Global Trade Analysis Project Circular Economy (GTAP-CE) Data Base Version 11

By

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Abstract

Rapidly increasing material extraction is putting major pressure on ecosystems. Future increases in incomes and population could result in over 2.5 times growth in global material demand by 2050, putting even more pressure on the environment. Thus, an absolute decoupling of material use from GDP and income is of major importance to preserve safe operating boundaries. It is vital to understand how current policy efforts, including climate mitigation, could impact material use patterns and what complementary circular economy (CE) policies could be implemented to support dematerialization. At the same time, there is a lack of global datasets and related modeling tools that could support such an analysis. To address this limitation, here we develop a special version of the Global Trade Analysis Project (GTAP) Circular Economy (GTAP-CE) Data Base with detailed representation of primary, secondary, and recycling activities for metals (steel, aluminum, copper, etc.) and plastics, detailed representation of fertilizers, as well as disaggregated cement activity. The GTAP-CE Data Base is based on the v11c of the GTAP-Power Data Base with the 2017 reference year, representing the global economy across 99 activities, 141 individual countries and 19 composite regions. Introduced sectoral splits are designed to facilitate both the assessment of the circular economy policies, as well as Carbon Border Adjustment Mechanism (CBAM) measures. The developed GTAP-CE Data Base is distributed in model-friendly formats and can be readily linked to the GTAP-based CGE models for the assessment of various policy scenarios either in the dynamic or static frameworks.

JEL classification: D57, D58, Q53, Q56.

Keywords: GTAP; Sectoral disaggregation; Circular economy; Primary and secondary production; Energy and emission intensities.

Contents

1. Introduction

Over the past 70 years, humanity has experienced an unprecedented improvement in the quality of life. Extreme poverty at a global scale has decreased from over 63% in 1950 to less than 10%, the share of literate world population exceeds 86% - a 30 percentage point increase since the mid-20th century and child mortality has fallen by almost 6 times since 1940 (Roser, 2020). These changes have been accompanied by rapid income growth, as global per capita GDP has increased three times since 1960 (WB, 2021).

Constantly growing incomes have substantially increased demand for material goods and therefore materials extraction has grown from 22 billion tons in 1970 to 70 billion tons in 2010 (Schandl et al., 2017). Analyzing a longer time period, Krausmann et al. (2018) show that between 1945 and 2015 global materials extraction has increased over seven times and that the growth rate has accelerated in recent decades. Consistent with these findings, the literature reports a relatively high resource elasticity of GDP, suggesting that 1% increase in GDP leads to around an 0.8% increase in consumption-based material use both in high-income and low-income countries (Haberl et al., 2020; Steinberger et al., 2013), thus providing a rather weak evidence even for existence of a relative decoupling between GDP growth and material use.

Contributing to the improvement of consumers' wellbeing, rapidly increasing material extraction is putting major pressure on ecosystems (Otero et al., 2020; Marques et al., 2019). According to the report of the International Resource Panel (IRP, 2019), biomass, metals, non-metallic minerals and fossil fuels together are responsible for over 90% of water stress and land-use related biodiversity loss. Future increases in incomes and population could result in over 2.5 times growth in global material demand by 2050, putting even more pressure on the Earth's ecosystem. Such trends could also put at risk the success of future climate mitigation policies, as materials management is a major contributor of the global greenhouse gas emissions (IRP, 2019). Thus, an absolute decoupling of material use from GDP and income is of a major importance in the context of preserving safe operating boundaries (Steffen et al., 2015).

In this context, it is important to understand how the current policy efforts, in particular, in terms of climate mitigation, could impact material use patterns and what complementary circular economy policies can be implemented to support the transition towards more sustainable consumption practices. At the same time, for a consistent assessment of the circular economy policies and measures within an economy-wide modelling framework, an explicit representation of the corresponding production technologies (i.e., primary, secondary and recycling activities, as well as material use flows (e.g., metal ores, fossil fuels, non-metallic minerals, etc.) is needed. A standard Global Trade Analysis Project (GTAP) Data Base that underlies literally all global CGE models, including those focused on the CE policies (e.g., Winning et al., 2017; OECD, 2018; Bibas et al., 2021) does not provide such level of details (except for the fossil fuel material flows). To overcome this limitation, here we develop a special version of the GTAP Circular Economy (GTAP-CE) Data Base that introduces additional sectoral details to the GTAP-Power Data Base v11 (Chepeliev, 2023) for the 2017 reference year. 76 sectors of the GTAP-Power Data Base are disaggregated into 99 sectors, including additional splits for mineral mining, metals, recycling, cement and fertilizers. An approach extends earlier efforts on the development of the GTAP-CE v10 Data Base discussed in WB (2022) and Chepeliev et al. (2026). The remainder of the document is structured as follows. Section 2 outlines the overall database development framework. Section 3 presents selected structural and environmental indicators of the constructed database. Section 4 discusses key data challenges and areas for future refinement of the GTAP-CE Data Base. Section 5 describes the database distribution formats.

