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Ecological Unequal Exchange

Winners and Losers in Global Raw Material Trade and Consumption

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Abstract

The Marxist theory of unequal exchange challenges the idea that trade never results in outright losses. As a biophysical process, ecological unequal exchange reveals global disparities in resource flows. Using material flow analysis, alternative indicators, and new country clusters, this study updates earlier research and identifies a new phase of intensified disparities since 2015, with rising net outflows of resources from low-income countries (LICs) to high-income countries (HICs). From 1970 to 2024, HICs accumulated 290 gigatons (Gt) of raw material equivalents (RMEs) as net imports, while upper-middle-income, lower-middle-income, and low-income countries net-exported 164 Gt, 53.1 Gt, and 9.6 Gt, respectively. In a relative sense, LICs consume 13.3 percent less RMEs than they extract domestically, while HICs consume 25.4 percent more. This study challenges assumptions about global divisions of labor: not all HICs are net-importers of RMEs, nor are all LICs net-exporters. However, net-exporter HICs earn more than net-exporter LICs, and net-importer HICs spend less than net-importer LICs. On average, LICs export 6 tons of RMEs to earn what HICs earns from 1 ton; for net-exporter LICs, this ratio rises to 12.7 tons. The more a country exploits the environment, domestically or abroad, the more it earns.

Keywords: Trade, Inequality, Material Flow Analysis, Ecological Unequal Exchange

The conventional economic perspective considers “unequal exchange” to be an oxymoron (Nordlund 2014): trade would not occur without mutual benefits. Milton Friedman once stated that “[t]he most important single central fact about a free market is that no exchange takes place unless both parties benefit” (Cran and Barker 2002). This conviction goes back to the (neo)classical theories of comparative advantage (Ricardo 1817; Ohlin 1933). Specializing in exports produced with relatively abundant resources supposedly benefits everyone involved in global trade. Some might benefit more than others, but the fundamental premise is that trade never leads to outright losses. This expectation has greatly influenced global governance for the past 80 years and continues to shape economic development and trade policies to this day (Foster and Holleman 2014; Ricci 2021). As stated by the International Monetary Fund (IMF) (2006: 163), “at the aggregate level, trade is a win-win game.”

A radically different position, rooted in the Marxist tradition, proposes that trade under capitalism generates uneven flows of costs and benefits, hidden from regular trade statistics. In today’s global production networks, each node involves a certain amount of “value,” including direct and indirect average labor-time “embodied” in machines and materials. Through normal trade practices, this value gets siphoned away, drained from low-wage, low-productivity regions of the globe to enrich high-wage, high-productivity regions—a process known as “unequal exchange” (Grossman 1929; Emmanuel 1972; Amin 1974).

Such trade not only transfers value in the Marxist sense (average labor-time) but also “use-value”: the useful material wealth produced through labor with natural resources. This has resulted in a net outflow of material and natural use-value from the global South to the global North (Dorninger et al. 2021a), and an accumulation of waste and impacts back into those same areas (Hornborg 1998, 2009). These drains and strains have the consequence of depriving the global South countries of vital resources and damaging their local ecosystems, while wealth continues to accumulate for a small minority (Jorgenson 2006; Rice 2007; Jorgenson, Austin, and Dick 2009). Pioneered by the work of Stephen Bunker (2019), unequal exchange has been reframed as an ecological process—a drain not of value as average labor-time, but of metabolic flows of resources through trade. Over time, such a drain leads to ecological debt (Hornborg and Martinez-Alier 2016).

Quantifications of (ecological) unequal exchange reveal substantial losses for the global South. These methods generally compare current trade with trade under the hypothetical situation of equal wages or currency rates. Depending on the method, estimates of what the global South lost through unequal exchange vary: US$2.8 trillion in 2012 (Cope 2019); $10 trillion in 2018 (Hickel, Sullivan, and Zoomkawala 2021); US$3.8 trillion in 2019 (Ricci 2021). Whatever the amount may be, these “tributes” transferred to the global North highlight an asymmetry in trade relations (Ricci 2021). It is important to note that these estimates use monetary proxies of unequal exchange and do not actually measure transfers of “value” or “use-value”—this paper contributes to a body of knowledge attempting to measure the latter.

The paper makes two key contributions. First, it updates empirical assessments of ecological unequal exchange, showing that the decline observed from 2008 to 2015 has reversed. Second, it introduces two methodological innovations: first, a measure of resource exports relative to domestic extraction, addressing the shortcomings of absolute metrics; and second, new approaches to country clustering, refining an outdated view of the global division of labor.

After presenting the paper's framework which introduces ecological unequal exchange, material flow analysis, multi-regional input-output analysis, and trade in value-added, as well as a brief review of the literature, we turn to our methodology and results. By exploring recent data and using alternative indicators, country classifications, and representations of trajectories, we aim to add critical distinctions and refinements to a relatively small number of studies of ecological unequal exchange at a global scale. We will conclude with some reflections on the interactions between unequal exchange in its original and ecological forms.

Materials and Methods

Ecological Unequal Exchange

Unequal exchange, as originally conceptualized by Grossman (1929), Emmanuel (1972), and Amin (1974), focuses on asymmetrical transfers of value (as socially necessary labor-time) from "periphery" to "center" countries. With these designations, world-system theorists differentiate nations and social strata based on their structural positions, relationships and dependencies in the world system. The world systems tradition further developed the designations to include semi-periphery/-centers, as well as domestic peripheries/centers (Galtung 1971; Wallerstein 1976), and they continue to serve as useful designations in world-systems research (e.g., see Gellert, Frey, and Dahms 2017).

UE does not directly expose the material flows propelled by trade. Two countries could export equal amounts of value embodied in unequal amounts of material resources if their production processes differ in labor intensity. To fill this gap, Bunker's (2019) ecological unequal exchange (EUE) emphasized the uneven transfer of what he called "natural values."

While some argue that EUE builds on the original theory of unequal exchange (Jorgenson et al. 2009; Bai and Givens 2021; Alonso-Fernández and Regueiro-Ferreira 2022), Bunker diverged from the Marxist framework by combining "labor value" with "natural value" to determine total commodity value. He suggested that extractive industries in peripheral regions export resources rich in "natural value," while "labor value" is added later in the supply chain by productive centers. According to Bunker (1984, 2019), unequal exchange theory thus neglects the appropriation of "natural value."

However, extractive sectors do produce labor value, making them vulnerable to unequal exchange. Moreover, by combining natural and labor value, we risk conflating human labor-time with natural substance, and consequently the exploitation of labor with the appropriation of nature (Hornborg 1998; Foster and Burkett 2018). On the other hand, Bunker (1984, 2019) correctly asserted that unequal exchange captures neither natural resource depletion nor the significant disparities in natural resource allocation through trade.

The challenge is to distinguish flows of value (as socially necessary labor-time) through unequal exchange from flows of natural use-value through EUE (Brolin 2007). However, this comes with a warning: while value is one-dimensional (labor-time), natural use-values vary in substance, quality, and function. Use-value cannot be captured by biophysical metrics like joules, tons, or hectares, but these are the only tools we have to empirically analyze EUE (Hornborg 2015).

