. In terms of percentage change in VA, Sumatra and Papua experience greater interregional spillover effect compare to the Java region.

In contrast, the hypothetical US demand shock for manufacturing products creates a totally different impact on different regions and provinces. The Java region now experiences the largest changes, with West Java province experiencing 1.8% increase in its VA, equivalent to 2.51 billion EUR. This increase is accompanied by a rise in GHG emissions by 1.71% or 2.38 Mt CO_2e. Other provinces on Java Island also experience an increase in VA, but at lower values (less than 900 million EUR). Sumatra and Kalimantan observe increases in VA of 1.31 billion and 257 million EUR, respectively. Figure 8 illustrates that some of these increases are due to inter-regional spillovers (e.g. 440 million EUR in Sumatra).

These two results indicate that, on the one hand, the economic structure of provinces in Indonesia is very heterogeneous, and that, on the other hand, Indonesia has strong interregional economic relations. As illustrated in Figures 7 and 8, these two import scenarios enlarge the VA of all provinces. However, the extent of this increase varies considerably depending on the economic structure of each province. A similar pattern is observed in the changes in GHG emissions.

This case study serves as an illustrates of how regions and provinces react differently to global shocks. The Kalimantan region is more vulnerable when there is a demand reduction in mining products from China or other countries. The Java region is be more vulnerable to demand reduction in manufacturing products from the US or other countries. This information is important for policies aimed at stimulating economic development or mitigating crises caused by changes in international demand. In summary, this simulation shows for countries with a very different economic structure and trade between provinces/states the added value of using a multi-scale MRSUT/IOT instead of a country SUT/IOT for economic and environmental policy analysis.

5. Conclusion

This study develops an Indonesian multi-scale MRSUT with environmental and labor extensions for 2010 and 2016. It is the first study that builds a comprehensive global-subnational multi-scale MRSUT for Indonesia with sector and province specific environmental extensions. This study represents a significant contribution to the fields of environmental and regional economics by offering a comprehensive dataset that can be utilized for various policy analyses, particularly in the context of sustainable development.

The key advantage of a multi-scale MRSUT/IOT is its ability to depict a provincial economy in a global context. In comparison, a national (global) MRSUT/IOT can only represent provincial (national) economies and their inter-regional trade within (between) countries. With a multi-scale MRSUT/IOT, the international exports and imports of a province will have linkages to a global market differentiated by sector and country. Such a database can be used to analyze the relationship between global consumption and local production, and the embodied economic and environmental impacts along global value chains. This is particularly relevant for countries with a large degree of heterogeneity in their economies at the subnational level.

The database we constructed comes with some limitations. The most recent national MRSUT data when writing this article is only available in 2016 (BPS, 2021), which is a drawback for a fast-developing economy such as Indonesia. However, now-casting leads to uncertainties, while working on a recent national MRIOT requires more data on environmental extensions, which are still limited to provincial and sectoral levels. Another limitation is how international trade is allocated to the subnational level. Due to the absence of specific trade data by province and sector, we apply similar to most other multi-scale MRSUT/IOT studies available in the literature using a proportionality assumption: each sector in each province is assumed to have an import/domestic use and export/domestic supply ratio equal to the national average for that sector. However, study that use province-specific trade data, such as China, is clearly superior to this proportionality assumption (Jiang et al., 2020).

For further research, it is important to improve the proportionality assumption. It is necessary to define trade coefficients for each domestic sector and province in relation to the trade partners. Supplementary data, such as custom data and gravity models, may be useful for supporting such improvements.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This research was funded by the Indonesian Endowment Fund for Education (LPDP) [grant number S-870/LPDP.4/2019], Ministry of Finance, Republic of Indonesia, as part of the first author's doctoral scholarship at the Institute of Environmental Science (CML), Faculty of Science, Leiden University, Netherlands.