2. Overview of the GTAP-CE Data Base development framework

2.1. GTAP-CE Data Base sectoral details

The GTAP-CE Data Base introduces additional disaggregation of certain GTAP sectors and incorporates material flow accounting for the selected commodities. The starting point for the disaggregation is the GTAP-Power 11 Data Base with 76 sectors, 160 regions and 2017 reference year (Chepeliev, 2023). Six sectors of the original GTAP-Power 11 Data Base are further split into 29 sub-sectors, providing a more detailed representation of categories like metallic and non-metallic minerals mining, rubber and plastic products, iron and steel, non-ferrous metals, fertilizers and cement (Figure 1). Corresponding sectoral splits are developed for all 160 regions reported in the GTAP-Power 11 Data Base. Introduced sectoral splits are designed to facilitate the assessment of the circular economy policies, as well as Carbon Border Adjustment Mechanism (CBAM) measures. In the latter case, the developed database explicitly covers all CBAM-targeted sectors/commodity groups, except for hydrogen, which is not widely traded.

No.	GTAP sector	New sector	Description
1	oxt	nmn	Non-metallic minerals mining
2		mio	Mining of iron ores
3		mao	Mining of aluminum ores
4		mcu	Mining of copper ores
5		moo	Mining of other ores
6	rpp	rbr	Rubber products
7		plp	Plastic products – primary
8		pls	Plastic products – secondary
9		plr	Recycling - plastics
10	nmm	cem	Cement
11		nmx	Other mineral products
12	i_s	isp	Iron and steel – primary
13		iss	Iron and steel – secondary
14		ris	Recycling - iron and steel
15		isc	Iron and steel casting
16	nfm	app	Aluminum – primary
17		aps	Aluminum – secondary
18		ral	Recycling - aluminum
19		cpp	Copper – primary
20		cps	Copper – secondary
21		rcp	Recycling - copper
22		mpp	Other metals – primary
23		mps	Other metals – secondary
24		rom	Recycling - other metals
25		nfc	Non-ferrous metals casting
26	chm	nfr	Nitrogen fertilizer
27		pfr	Phosphorus fertilizer
28		kfr	Potassium fertilizer
29		xch	Other chemicals

Figure 1. An overview of the sectoral splits introduced to the GTAP-Power 11 Data Base

2.2. Key data inputs and processing steps

The GTAP-CE Data Base development process includes five core steps, as outlined in Figure 2. *First*, data on output quantities is collected from multiple data sources (see Appendix A for additional details). Data on the volumes of ore mining and production of metals across technologies (e.g. electric arc furnaces vs blast furnaces) is directly available from the United States Geological Survey (USGS), as further discussed in Appendix A. Data on cement production across countries has been also sourced from the USGS, while price estimates have been derived from the World Bank's International Comparison Program (ICP) data following IFC (2023). For fertilizers split we followed the approach introduced in Bartelings et al. (2016), sourcing data on fertilizer production from Food and Agricultural Organization (FAO) and fertilizer use by crops from the International Fertilizers Association (IFA) data. Split between plastic and rubber production is based on the UNIDO data (UNIDO, 2024). Recycling rates are derived from a number of country-specific sources and complemented with regional averages, as discussed in more detail in the Appendix A. This data is complemented by the bilateral trade quantities and values from the CEPII BACI database (CEPII, 2021). Trade-based prices are combined with quantities of output to derive the output value across sectors of interest.

(1) Data preparation (output splits)	• ***Data:*** Volumes of primary and secondary production, volumes of waste, recycling rates, bilateral trade data for sectors or interest. • ***Data sources:*** USGS, UNIDO, BACI, UNEP IRP MFA, PRODCOM, World Steel, Jambeck et al. (2015), Plastics Europe, Veolia, multiple country-specific data sources (for plastic recycling rates), World Bank, International Fertilizer Association (IFA), FAO. • Construction of the production targets using volume and price data.
(2) Data preparation (supply/use splits)	• ***Data:*** Disaggregated individual country input-output tables (USA, Korea, Japan, Canada), EXIOBASE, specific cost structure assumptions from the literature. • Construction of the cost structure targets.
(3) Targets' reconciliation	• ***Data:*** GTAP 11 Power Data Base, data inputs from Steps 1 and 2. • Reconciliation of the production targets, supply/use structures and trade data for disaggregated SAMs extracted from the GTAP.
(4) Database split	• ***Data:*** Split targets from Step 3. • GTAP Data Base split using SPLITCOM.
(5) Construction of the final database	• ***Data:*** Disaggregated database from Step 4. • Incorporation of the energy and emission flows for disaggregated sectors. Compilation of the final database.

Figure 2. An overview of the GTAP-CE Data Base construction steps

Source: Developed by author.

Second, supply and cost structure assumptions are developed based on various data sources, such as individual country input-output tables, EXIOBASE multi-region input-output (MRIO) and selected studies of the energy intensity of the primary and secondary production activities (see Appendix A for additional details). For the case of the energy inputs across commodities, additional adjustments are primarily based on the literature review (techno-economic analyses). The latter provide estimates of energy inputs per unit of output and are used to better reflect the energy- and emission-intensities of the sectors under disaggregation. Figures 3 and 4 below provide an overview of the assumptions on energy inputs for key energy-intensive sectors under disaggregation. Additional details on data inputs are provided in Appendix A.