EUE refers to uneven flows of natural use-values, involving the net appropriation of low-entropy[1] matter and energy from environmental sources and the processing capacity of environmental sinks for high-entropy matter and energy. The existing literature generally links EUE to the trade-related transfers of two types of impacts: resource depletion and environmental burden displacement (Chase-Dunn 1998; Jorgenson 2006; Rice 2007; Jorgenson et al. 2009; Shandra et al. 2009; Dorninger and Hornborg 2015; Jorgenson 2016; Warlenius 2016; Bai and Givens 2021; Tong et al. 2022). Essentially, EUE drains and strains natural territories in peripheral trading partner countries.

EUE research hypothesizes that powerful centers control these processes, allowing them to maintain material trade surpluses and avoiding domestic environmental harm (Moran et al. 2013). Consequently, EUE strengthens wealth accumulation in the centers at the expense of the peripheries. For example, Jorgenson (2006) shows that “more-developed countries” exploit resources from “less-developed countries,” driving higher deforestation rates in the latter. The literature also suggests a third form of EUE arising from the centers’ disproportionate use of global commons such as the atmosphere, oceans, and biogeochemical cycles (Martinez-Alier 2002; Rice 2007; Jorgenson et al. 2009; Paredis et al. 2009). These global impacts often harm peripheries the most but differ from the direct ecological harm inflicted through trade. This paper focuses on the first form of EUE: the center’s net appropriation of natural use-values from the periphery.

Many EUE scholars attribute the phenomenon to a global division of labor where centers dominate manufacturing and peripheries focus on extraction. Imposed during colonialism, this division persisted into the post-colonial era, with world-system economists predicting a steady decline in the periphery's terms of trade as primary product prices fell relative to manufactured goods (Prebisch 1950; Singer 1950).

While extraction, production, consumption, and disposal remain geographically unequal (Theis, Betancourt, and Sikirica 2024), the division blurred during the 20th century. Resource-rich nations like Australia and Canada thrive as net exporters, and many (semi-)peripheries have industrialized, spurred by global value chains (Hickel et al. 2022). Unequal exchange scholars have long argued that the periphery’s trade challenges stem more from structural economic disparities (in wages and productivities) rather than commodity types (Emmanuel 1972; Amin 1974). EUE research should therefore account for countries and regions that deviate from the classic global division of labor (Brolin 2007; Ricci 2023).

[1] Low entropy indicates a state of matter and energy with high order and less dispersal, meaning it tends to be more useful for human use. On the other hand, high entropy reflects a state with greater disorder and more energy spread out, that is to say, less useful (Rammelt 2024).

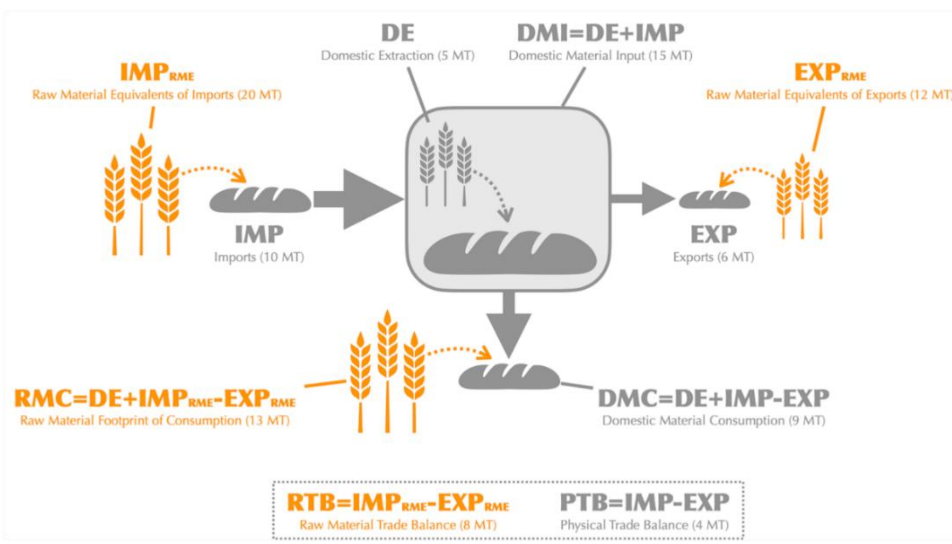
Material Flow Analysis

Empirical assessments of EUE sometimes employ life-cycle analyses of individual products (Oulu 2015; Roos 2022). Other, more systemic assessments encompass entire sectors or nations, for example, deriving estimates from the global human appropriation of net primary production (Dorninger et al. 2021b), or ecological, carbon, and water footprints (Rice 2007; Steen-Olsen et al. 2012). In this paper, we will focus on two other systemic methods: Material Flow Analysis and Multi-Regional Input–Output analysis.

Material Flow Analysis tracks biophysical resource movements and assesses accountability for extraction and environmental impacts. The method employs two approaches: domestic and footprint. Consumption in the first approach sums materials extracted domestically, adjusting for direct imports and exports. Conversely, the footprint approach assigns upstream material inputs based on final consumption, irrespective of production origin (Schandl et al. 2018). This approach is essential for capturing embodied inputs not reflected in final goods' weight. For example, in 2023, the global consumption of raw materials amounted to 15.1 Gt using the domestic approach and 31.4 Gt using the footprint approach (WU Vienna 2023).

Figure 1 depicts the various material flow indicators, their relationships within the national material balance and through trade with the rest of the world. These indicators are also summarized in Table 1.

Figure 1: Example Material Flow Analysis Indicators.[2]



[2] The territorial approach calculates domestic material consumption (DMC) by adding domestic extraction (DE) to direct imports (IMP) and subtracting direct exports (EXP), or by adding domestic extraction to the physical trade balance (PTB). In contrast, the footprint approach calculates the raw material footprint of consumption (RMC) by adding domestic extraction (DE) to RME imports (IMP_{RME}) and deducting RME exports (EXP_{RME}), or by adding domestic extraction to the raw material trade balance (RTB).

Material Flow Analysis data includes traded raw materials (indicated by the grain symbol in Figure 1) and their embodiment as Raw Material Equivalents (RMEs) in (semi-)finished products (indicated by the bread symbol), and categorizes four main material resources, (Commonwealth Scientific and Industrial Research Organisation [CSIRO] 2022): (1.) fossil fuels (e.g., natural gas, derived gas, crude oil, petroleum products); (2.) biomass (feedstock and energy crops); (3.) metal ores (mined materials from which metals are extracted); and (4.) non-metallic minerals (e.g., sand, gravel, limestone, fertilizers).