ORCID

Irlan A. Rum http://orcid.org/0000-0003-0301-4953
Arjan de Koning http://orcid.org/0000-0001-9765-3179
Arnold Tukker http://orcid.org/0000-0002-8229-2929
Arief A. Yusuf http://orcid.org/0000-0002-3126-3853

References

Aguiar, A., Chepeliev, M., Corong, E. L., McDougall, R., & van der Mensbrugghe, D. (2019). The GTAP data base: Version 10. *Journal of Global Economic Analysis*, *4*(1), Article 1. https://doi.org/10.21642/JGEA.040101AF
Bachmann, C., Roorda, M. J., & Kennedy, C. (2015). Developing a multi-scale multi-region input–output model. *Economic Systems Research*, *27*(2), 172–193. https://doi.org/10.1080/09535314.2014.987730
BPS. (2010). *Survei angkatan kerja nasional 2010 semester 2*. https://mikrodata.bps.go.id/mikrodata/index.php/catalog/92
BPS. (2014). *Gross regional domestic product of provinces in Indonesia by industry*.
BPS. (2016). *Survei angkatan kerja nasional 2016 semester 2*. https://mikrodata.bps.go.id/mikrodata/index.php/catalog/SAKERNAS
BPS. (2020). *Gross regional domestic product of provinces in Indonesia by industry*.
BPS. (2021). *Tabel interregional input–output tahun 2016*.
de Souza, J. B., dos Santos, C. V., & do Prado, S. M. (2010). Tax reform, income distribution and poverty in Brazil: An applied general equilibrium analysis. *International Journal of Microsimulation*, *3*(1), 114–117.
Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & de Vries, G. (2013). The construction of world input–output tables in the wiod project. *Economic Systems Research*, *25*(1), 71–98. https://doi.org/10.1080/09535314.2012.761180
Edens, B., Hoekstra, R., Zult, D., Lemmers, O., Wilting, H., & Wu, R. (2015). A method to create carbon footprint estimates consistent with national accounts. *Economic Systems Research*, *27*(4), 440–457. https://doi.org/10.1080/09535314.2015.1048428
Faturay, F., Lenzen, M., & Nugraha, K. (2017). A new sub-national multi-region input–output database for Indonesia. *Economic Systems Research*, *29*(2), 234–251. https://doi.org/10.1080/09535314.2017.1304361
Faturay, F., Vunnava, V. S. G., Lenzen, M., & Singh, S. (2020). Using a new USA multi-region input output (MRIO) model for assessing economic and energy impacts of wind energy expansion in USA. *Applied Energy*, *261*, 114141. https://doi.org/10.1016/j.apenergy.2019.114141
Fry, J., Geschke, A., Langdon, S., Lenzen, M., Li, M., Malik, A., Sun, Y.-Y., & Wiedmann, T. (2022). Creating multi-scale nested MRIO tables for linking localized impacts to global consumption drivers. *Journal of Industrial Ecology*, https://doi.org/10.1111/jiec.13165
Giljum, S., Bruckner, M., & Martinez, A. (2015). Material footprint assessment in a global input–output framework. *Journal of Industrial Ecology*, *19*(5), 792–804. https://doi.org/10.1111/jiec.12214
Horridge, M. (2012). *The TERM model and its database*. https://link.springer.com/chapter/10.1007978-94-007-2876-9_2

Horridge, M., & Wittwer, G. (2006). *The impacts of higher energy prices on Indonesia's and West Java's economies using INDOTERM, A multiregional model of Indonesia* (working papers in economics and development studies (WoPEDS) No. 200607). Department of Economics, Padjadjaran University. https://econpapers.repec.org/paper/unpwpaper/200607.htm

Horridge, M., & Wittwer, G. (2008). SinoTERM, a multi-regional CGE model of China. *China Economic Review*, *19*(4), 628–634. https://doi.org/10.1016/j.chieco.2008.05.002

IFPRI. (2019). *Global spatially-disaggregated crop production statistics data for 2010 version 2.0* [data set]. Harvard Dataverse. https://doi.org/10.7910/DVN/PRFF8V

Jiang, M., Behrens, P., Wang, T., Tang, Z., Yu, Y., Chen, D., Liu, L., Ren, Z., Zhou, W., Zhu, S., He, C., Tukker, A., & Zhu, B. (2019). Provincial and sector-level material footprints in China. *Proceedings of the National Academy of Sciences*, *116*(52), 26484–26490. https://doi.org/10.1073/pnas.1903028116