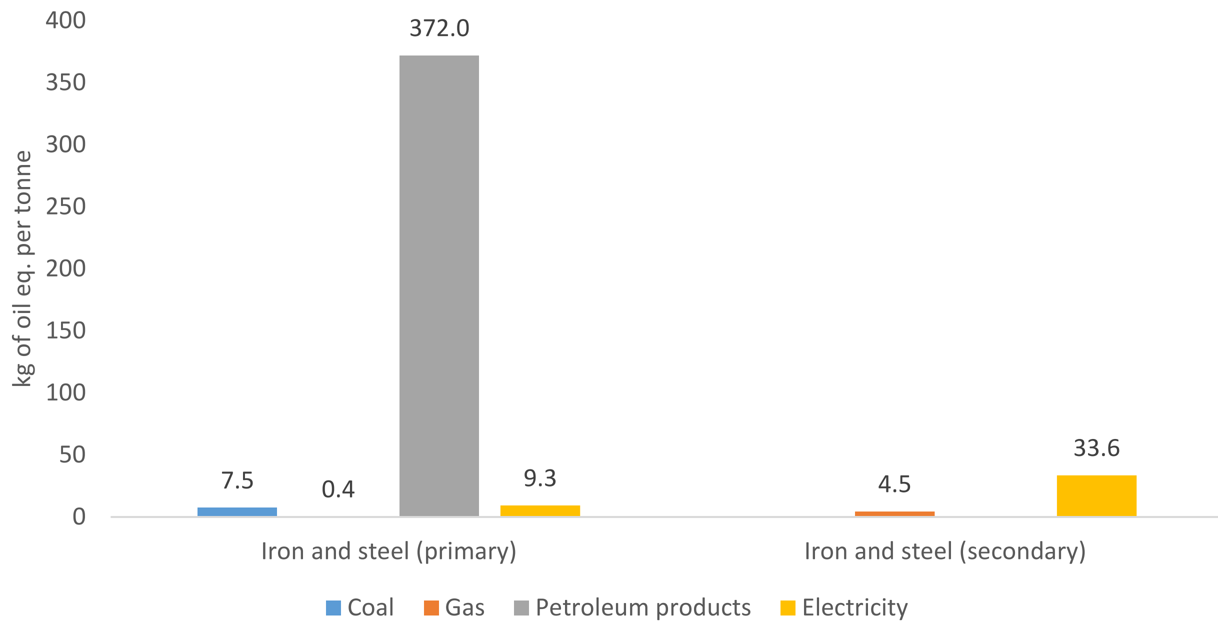

Figure 3. Assumptions for energy use by ferrous metals, kg of oil equivalent per tonne
Source: Author's estimates based on Burchart-Korol (2013), Kirschen et al. (2011), Sosinsky et al. (2008).

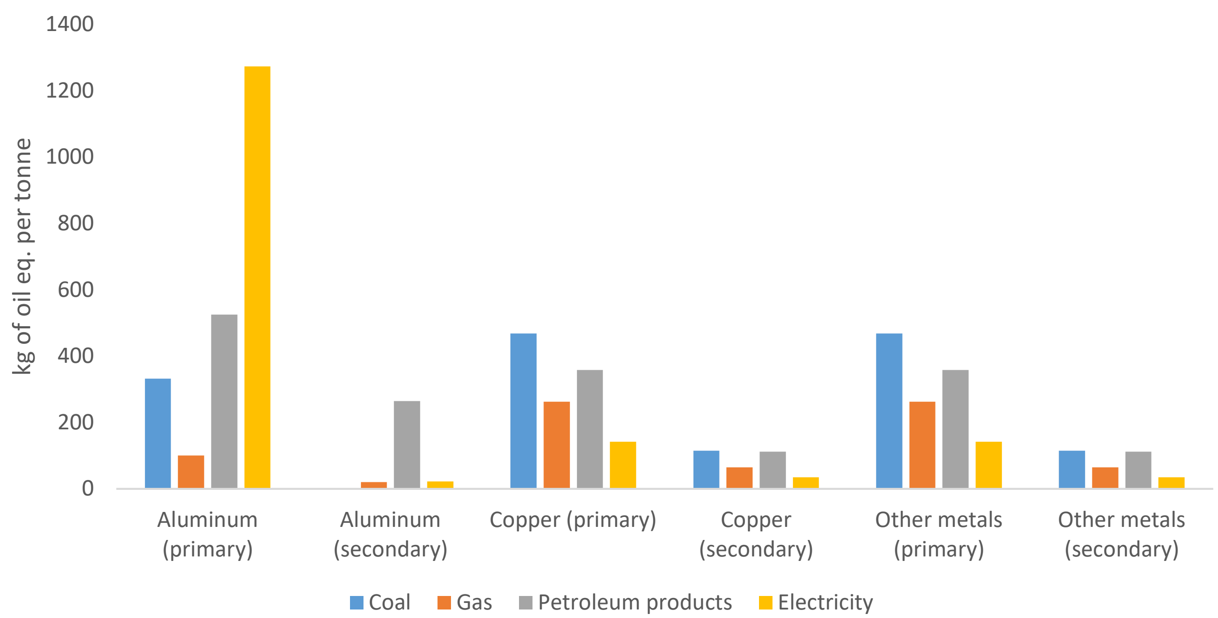

Figure 4. Assumptions for energy use by non-ferrous metals, kg of oil equivalent per tonne
Source: Author's estimates based on data from Liu et al. (2016) for aluminum, Dong et al. (2020) for copper, and BIR (2008) for other non-ferrous metals.