Table 1: Summary Material Flow Analysis Indicators[3]

Indicator	Meaning of indicator
Domestic Extraction (DE)	Biotic and abiotic primary materials extracted within domestic territory
Imports (IMP)	Direct physical imports at various processing stages into domestic territory
Domestic Material Input (DMI = DE + IMP)	Direct physical inputs from domestic and foreign sources into domestic production system
Exports (EXP)	Direct physical exports at various processing stages from domestic territory
Physical Trade Balance (PTB = IMP - EXP)	Difference between the direct physical imports and exports of a territory
Domestic Material Consumption (DMC = DE + PTB)	Direct physical inputs from domestic and foreign sources to meet final domestic consumption
Raw Material Equivalents	Biotic and abiotic primary material requirements of upstream supply chains
Raw Material Equivalents of Imports (IMP_{RME})	RME requirements of foreign supply chains to produce the imports into domestic territory
Raw Material Equivalents of Exports (EXP_{RME})	RME requirements of foreign and domestic supply chains to produce the exports from domestic territory
Raw Material Trade Balance (RTB = IMP_{RME} - EXP_{RME})	Difference between the RME imports and exports of a domestic territory
Raw Material Footprint of Consumption (RMC = DE + RTB)	RME requirements of foreign and domestic supply chains to meet final domestic consumption

In short, unlike domestic material consumption (DMC) and physical trade balance (PTB), which consider only direct flows, raw material footprint of consumption (RMC) and raw material trade balance (RTB) include indirect flows, providing a more accurate reflection of a country's claim on global material resources. These indicators allocate upstream material requirements of traded goods and services to the country of final demand (Dorninger and Hornborg 2015; Krausmann et al. 2017).

[3] Adapted from Krausmann et al. (2017), Schandl et al. (2018), Alonso-Fernández and Regueiro-Ferreira (2022).

Multi-Regional Input-Output Analysis

Having conceptualized the economy-wide material flows, Multi-Regional Input-Output analysis then quantifies international upstream flows and allocates responsibility to final demand. Due to limitations in reliable inter-sectoral physical trade data, Multi-Regional Input-Output analysis does the allocation by using monetary data from input-output tables. The approach first allocates material requirements of commodities to sectors within the national economy. Bilateral monetary trade data then helps assign environmental impacts to a country's exports or imports, ensuring that domestic extraction is allocated to where final consumption occurs (UNEP 2021; Commonwealth Scientific and Industrial Research Organisation [CSIRO] 2022).

Acknowledging the methodological constraints that force us to be cautious interpreting Multi-Regional Input-Output results (Kitzes 2013; Schaffartzik et al. 2014; Dorninger and Hornborg 2015), the approach has a lot to offer—especially when the data is aggregated at the global level, which reduces the impact of various over- and underestimates and local inaccuracies in the data.

Indicators of Ecological Unequal Exchange

PTB and RTB are both indicators of EUE: a positive or negative balance indicates that physical or material inflows into a country are greater or smaller than outflows (Alonso-Fernández and Regueiro-Ferreira 2022). The more comprehensive RTB method provides a better approximation of EUE, but RTB data may not always be available for certain time frames, regions, or indicators (Dorninger and Eisenmenger 2016; Samaniego, Vallejo, and Martínez-Alier 2017). Despite their utility, PTB and RTB only partially reveal EUE as they fail to specify the environmental damage caused (Krausmann et al. 2017; Alonso-Fernández and Regueiro-Ferreira 2022). They also use countries as the unit of analysis, overlooking intra-national EUE (Martinez-Alier et al. 2016), and do not reveal changes in entropy along supply chains (Hornborg 1998, 2009; Foster and Holleman 2014). Therefore, alternative biophysical indicators may be needed alongside those used here (Dorninger and Hornborg 2015; Dorninger et al. 2021a; Hickel et al. 2022).

Using RTB as the EUE indicator compares RME imports and exports in absolute terms, failing to compare those flows to local resources like DE or RMC. For example, country A may have a lower net outflow of RMEs than country B, but a higher net outflow when considered in proportion to their domestic consumption. We therefore propose an additional novel EUE estimate that focuses on net appropriation in a relative sense: the relative Raw Material Trade Balance (relative RTB), representing the percentage by which a country's consumption of raw materials (RMC) exceeds or falls short of its domestic extraction (DE).

- The relative RTB can be calculated as:
  $100 \times (RMC - DE) / DE$, where $RMC = DE + IMP_{RME} - EXP_{RME}$.
- Thus, relative RTB can also be expressed as:
  $100 \times (IMP_{RME} - EXP_{RME}) / DE = 100 \times RTB / DE$.

The relative RTB thus indicates how much a country relies on imports or exports relative to its domestic extraction. A positive value shows a greater reliance on imports ($IMP_{RME} > EXP_{RME}$) and less on domestic extraction (RTB > DE). Conversely, a negative value indicates less reliance on imports ($IMP_{RME} < EXP_{RME}$) and more on domestic extraction (RTB < DE).

Evidence of Ecological Unequal Exchange

Research supports the existence of EUE, starting with some national and regional studies. For example, France's rapid RMC growth compared to DMC indicates raw material appropriation, benefiting France at its trading partners' expense, as shown by PTB and RTB surpluses (Cahen-Fourot and Magalhães 2023). In contrast, South American economies and the region as a whole exhibit persistent PTB and RTB deficits (Samaniego et al. 2017; Alonso-Fernández and Regueiro-Ferreira 2022). The EU and United States benefit ecologically from trade, as evidenced by positive RTB values compared to regions like South America and China (Alonso-Fernández and Regueiro-Ferreira 2022).

However, a negative RME trade balance doesn't necessarily indicate EUE; other resources must be considered. A study of Latin America's trade with center regions during 1990–2015 found EUE in 20 of 22 indicators, including land use, water consumption, carbon emissions, and raw materials (Rivera-Basques, Duarte, and Sánchez-Chóliz 2021). Other studies reveal net transfers of embodied energy and land from China to Germany (Roos 2022), and embodied water and land from Africa to the UK (Oppon et al. 2018).

China's situation is complex; it exhibits a PTB surplus but hides significant RME flows, resulting in an RTB deficit (Alonso-Fernández and Regueiro-Ferreira 2022). While the centers appropriate water and land from China, China in turn appropriates resources from the peripheries. For instance, Africa exports virtual water to China at a rate 18 times higher than the reverse (Yu, Feng, and Hubacek 2014).

A few studies have examined EUE on a global scale. A 2013 study initially challenged EUE, revealing unexpected negative RTBs for high-income nations (Moran et al. 2013). However, a subsequent study using updated data showed high-income countries net-imported 3.5 Gt of RMEs, mainly from upper-middle-income nations (Dorninger and Hornborg 2015). It also found consistent positive trade balances for embodied energy and land in the EU, United States, and Japan. In 2015, "high-income countries" (drawing from the World Bank's classification) net-appropriated embodied land close to 31 percent of global land and surpassed their domestic extraction by 10 Gt of RMEs (Dorninger et al. 2021a). Another study showed that the "advanced economies" group (as defined by the IMF) appropriated 12 Gt of resources, 822 Mha of land, and 21 EJ of energy from the "emerging and developing economies" in 2015. These imbalances have worsened since 1990 (Hickel et al. 2022).

In conclusion, research suggests that EUE is a salient feature of global capitalism. The centers rely more on international trade for natural resources, leading to significant gains as they acquire goods without incurring domestic production costs. This is generally supported by other empirical studies of EUE as reviewed by Brolin and Kander (2022), Corsi and colleagues (2024), and Theis, Betancourt, and Sikirica (2024).