Jiang, M., Liu, L., Behrens, P., Wang, T., Tang, Z., Chen, D., Yu, Y., Ren, Z., Zhu, S., Tukker, A., & Zhu, B. (2020). Improving subnational input–output analyses using regional trade data: A case-study and comparison. *Environmental Science & Technology*, *54*(19), 12732–12741. https://doi.org/10.1021/acs.est.0c04728

Kobayakawa, T. (2022). The carbon footprint of capital formation: An empirical analysis on its relationship with a country's income growth. *Journal of Industrial Ecology*, https://doi.org/10.1111/jiec.13199

Lenzen, M., Geschke, A., Malik, A., Fry, J., Lane, J., Wiedmann, T., Kenway, S., Hoang, K., & Cadogan-Cowper, A. (2017). New multi-regional input–output databases for Australia – enabling timely and flexible regional analysis. *Economic Systems Research*, *29*(2), 275–295. https://doi.org/10.1080/09535314.2017.1315331

Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building eora: A global multi-region input–output database at high country and sector resolution. *Economic Systems Research*, *25*(1), 20–49. https://doi.org/10.1080/09535314.2013.769938

Meng, F., Liu, G., Hu, Y., Su, M., & Yang, Z. (2018). Urban carbon flow and structure analysis in a multi-scales economy. *Energy Policy*, *121*, 553–564. https://doi.org/10.1016/j.enpol.2018.06.044

Mi, Z., Meng, J., Zheng, H., Shan, Y., Wei, Y.-M., & Guan, D. (2018). A multi-regional input–output table mapping China's economic outputs and interdependencies in 2012. *Scientific Data*, *5*(1), 180155. https://doi.org/10.1038/sdata.2018.155

Miller, R., & Blair, P. (2022). *Input–output analysis: Foundation and extensions* (3rd ed.). Cambridge University Press.

MoEF. (2015). *SIGN SMART – Direktorat Inventarisasi Gas Rumah Kaca dan Monitoring, Pelaporan, dan Verifikasi*. https://signsmart.menlhk.go.id/v2.1/

MoEF. (2020). *Sistem monitoring hutan nasional (SIMONTANA)*. https://nfms.menlhk.go.id

OECD. (2016). *Estimating CO_2 emissions embodied in final demand and trade using the OECD ICIO 2015: Methodology and results*. https://doi.org/10.1787/5jlrcm216xkl-en

OECD. (2018). *Inter-country input–output database*. https://oe.cd/icio/

OECD. (2021a). *Exchange rates (indicator)*. https://doi.org/10.1787/037ed317-en

OECD. (2021b). *Trade in value added (TiVA) 2021 ed: Principal indicators*. https://stats.oecd.org/Index.aspx?DataSetCode=TIVA_2021_C1

Oosterhaven, J., & Többen, J. (2017). Wider economic impacts of heavy flooding in Germany: A non-linear programming approach. *Spatial Economic Analysis*, *12*(4), 404–428. https://doi.org/10.1080/17421772.2017.1300680

Paniccia, R., & Rosignoli, S. (2018). *A methodology for building multiregional supply and use tables for Italy*. IPRET. https://www.irpet.it/wp-content/uploads/2018/09/sa-a-methodology-for-building-27-09-2018-paniccia_rosignoli.pdf

Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J. H., Theurl, M. C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.-H., … Tukker, A. (2018). Exiobase 3: Developing a time series of detailed environmentally extended multi-region input–output tables: EXIOBASE 3. *Journal of Industrial Ecology*, *22*(3), 502–515. https://doi.org/10.1111/jiec.12715

Steen-Olsen, K., Owen, A., Hertwich, E. G., & Lenzen, M. (2014). Effects of sector aggregation on CO_2 multipliers in multiregional input–output analyses. *Economic Systems Research*, *26*(3), 284–302. https://doi.org/10.1080/09535314.2014.934325