The *third step* reconciles and harmonizes the data collected in steps 1 and 2 to further develop the targets for the database split (step four). The *fourth step* implements the database disaggregation procedure, where constructed use and supply structures are incorporated into the GTAP-Power 11 Data Base via the MSPLITCOM utility, which balances the GTAP Data Base using the RAS procedure and preserves the original flows of the underlying GTAP Data Base (Horridge, 2008). Finally, in the *fifth step*, we incorporate energy and emission flows into the disaggregated database, covering both greenhouse gases and air pollutants. A detailed overview of the underlying data and assumptions behind the GTAP-CE sectoral splits is provided in the Appendix A.

Energy and emissions coverage of the GTAP-CE Data Base follow the GTAP-Power Data Base. In particular, fossil fuel combustion CO_2 emission flows are estimated using the Tier 1 IPCC 2006 method, following the approach used in the main GTAP Data Base (Chepeliev, 2022). For the case of process CO_2 emissions from cement production, estimates are sourced from EDGAR database following the procedures described in Chepeliev (2024). In the case of process CO_2 emissions from fertilizers, these are calibrated to the emission estimates from FAO. Where available, air pollutants and complementary GHG emissions for newly disaggregated sectors are directly sourced from the EDGAR database following the approach used for the standard GTAP Data Base (Chepeliev, 2021; Chepeliev, 2024). In the cases, when EDGAR database provides data at a less granular level (than GTAP-CE) emissions are distributed proportionally to energy of value flows (depending on the emission driver).

3. Overview of the GTAP-CE Data Base

In this section we highlight selected metrics and features of the GTAP-CE v11 Data Base. Figure 5 illustrates the global production structure across the newly disaggregated material sectors in the GTAP-CE Data Base, distinguishing between primary and secondary output in value terms and reporting the corresponding secondary shares. The results highlight substantial heterogeneity in circularity patterns across materials. Iron and steel exhibit both the largest absolute market size and a high secondary share (over 40%), reflecting the maturity and global integration of scrap-based steel production. Aluminum displays a similarly elevated secondary share (close to 40%), consistent with well-established recycling streams and strong economic incentives for remelting. In contrast, copper and other non-ferrous metals show intermediate secondary shares, while plastics remain characterized by a comparatively low contribution of secondary output (below 20%), despite their large overall production value.

From a database development perspective, these patterns underscore the importance of explicitly representing secondary production within the GTAP-CE framework. Aggregating primary and secondary activities would mask substantial differences in input structures, trade intensities, and emissions profiles across materials. By separating these activities, the GTAP-CE Data Base enables more accurate modeling of material substitution, scrap availability constraints, and circular economy policies, as showcased in Chepeliev et al. (2026).

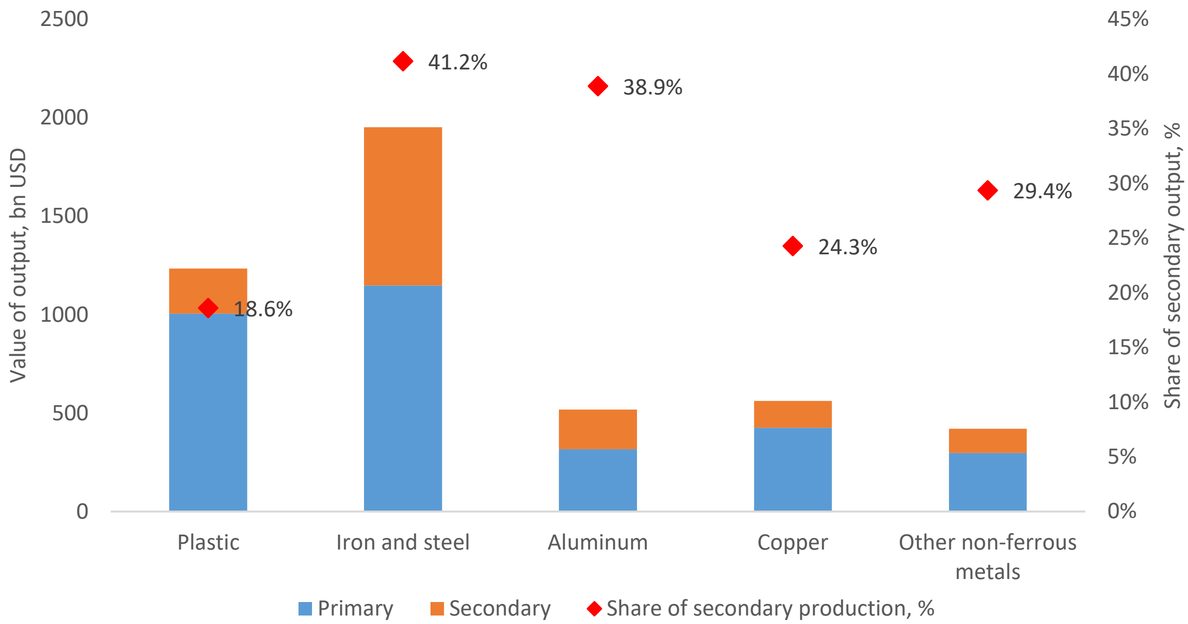

Figure 5. Global primary and secondary production values across newly disaggregated sectors in the GTAP-CE Data Base, billion USD (left axis) and % of secondary production in total output (right axis) in 2017