Country Clusters

We examine countries' positions in the world system using income- and material-based clusters, acknowledging that these do not fully encapsulate the center-periphery positions in the world system. As Theis and colleagues (2024) highlight, clustering nations solely by income fails to align with EUE theory, as extractive export hubs may not correspond to income levels. Our analysis contributes by differentiating net-importing and net-exporting sub-clusters within high- and low-income groups. This adds important information considering the blurred global division of labor discussed below. This distinction also enriches existing Material Flow Analyses of EUE that typically overlooks such intra-cluster differences.

Furthermore, Theis and colleagues (2024) emphasize the need to start identifying nations as significant commodity exporters rather than presuming lower-income countries dominate this group. In line with this, we introduce a decile-based clustering from the most net-exporting to the most net-importing countries, revealing which countries have tended to remain in those deciles over time.

How "Unequal" is Unequal Exchange?

As discussed above, EUE is considered "unequal" when it causes environmental burden displacement or suppresses resource consumption in net-exporting countries (Jorgenson 2006; Jorgenson and Clark 2009; Theis et al. 2024). Following these interpretations of EUE, we include total and per capita consumption footprints (RMC and RMC per capita) in our analysis.

Rather than unequal biophysical "drains and strains," EUE is also considered "unequal" when the biophysical resources used in production differ from the monetary compensation received (Hickel et al. 2022; Ricci 2023; Olk 2024). To estimate this compensation, we consider the growing integration of countries in global value chains (GVCs), controlled by large transnational corporations that outsource and offshore production. Intermediate goods traded within GVCs account for 70 percent of total global trade (Organisation for Economic Co-operation and Development [OECD] 2021). This shift from bilateral trade to GVCs means that export earnings are best assessed through Trade in Value-Added (TiVA) analysis, which considers the monetary value-added by each country (wages, profits, rent, interest, taxes, etc.) involved in GVCs. More specifically, in the context of TiVA analysis, Domestic Value Added provides insights into how much of the export revenue stays within the exporting country versus how much value originates from foreign inputs (or Foreign Value Added).

We can combine TiVA with Material Flow Analysis to calculate the monetary compensation per unit of biophysical resources (dollar per embodied ton, joule, or hectare exported). This ratio is expressed as: $M = X / E$, with X as export earnings (Domestic Value Added, in \$) and E as the embodied resource (e.g., ton). Calculating this ratio for the periphery and the center yields:

- Periphery: M_p = X_p / E_p
- Center: M_c = X_c / E_c
- Net balance: M_p - M_c = X_p / E_p - X_c / E_c

If monetary trade is balanced (X_p = X_c) and there is a net resource transfer in one direction (E_p > E_c), the monetary compensations must deviate in the opposite direction (M_p < M_c) (Olk 2024). We hypothesize that the periphery must export multiple units to earn what the center earns from one unit. This inequality was estimated at 5 units of RME from the periphery for 1 from the center, with similar ratios for land (5:1) and energy (3:1) (Hickel et al. 2022). Our results reveal even wider inequalities using different classifications.

This approach is limited by a lack of information on the direction of the exports (e.g., ratios of exports from LICs going to HICs). Not only is this important when considering unequal biophysical drains and strains (Jorgenson 2006), we also recommend this to be included in future estimates of monetary gaps resulting from price differences (Köhler 1998; Ricci 2023).

Data

Our study uses data from 187 countries, plus an additional "rest of the world" category which measures the difference between global imports and exports to ensure a closed global trade balance. The time frame spans 1970 to 2024, with some indicators available only from around 1990 due to data limitations. Also, some analyses begin in the early 1990s when the "rest of the world" category becomes notably smaller. The primary data is sourced from the UN IRP Global Material Flows Database (WU Vienna 2023), which relies on an Economy-Wide Material Flow Accounting and Analysis—an internationally standardized method for the measurement and analysis of raw material use on the national level (UNEP 2021). The data includes the five Material Flow Analysis indicators explained in 2.2 (DE, IMP_{RME}, EXP_{RME}, RMC, RTB) across four material categories: fossil fuels, biomass, metal ores and non-metallic minerals. Additional indicators include population data[4], income classification[5], GDP at constant 2015 prices[6], and Trade in Value Added[7].

The data was processed using STATA. Country clustering follows Dorninger and their colleagues (2021a) with the updated 2022 World Bank income classification[8]: high-income countries (HIC), upper-middle-income countries (UMIC), low-middle income countries (LMIC), and low-income countries (LIC). China (CHN) and India (IND) are treated separately due to their

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4 https://data.worldbank.org/indicator/SP.POP.TOTL

5 https://datatopics.worldbank.org/world-development-indicators/stories/the-classification-of-countries-by-income.html

6 https://data.worldbank.org/indicator/NY.GDP.MKTP.KD?year_high_desc=false

7 https://worldmrio.com/unctadgvc/

8 https://datatopics.worldbank.org/world-development-indicators/stories/the-classification-of-countries-by-income.html

large populations, significant trade flows, and influence on cluster averages. Data from various databases were merged using country codes.

We analyzed four key models based on the constructed data:

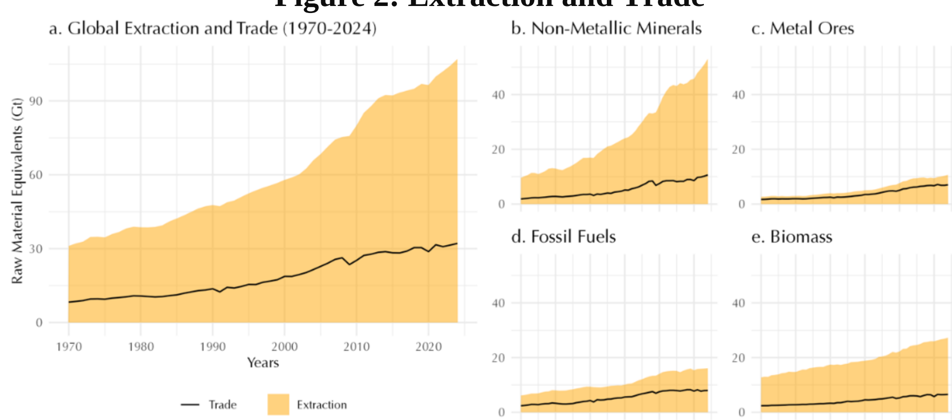
1. A baseline model assessing global material extraction and trade across all four material categories (Figure 2).
2. An income cluster model, building on Dorninger and colleagues (2021a) to assess the historical trajectory of the Raw Material Trade Balance (RTB) for all six income clusters (Figure 3, Figure 4, and Figure 5).
3. A two-axis model mapping RTB and Raw Material Consumption (RMC) per capita, showing trajectories from 1970 to 2024 for all income clusters, and including Domestic Value Added (Figure 6 and Figure 7).
4. A decile clustering model that bypasses the constraints of income-based clustering explained in 2.6 (Figure 8).