Stofberg, F. J. (2016). The short term economic impact of levying E-tolls on industries. *South African Journal of Economics*, *84*(4), 574–593. https://doi.org/10.1111/saje.12106

Temurshoev, U., Miller, R. E., & Bouwmeester, M. C. (2013). A note on the gras method. *Economic Systems Research*, *25*(3), 361–367. https://doi.org/10.1080/09535314.2012.746645

Towa, E., Zeller, V., & Achten, W. M. J. (2021). Assessing the circularity of regions: Stakes of trade of waste for treatment. *Journal of Industrial Ecology*, *25*(4), 834–847. https://doi.org/10.1111/jiec.13106

Többen, J., Wiebe, K. S., Verones, F., Wood, R., & Moran, D. D. (2018). A novel maximum entropy approach to hybrid monetary-physical supply-chain modelling and its application to biodiversity impacts of palm oil embodied in consumption. *Environmental Research Letters*, *13*(11), 115002. https://doi.org/10.1088/1748-9326/aae491

Tukker, A., & Dietzenbacher, E. (2013). Global multiregional input–output frameworks: An introduction and outlook. *Economic Systems Research*, *25*(1), 1–19. https://doi.org/10.1080/09535314.2012.761179

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T., Neuwahl, F., Rueda-Cantuche, J. M., Giljum, S., Moll, S., Oosterhaven, J., & Bouwmeester, M. (2009). Towards a global multi-regional environmentally extended input–output database. *Ecological Economics*, *68*(7), 1928–1937. https://doi.org/10.1016/j.ecolecon.2008.11.010

United Nation. (2018). *Handbook on supply and use tables and input–output tables with extensions and applications*.

Walmsley, T., Aguiar, A., & Narayanan, B. (2012). *Introduction to the global trade analysis project and the GTAP data base*. GTAP Working Paper No. 67. https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=3965

Wang, Y., Geschke, A., & Lenzen, M. (2017). Constructing a time series of nested multiregion input–output tables. *International Regional Science Review*, *40*(5), 476–499. https://doi.org/10.1177/0160017615603596

Wiebe, K. S., Bjelle, E. L., Többen, J., & Wood, R. (2018). Implementing exogenous scenarios in a global MRIO model for the estimation of future environmental footprints. *Journal of Economic Structures*, *7*(1), 20. https://doi.org/10.1186/s40008-018-0118-y

Wittwer, G. (Ed.). (2012). *Economic modeling of water: The Australian CGE experience*. Springer Netherlands. https://doi.org/10.1007/978-94-007-2876-9

Wittwer, G. (2021). Modelling the economy-wide marginal impacts due to climate change in Australian agriculture. In *Centre of policy studies/IMPACT centre working papers (g-312; centre of policy studies/IMPACT centre working papers)*. Victoria University, Centre of Policy Studies/IMPACT Centre. https://ideas.repec.org/p/cop/wpaper/g-312.html

Wittwer, G., & Horridge, M. (2010). Bringing regional detail to a CGE model using census data. *Spatial Economic Analysis*, *5*(2), 229–255. https://doi.org/10.1080/17421771003730695

Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., De Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J. H., Merciai, S., & Tukker, A. (2015). Global sustainability accounting—developing EXIOBASE for multi-region footprint analysis. *Sustainability*, *7*(1), Article 1. https://doi.org/10.3390/su7010138

Wu, D., & Liu, J. (2016). Multi-region input–output (MRIO) study of the provincial ecological footprints and domestic embodied footprints traded among China's 30 provinces. *Sustainability*, *8*, Article 12. https://doi.org/10.3390/su8121345

Yuan, R., Rodrigues, J. F. D., & Behrens, P. (2018). Impact of non-fossil electricity on the carbon emissions embodied in China's exports. *Journal of Cleaner Production*, *192*, 582–596. https://doi.org/10.1016/j.jclepro.2018.04.255

Yusuf, A. A., Roos, E. L., & Horridge, J. (2018). *Indonesia's moratorium on palm oil expansion from natural forests: Economy-wide impacts and the role of international transfers* (SSRN Scholarly Paper ID 3249140). Social Science Research Network. https://papers.ssrn.com/abstract=3249140