By explicitly capturing technological differentiation across production routes (i.e., primary versus secondary), the GTAP-CE Data Base reflects corresponding differences in emission intensities, thereby providing a more granular and policy-relevant representation of emission differentials across material supply chains. Figure 6 decomposes life-cycle emissions of primary and secondary production across the newly disaggregated material sectors in the GTAP-CE Data Base into Scope 1, Scope 2, and Scope 3 components following the approach discussed in the Appendix B. A clear pattern emerges across all materials: primary production is consistently more emission-intensive than secondary production, with the largest absolute differences observed for steel and aluminum. For steel, the global average carbon intensity of primary production is approximately twice that of secondary production, while aluminum exhibits an even greater divergence between the two routes. In steel, the differential is driven primarily by Scope 1 emissions associated with coke combustion and process-related reductions in blast furnace operations. In contrast, for aluminum, the gap is largely attributable to Scope 2 emissions, reflecting the high electricity intensity of primary smelting relative to scrap-based remelting. Across all materials, secondary production pathways—relying on scrap inputs rather than ore extraction and primary processing—consistently display substantially lower Scope 1 and Scope 2 emission intensities.

For copper, other non-ferrous metals, and plastics, the gap between primary and secondary production remains substantial but smaller in absolute magnitude. Notably, Scope 3 emissions constitute a significant share in several sectors, highlighting the importance of upstream supply chains in shaping total carbon footprints. From a database perspective, this decomposition underscores the analytical value of separating primary and secondary activities within GTAP-CE. Without such disaggregation, differences in process emissions, electricity intensity, and upstream supply-chain contributions would be averaged out, limiting the model's ability to assess circular economy strategies, material substitution, and recycling-driven decarbonization pathways.

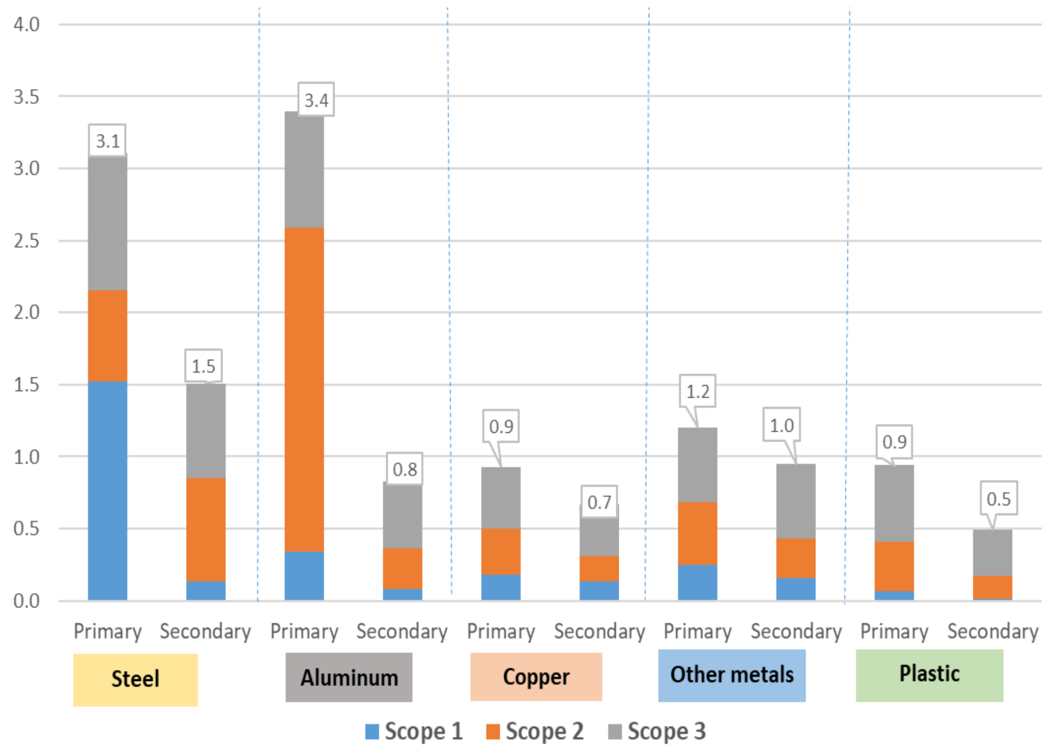

Figure 6. Global-average carbon intensity by emission scopes for metals and plastic, kg CO_2 per 1 USD

Source: developed by author.

Notes: Scope 1 represents direct emissions from fossil fuel use; Scope 2 represents emissions embodied in electricity and heat used in the corresponding production process across activities; Scope 3 represents all other emissions along value chains.