Results and Discussion

Extraction and Trade

Figure 2 provides a comparative overview of trends in global resource extraction and trade over time, highlighting the dynamics and shifts in material flows. In 2024, the global economy extracted 106 gigatons (Gt) of raw materials, with ~30 percent (32 Gt) used for producing traded commodities (graph a). Minerals constitute the largest mass of extracted resources (graph b), followed by biomass (graph e), fossil fuels (graph d), and metals (graph c). The breakdown of traded resources relative to extracted resources is as follows: 20 percent for minerals, 66 percent for metals, 50 percent for fossil fuels, and 24 percent for biomass. From 1970 to 2024, there has been a gradual but increasing trend in the proportion of traded resources relative to extracted resources, with an average annual increase of 0.11 percent.

Figure 2: Extraction and Trade[9]



[9] Graph a. presents global extraction data by aggregating all domestic extractions (DE). The right graphs separate the aggregate material flow into its constituent components: b. non-metallic minerals, c. metal ores, d. fossil fuels, and e.

Raw Material Trade Balance

Figure 3 and Figure 4 follow the methodological approach of Dorninger and their colleagues (2021a), providing a comprehensive analysis of the global raw material trade balance (RTB) from 1970 to 2024, categorized by different income clusters. The line graphs illustrate the annual absolute gains and drains in gigaton (Gt) for low-income (LIC), lower-middle-income (LMIC), upper-middle-income (UMIC), and high-income (HIC) countries, as well as for India and China. These graphs highlight trends and fluctuations in resource trade balance over time for each income cluster and different materials.

The bar charts show the accumulated RTB for the entire period (1970–2024), providing a comparison of total resource gains and drains across different income clusters and material categories. A positive RTB indicates that the income cluster in question net-imports embodied raw materials, meaning it imports more than it exports. On the other hand, a negative RTB (occurring in the grey area below the horizontal axis) indicates that the cluster net-exports RMEs. As explained, "embodied" implies that the graph shows not only trade in raw materials, but also in (semi-)finished goods and services that relied for their production on those raw materials. (Semi-) finished goods and services are therefore expressed in raw material equivalents (RME).

Updating similar studies by Dorninger and colleagues (2021a) and Hickel and colleagues (2022), Figure 3 shows that the decline in HIC's positive RTB, which began with the 2007/08 global financial crisis and lasted until approximately 2015, has since reversed, with net-imports starting to rise again. HIC's net-imports amount to 6.3 Gt in 2024. Another significant update is the reversal of China's status from a net-exporter to a net-importer of RME between 2012 and 2013. By 2024, China net-imports 1.6 Gt.

Consistent with the findings of Dorninger and colleagues (2021a) and Hickel and colleagues (2022), the bar chart shows that HIC is the only cluster with accumulated net-imports, amounting to 290 Gt (1970-2024). All other clusters experience accumulated net-exports, underscoring disparities in global resource distribution. UMICs and LMICs experienced the greatest net-exports, with 164 Gt and 53.1 Gt, respectively. Although China became a net-importer in 2013, the accumulated net-exports still amount to 22.3 Gt over the entire period. With 9.6 Gt, LICs experienced the lowest accumulated net-exports.

Figure 4 breaks down the aggregate into the four material resources. Several key trends emerge. HICs consistently exhibit a net-import of RME for all resources. As mentioned, the positive RTB for HICs began declining around the time of the global financial crisis and has since stabilized, except for minerals for which the RTB continues to increase. Minerals therefore drive the recent rise in HICs' total net-imports, as seen in Figure 3. LICs are net-exporters for all resources over the entire period, except for fossil fuels which they net-import. LMICs and UMICs also maintain a net-export position across all resources, with UMICs particularly prominent in this regard. India has been a net-exporter for minerals and biomass and a net-importer for metals and

biomass. The figures show area plots for extraction weights and line plots for trade weights. Data covers the period 1970 to 2024.

fossil fuels throughout the entire period. China, over the decades, has predominantly been a net-exporter for all resources except metals, for which if became a net-importer around 2000. Recently, China has also shifted towards net-importing fossil fuels and biomass, marking a notable change in its resource trade dynamics.

Figure 3: Raw Material Trade Balance—All Resources (1970–2024).[10]

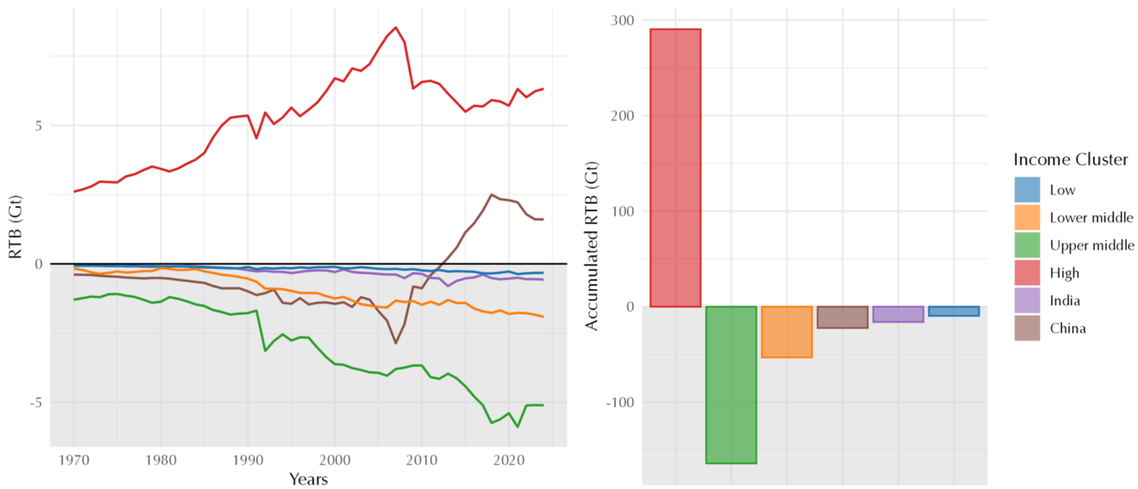
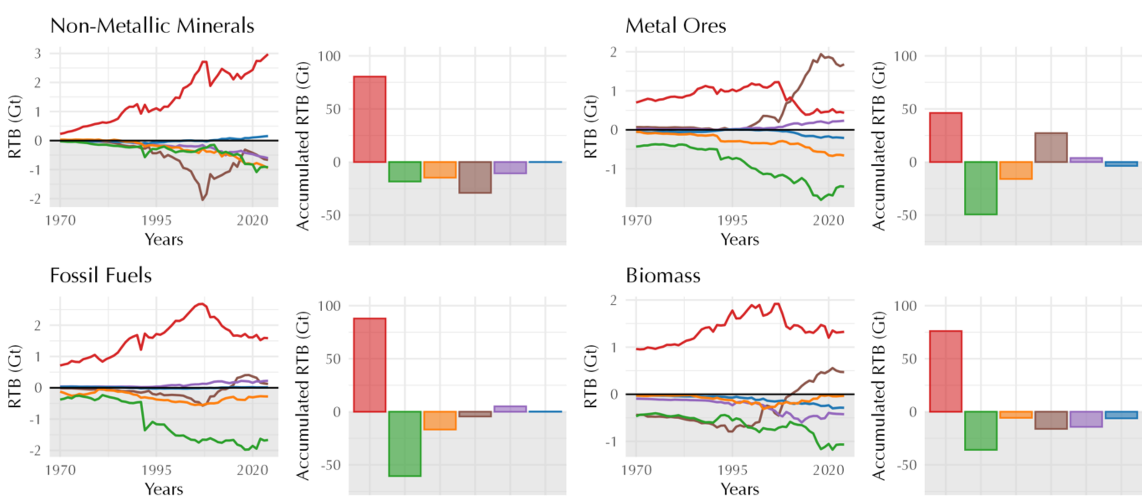


Figure 4: Raw Material Trade Balance—Per Resource (1970–2024).[11]



[10] The line graph shows the annual absolute net gains and drains in gigaton (Gt) for different income clusters. The bar chart shows the accumulated RTB for the entire period (1970–2024).