Figure 7 reports global-average carbon intensities for cement and selected fertilizer products, decomposed by emission scope. Two structural patterns are evident. First, Scope 1 emissions dominate total carbon intensity across all products, particularly for nitrogen fertilizers and cement. Nitrogen fertilizers display the highest overall intensity (around 10.1 kg CO_2/USD), driven overwhelmingly by direct process emissions associated with ammonia synthesis and feedstock combustion. Cement also exhibits a high carbon intensity (around 6.6 kg CO_2/USD), reflecting both fuel combustion and process emissions from clinker production. In contrast, phosphorus and potassium fertilizers show lower overall intensities (3.7 and 4.9 kg CO_2/USD, respectively), although Scope 1 emissions remain the principal contributor. Second, Scope 2 and Scope 3 emissions play a comparatively smaller but non-negligible role. Scope 2 contributions are modest relative to direct process emissions, especially compared to the case of metals and plastic production routes discussed above. Scope 3 emissions capture upstream supply-chain effects, including energy and intermediate inputs and in most cases represent somewhat larger share of the total footprint compared to Scope 2 emissions. From a database design perspective, this scope-based decomposition highlights the importance of explicitly distinguishing process-driven emissions (e.g., calcination in cement, steam methane reforming in ammonia) from electricity-related and upstream emissions. Such differentiation is essential for accurately modeling decarbonization pathways, including electrification, fuel switching, carbon capture, and supply-chain restructuring within the GTAP-CE framework. In addition, such level of sectoral detail enables a more refined assessment of selected policy measures, such as CBAM (e.g. Maliszewska et al., 2025; Chepeliev et al., 2025).

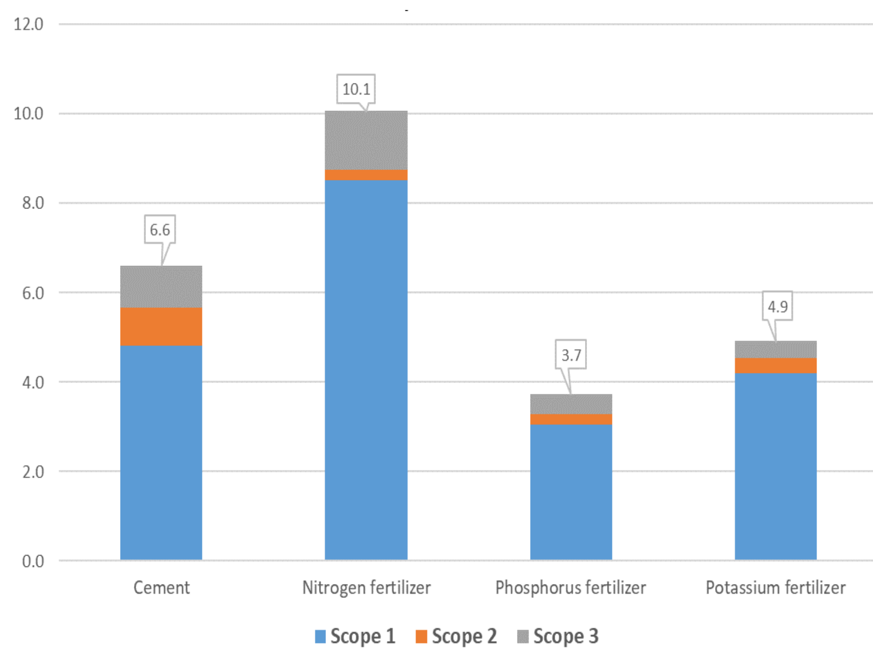

Figure 7. Global-average carbon intensity by emission scopes for cement and fertilizers, kg CO_2 per 1 USD

Source: developed by author.

Notes: Scope 1 represents direct emissions from fossil fuel use; Scope 2 represents emissions embodied in electricity and heat used in the corresponding production process across activities; Scope 3 represents all other emissions along value chains.

4. Selected data challenges and potential for future refinement

The construction of the GTAP-CE Data Base involved several methodological and data-related challenges, necessitating a range of realignment and reconciliation assumptions. While detailed discussion of specific assumptions and data inputs is provided in Appendix A, we briefly summarize below the principal challenges encountered, along with areas where future improvements and refinements could further enhance the structural consistency of the database.

In a number of cases, inconsistencies between trade and output values collected from available data sources and flows underlying GTAP Data Base have been observed. For instance, estimated output of iron and steel in selected countries could exceed total output reported in GTAP for the iron and steel sector. Under the adopted reconciliation procedure, GTAP Data Base flows were treated as control totals. Observed values for the newly disaggregated sectors were used exclusively to derive allocation weights and shares, which were then applied to split the original GTAP flows. Consequently, the newly defined subsectors are fully nested within the GTAP-Power

Data Base structure. By construction, aggregating the disaggregated sectors back to the original GTAP-Power classification reproduces the initial sectoral totals exactly. A potential avenue for future refinement is the systematic adjustment of related upstream and downstream sectors within the GTAP framework to ensure greater consistency and more precise targeting of the newly disaggregated activities across the full supply–use structure.

According to the standard activity classification, "Waste collection, treatment and disposal; materials recovery" should be mapped to the GTAP "wtr" sector. However, inspection of the GTAP input–output tables reveals that intermediate inputs from "wtr" to metal- and plastic-producing sectors are systematically too small to account for the observed value of scrap in most countries, including high-income economies with well-developed secondary material markets. This suggests that "wtr" primarily captures specific waste management services or associated margins, rather than the full transaction value of scrap commodities entering production.

In our data framework, the objective was to represent the actual economic value of scrap used as an input into secondary production processes. Accordingly, scrap was explicitly separated from the parent producing sector (e.g., from "i_s" in the case of steel scrap). This treatment is further supported by the relatively large own-sector (self-consumption) flows frequently observed in metal and plastic activities in the input-output tables, which are consistent with the internal use of recovered materials rather than solely the purchase of waste management services. Going forward, a more comprehensive representation of scrap flows could be developed by systematically disaggregating scrap generation across a broader set of supplying sectors, thereby capturing heterogeneity in feedstock composition, recovery rates, and market structures. Such an extension would allow for a more granular differentiation of scrap types (e.g., post-consumer vs. industrial, ferrous vs. non-ferrous, plastic polymers by resin category) and improve the consistency of material flow accounting within the broader supply–use framework.

While the relevant supply–use structures are represented in the database, explicit sector-specific cost and supply assumptions are not available for all newly disaggregated activities—for example, for recycling sectors. In such cases, database development relied on a hybrid approach, combining the cost and supply structures of the corresponding parent sector with targeted adjustments to better reflect the characteristics of the disaggregated activity. As additional data inputs become available, these supply and use assumptions could be further refined and improved.

Output value targets were derived using trade-based unit values (i.e., implicit prices inferred from bilateral trade flows), which were then proportionally scaled to remain consistent with GTAP control totals. While this approach ensures cross-country consistency and alignment with observed trade data, it may not fully capture domestic price differentials. In cases where reliable country-specific producer prices become available, these could be used to construct output value targets that better reflect domestic market conditions prior to reconciliation with GTAP totals.

The current framework does not fully capture country-specific sources of scrap and waste by supplying sectors and institutional agents—particularly for plastics. While selected major economies are represented using country-specific data, regional proxy information was applied in a number of cases where detailed national statistics were unavailable, as documented in the Appendix A. This may mask cross-country heterogeneity in waste generation patterns and recovery structures. Expanded country-specific data collection for these remaining economies would allow for a more precise allocation of secondary material flows and improve overall material balance consistency.

5. GTAP-CE Data Base distributions

The developed GTAP-CE v11 Data Base is distributed in three data formats, similar to the standard GTAP Data Base. These include GTAPAgg and Flexagg archives (with HAR files), as well as GDX containers (GAMS files). These data distributions report information for a single reference year, i.e. 2017, covering 99 commodities/activities and 160 countries/regions. The developed database reports emissions of both greenhouse gases and air pollutants. The GTAP-CE v11 Data Base is available for download on the GTAP website (https://www.gtap.agecon.purdue.edu/) together with other GTAP Data Base satellites and extensions.

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Appendix A. Data sources used for the GTAP-CE Data Base construction

For the case of **iron ores** production, data are based on USGS 2017 Mineral Yearbook (https://apps.usgs.gov/minerals-information-archives/iron-ore/myb1-2017-iron-ore.xlsx).

For the case of **bauxite ores** production, data are based on USGS 2017 Mineral Yearbook (https://d9-wret.s3.us-west-2.amazonaws.com/assets/palladium/production/atoms/files/myb1-2017-bauxi.xls). In the case of US, data are not reported in the USGS Yearbook due to the proprietary reasons. To gap fill data for US, data from GTAP-CE v10 Data Base was used (243.5 tmt).

For the case of **copper ores**, data are based on the USGS 2017 Mineral Yearbook (https://pubs.usgs.gov/myb/vol1/2017/myb1-2017-copper.xlsx). Production is reported in tons of copper content and is differentiated by two technologies – concentrating and leaching (e.g. see https://copperalliance.eu/about-copper/copper-and-its-alloys/processes/).

For the case of **copper production (distinguished by primary and secondary)**, estimates are derived from USGS 2017 Mineral Yearbook (https://pubs.usgs.gov/myb/vol1/2017/myb1-2017-copper.xlsx).

For the case of **primary aluminum production**, estimates are derived from USGS 2017 Mineral Yearbook (https://d9-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/atoms/files/myb1-2017-alumi.xls).

Secondary aluminum production data (producer's capacity as of 2020) is sourced from https://www.lightmetalage.com/resources-section/secondary-producers/ and further aggregated by countries. These data can be further scaled to match secondary production volumes for 2017 using aggregate regional data from https://www.world-aluminium.org/statistics/primary-aluminium-production/ and country/region-specific data (for EU and USA). For the 2017 totals of the secondary (recycled) aluminum production we rely on https://alucycle.world-aluminium.org/public-access/#regional that reports data for 9 aggregate regions.

Total steel production is derived from USGS 2017 Mineral Yearbook. **Secondary steel production** quantities are sourced from the 2018 Steel Statistical Yearbook (World Steel Association publication) https://worldsteel.org/wp-content/uploads/Steel-Statistical-Yearbook-2018.pdf using Electric Furnaces production volumes. Total of the world steel data for steel production aligns with the USGS total for steel production, though several minor producers are reported in the World Steel data and not reported by USGS. These are added to the USGS volumes.

Extraction of non-metallic minerals and non-ferrous metal ores is sourced from the UNEP IRP MFA database version 2018 https://www.resourcepanel.org/global-material-flows-database Extraction of other ores (moo) is estimated as total non-ferrous ores mining less bauxite and copper ores.

Output values of selected commodity groups for 2007 are sourced from the UNIDO database. **Exchange rates** for converting country-specific currencies to USD are sourced from the World Bank.