[11] The line graphs show annual net gains and drains in gigaton (Gt) by income cluster, while the bar charts show the accumulated RTB from 1970 to 2024.

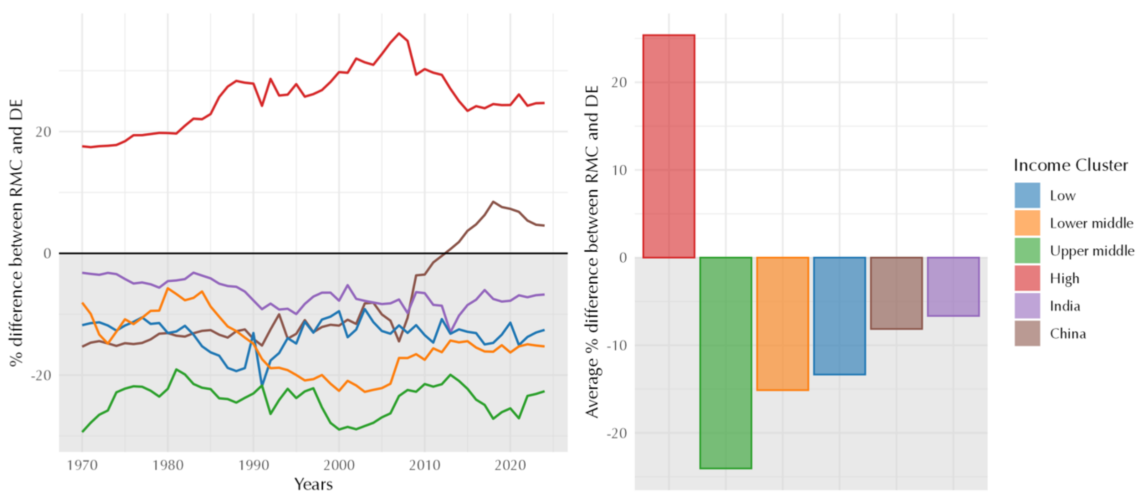
Relative Raw Material Trade Balance

In Figure 3, it looks like LIC's net-exports are not so significant in comparison with the net-exports of the other income clusters. However, the picture changes when we compare the net-exports with levels of domestic extraction. To show this, we estimate the raw material trade balance in a relative sense following the approach proposed in Table 1.

To illustrate the calculations, total domestic extraction (DE) and consumption (RMC) for HICs in 2024 was 25.61 Gt and 31.93 Gt, respectively. The relative Raw Material Trade Balance (relative RTB) was then: (100 * (31.93 - 25.61) / 25.61) ≈ 24.7 percent. It means that HICs consumed 24.7 percent more raw materials than they extracted domestically, importing the difference from the global market. On the other hand, DE and RMC were 2.59 Gt and 2.26 Gt for LICs. The relative RTB was therefore -12.6 percent (≈ 100 * (2.26 - 2.59) / 2.59)). In 2024, LICs consumed 12.6 percent less raw materials than they extracted domestically, exporting the difference to the global market. These results are shown in Figure 5.

In an absolute sense, LICs net-export much less than the other income clusters (Figure 3). In a relative sense, however, we see that these net-exports matter much more. As shown in the bar chart in Figure 5, the average LIC consumed 13.3 percent less raw materials than it extracted domestically over the entire period, exporting the difference to the global market. The average relative RTB over the whole period was -15.1 percent for the LMIC cluster and -24.1 percent for UMIC. On the other hand, the average HIC enjoyed a positive relative RTB. It consumed an average of 25.4 percent more raw materials than it extracted domestically over the entire period.

Figure 5: Relative Raw Material Trade Balance (1970–2024)



Raw Material Footprints of Consumption

To further explore how countries and clusters are faring, we can look at the raw material footprints of consumption (RMC) in ton per capita (t/c). As shown in Table 2, there are large differences in per capita RMCs between income clusters, but also wide ranges. In 2022, LICs, LMICs and India had mean RMCs of 3.1, 7.3, and 5.0 t/c, compared to 11.6, 24.7, 24.8 for UMICs, HICs, and China. All clusters increased their per capita RMCs compared to 1992 (when the data became more robust), but LICs least of all (16 percent), and China standing out with an exceptionally strong increase (290 percent). By 2022, China's RMC per capita has reached the same heights as that of HICs (~25 t/c).

Table 2: Raw Material Footprints of Consumption (1992 and 2022)

Income cluster	2022 mean RMC (t/c) (with range)	Country close to mean	Lowest RMC (t/c)	Highest RMC (t/c)	1992 mean RMC (t/c)	Change (1992-2022)
Low	3.1 (1.3–8.9)	Gambia	Afghanistan	Chad	2.68	16%
Lower middle	7.3 (2.0–27.7)	Tunisia	Sao Tome and Principe	Mongolia	5.04	45%
Upper middle	11.6 (4.0–32.4)	Thailand	Iraq	Suriname	7.69	50%
High	24.7 (0.1–77.4)	Austria	British Virgin Islands	Qatar	20.09	23%
India	5.0	/	/	/	3.12	61%
China	24.8	/	/	/	6.35	290%

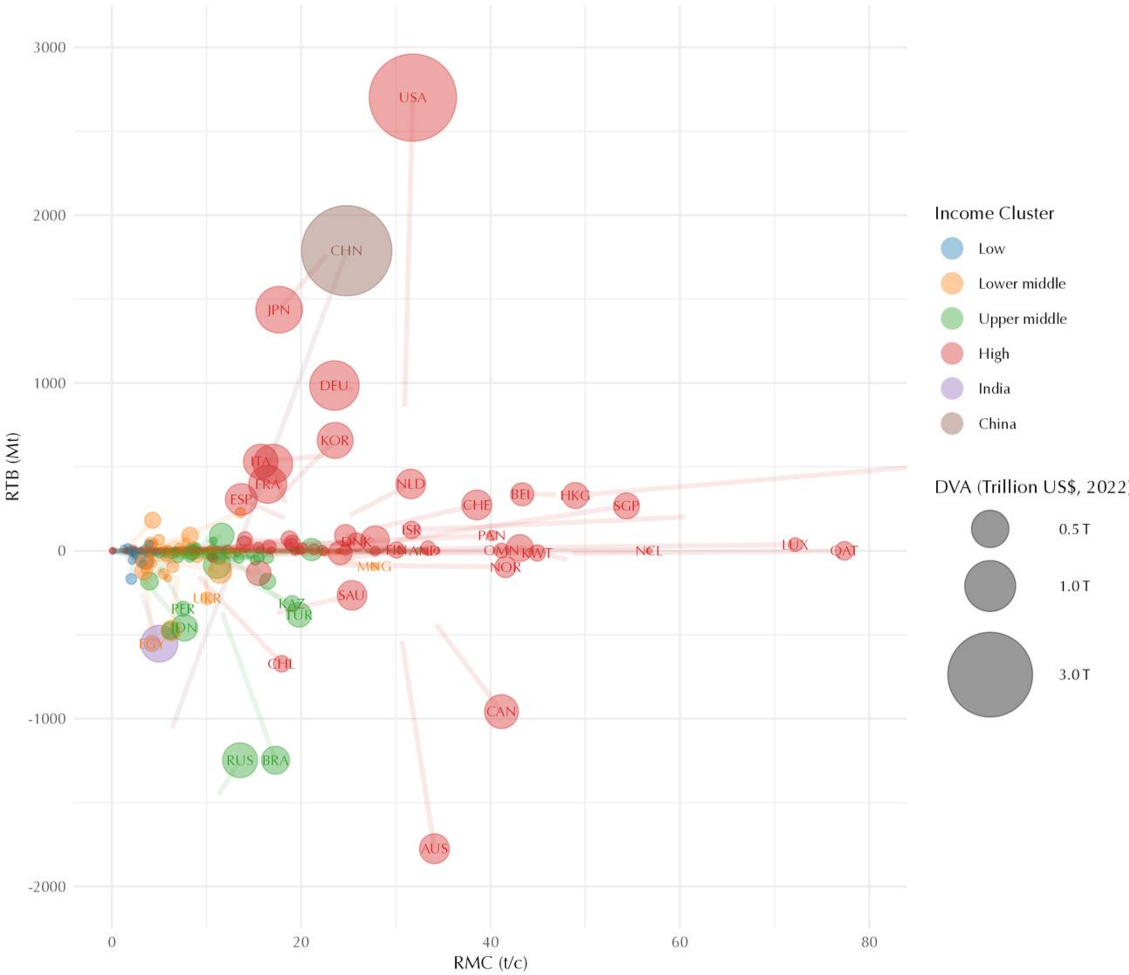
Comparing RTB, RMC and Domestic Value Added

In Figure 6, we take an individual country focus but color-code them to match their income cluster. While an income cluster can net-import (or -export) RMEs, individual countries within that cluster can net-export (or -import) RMEs. This important information is missing in Figure 3 and Figure 5. We also add per capita RMC (t/c) on the y-axis. We then add historical trend lines for each country, starting from 1992 (when the data becomes more robust), ending with 2022, but ignoring the years in between for visibility. Finally, we expand the information by scaling the size of the 2022 bubble proportionally to the country's Domestic Value Added.

Net-importer countries are mostly HICs and UMICs: together covering 66 percent of all net-importer countries, or 33 percent of the net-importer countries' total population (see appendix, Table A. 1). These economies match with the classic EUE contention that centers drain the periphery. A first notable qualification to this claim is China's position. While strictly-speaking falling under the UMIC cluster, China appears in the top three net-importers with an RTB surplus of 1788 million ton (Mt) in 2022, compared to 2701 Mt for the United States and 1437 Mt for Japan (see appendix, Table A. 2). At the same time, the United States and China also stand out with the two largest amounts of Domestic Value Added: 3.2 and 3.4 trillion US$, respectively.

Looking at Figure 6, it appears that many other countries enjoy considerable returns while net-importing resources from the rest of the world. We will discuss the evidence for this below.

Figure 6: Comparing RTB, RMC, and Domestic Value Added (1992–2022)



Another qualification to the classic EUE contention is that some LICs and LMICs also net-import RMEs (together 33 percent of all net-importer countries, covering 27 percent of the total population, see appendix, Table A. 1). However, net-importing LICs typically have a much lower (positive) RTBs: 16.1 Mt on average compared to 270 Mt for the average HIC (a 1 to 16.8 ratio), even when accounting for the difference in their population size (a 1 to 5.6 ratio). Moreover, LICs do not benefit from being net-importers in the same way as HICs do: LICs earn 2.5 million US$ Domestic Value Added on average compared to 265 million US$ for the average HIC—a 1 to 106 ratio (Table A. 1). Clearly, unequal ecological exchange should not be assessed purely on whether a country has a positive or negative RTB. While some LICs also net-import RMEs, the economic returns differ. We will summarize the evidence for this below.

Turning now to net-exporting side (RTB<0), LICs and LMICs consist of 50 percent of all net-exporter countries, covering 33 percent of the net-exporter countries' total population (see appendix, Table A. 1). These economies match with the classic EUE thesis that relatively poorer countries are drained by the rest of the world. However, this thesis also needs to be qualified further, as several HICs also net-export RMEs (together 15 percent of all net-exporter countries, and 4 percent of their total population). These include Australia (as top net-exporter country), Canada and Chile, with RTB deficits of -1775 Mt, -958 Mt and -673 Mt in 2022 (see appendix, Table A. 2). However, unlike the typical periphery net-exporters, these HICs are not in a "dependent relationship": they are able to uphold net-exports of RMEs while maintaining high levels of returns: 299, 399, and 66 million US$ Domestic Value Added for Australia, Canada, and Chile. More generally, HICs benefit much more from being net-exporters than LICs, with an average value-added of 132 million US$ for the average HIC and 7.6 million for the average LIC—a 1 to 17 ratio.

Finally, India, which we took out of the LMIC cluster, stands out with an RTB deficit of -553 Mt, which is much higher than the -103 Mt average for that cluster (see appendix, Table A. 2). India also benefits economically much more than its LMIC counterparts with 482 million US$ value-added compared to an average of 26 million US$ for the LMIC cluster. China's case is also exceptional, going from a net-exporter to net-importer status (from negative to positive RTB), as well as experiencing fast rising footprints (RMC) per capita.

Correlation (absolute) RTB and Domestic Value Added

As mentioned, from Figure 6 we get a sense that the further away a country stands from balanced RTB (RTB=0), the greater the Domestic Value Added. The United States, China, Japan, Germany, and so on are obvious cases with considerable value-added and large (positive) RTB surplus (largest net-imports) (see appendix, Table A 2). India, Russia, Brazil, Australia, and Canada represent cases with considerable value-added but large (negative) RTB deficit (largest net-exports) (Table A 2). The more a country exploits the environment, either in one's own territory or someone else's, the more value-added it claims.