Plastics waste generation data by countries for 2010 is sourced from https://ourworldindata.org/plastic-pollution which is in turn based on the per capita plastic waste generation reported in Jambeck et al. (2015) http://science.sciencemag.org/content/347/6223/768/

Plastics recycling and recovery rates for the **EU** are sourced from https://committee.iso.org/files/live/sites/tc61/files/The%20Plastic%20Industry%20Berlin%20Aug%202016%20-%20Copy.pdf (representing 2014 reference year)

For **United States, India, China and Canada**, plastic recycling rates are sourced from OECD Global Plastics Outlook Database (https://doi.org/10.1787/c0821f81-en).

For **Morocco**, an 8% recycling rate was used based on https://link.springer.com/chapter/10.1007/978-981-16-0913-8_2

For the case of **Nigeria** a 10% **plastics recycling rate** is used based on https://enveurope.springeropen.com/articles/10.1186/s12302-019-0254-5

For **Afghanistan, Bangladesh and Sri Lanka** plastic recycling rates are sourced from https://www.unescap.org/sites/default/files/SSWA%20Development_Paper20-02_Marine%20Plastic%20Pollution%20in%20South%20Asia.pdf

For the case of **Malaysia a plastics recycling rate** of 4.5% (for 2017) was sourced from http://www.krinstitute.org/Views-@-Plastic-;_An_Undegradable_Problem.aspx

For the case of **Philippines, a plastics recycling rate** of 9% (for 2015) was sourced from https://wwf.org.ph/wp-content/uploads/2020/12/WWF_REPORT_EPR_Philippines_.pdf

For **South Asia** and **East Asia and Pacific**, including all countries in these regions without available country-specific data, regional average recycling rates from GTAP-CE v10 Data Base are used.

For the **remaining individual countries and composite regions**, regional-average plastics recycling rates from OECD Global Plastics Outlook Database (https://doi.org/10.1787/c0821f81-en) are used.

Global plastics production and shares by **key** producing **regions** are adopted from https://plasticseurope.org/wp-content/uploads/2021/10/2018-Plastics-the-facts.pdf

To estimate the **price of other 'nfm' ores relative to the price of corresponding metal**, we use the share of ore inputs to the metals aggregate production structure as reported in the IOTs. The corresponding share varies between around 14% in Japan, 34% in Korea and 52% in Canada. We use an average of these three shares, which is 33%.

Cement output volumes and values by countries are sourced from the data underlying IFC (2023) report.

For the case of **fertilizers**, the disaggregation procedure broadly follows an approach discussed in Bartelings et al. (2016). Production data were collected from the United Nation Food and Agriculture Organization (FAO) database for nitrogen, phosphate, and potassium fertilizers. Cost structures were estimated based on data from Bartelings et al. (2016). Data on fertilizer use by crops was gathered from the International Fertilizer Association that releases estimates for fertilizer usage by crop type and country. Emission factors for fertilizer production and applications have been derived from the FAO database.

Bilateral trade volumes, values and prices are derived from the BACI database http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=37

Cost and supply structures for the **disaggregated sectors** are based on selected individual country input-output tables for the United States (US BEA, 2018), Canada (Statistics Canada, 2019), Japan (MIC, 2019) and Korea (Bank of Korea, 2019), as well as EXIOBASE MRIO (Stadler et al., 2019).

Further refinements for the **representation of energy inputs** to the **production process of primary and secondary activities** are implemented based on the multiple data sources: steel production and casting (Burchart-Korol, 2013; Kirschen et al., 2011; Sosinsky et al., 2008), aluminum (Liu et al., 2016), copper (Dong et al., 2020), other non-ferrous metals (BIR, 2008) and plastics (APR, 2020; Hopewell et al., 2009).

Appendix B. Estimation of emission intensities

The relationship between the demand and supply sides in the global MRIO framework can be represented by the following equation:

$X = AX + (Y\mathbf{1})$,

where *X* is the vector of the output of commodity *i* in region *s* (with elements $x_{s,i}$); *A* is the matrix of technological coefficients with elements $a_{si,rj}$, which represent the cost share of commodity *i* supplied by region *s* used in the production process of commodity *j* produced in region *r*; *Y* is the matrix of final demand with elements $y_{s,i,r}$ corresponding to the direct final consumption of commodity *i* produced in region *s* and consumed in region *r*; **1** is the vector of "1" with a dimension *r*.

Solving for *X* we obtain the following:

$X = (I-A)^{-1}(Y\mathbf{1})$,

Where *I* is the identity matrix and $(I-A)^{-1}$ is the Leontief inverse, which represents the aggregate amount of direct and indirect inputs that are required to satisfy the one unit of final demand.

Assuming that the emission intensity of the output of commodity *i* in region *s* is given by $e_{s,i}$ and E is the vector of the corresponding emission intensities with the dimension of s x i, one can estimate the complete coefficient or the emission intensity of final consumption as follows:

$E_P = E(I-A)^{-1}$.

For the distinction between emission scopes, scope 1 emissions corresponds to the emission from directly fossil fuels consumption, scope 2 corresponds to the emissions embedded into the electricity and heat consumed within the production process, while scope 3 corresponds to the remaining (indirect) emissions along the supply chain (e.g. emission embodied in steel used to produce car for the case of the emission intensity of car production).