A test of this hypothesis reveals a significant positive relationship between absolute RTB and value-added (see appendix, Figure B. 1). The linear regression model, $y = 0.86*x - 21.47$, indicates that increases in RTB are associated with higher amounts of value-added ($R = 0.8$). The coefficient of determination ($R^2 = 0.65$) suggests that 65 percent of the variability in value-added can be explained by changes in RTB, with a highly significant p-value ($< 2e-16$), confirming the robustness of this relationship. This analysis underscores the critical role of RTB, either in terms of surplus or deficit, in influencing value-added. The more a country net-imports (large positive RTB) or net-exports (large negative RTB), the greater its value-added.

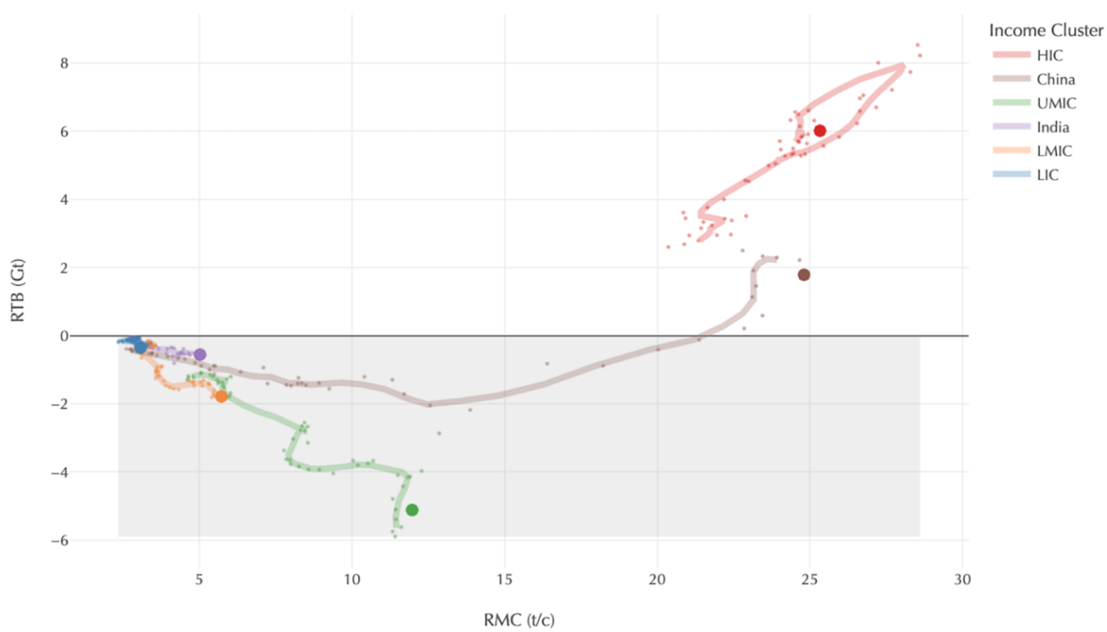
Importantly, a low RTB (balanced trade) can occur with either small or large imports and exports. This means we can't directly infer how countries near a net trade balance utilize both domestic and foreign resources. To investigate this, we correlated absolute RTB with Raw Material Equivalents of Exports to see if countries with low trade balances also tend to have low trade flows, indicating less integration into the world economy. The correlation is indeed very strong (R = 0.79, see appendix, Figure B. 2). This strengthens our conclusion that the more a country exploits environmental resources, domestically or abroad, the more value-added it tends to claim.

Historical Trajectories

The country-based linear start-and-endpoint trajectories in Figure 6 make it harder to see the general patterns. Clustering the countries makes it possible to incorporate earlier years and interpolate the data to show a general trend. In Figure 7, time is plotted as dots, so that they form a trajectory over time from 1970 to 2022. We interpolate the years using a 10-year moving average, and we indicate the final year (2022) with a larger marker.

As in Figure 3, Figure 7 shows that, on average, HICs were able to achieve high RMC levels by draining other countries through positive RTBs. In contrast, low RMCs and negative RTBs persist for LICs, India and LMICs. UMICs have increased their RMCs while being increasingly drained (negative RTBs), except for China. The graph therefore does not add information to what we already have, except that the trajectories (and their ups and downs) become visible. In general, we see that all clusters increase their footprints per capita over time, but that there are huge inequalities (as indicated also in Table 2). However, HICs saw a return to lower RTB and RMC levels since the 2007/08 global financial crisis. We also see China's role change from a net-exporter to a net-importer country (as indicated also in Figure 3).

Figure 7: Historical Trajectories (1970–2022)



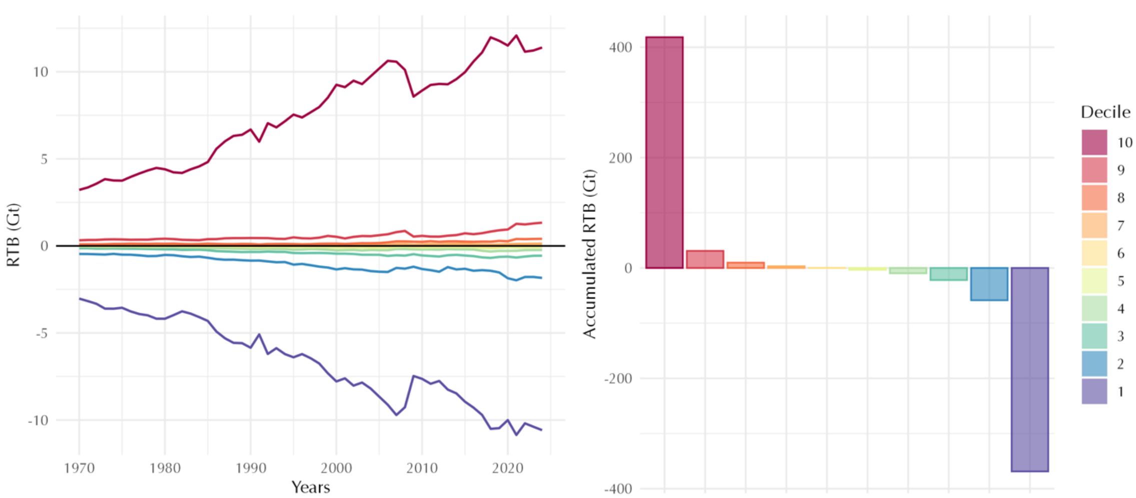
Decile Clustering

As explained in 2.6, we now introduce a decile-based clustering in line with Theis and their colleagues (2024) who argued for identifying significant exporters and importers before applying an income-based clustering. Pre-imposed income clusters conceal wide and overlapping ranges, as shown in Table 2. As a final way of presenting the data, we calculate each country's average RTBs for the entire period and then organize that by decile. The graphs are otherwise like Figure 3. This approach avoids pre-imposed categories (LIC, LMIC, etc., or "North" and "South"). The original method shown in Figure 3 and Figure 5 is akin to analyzing how different teams perform in a relay race, rather than the individual performance of each runner. The new method proposed here is akin to comparing the relative speed of runners irrespective of the team they are in, and then re-clustering those runners into deciles.

This is interesting because it reveals that net-imports and net-exports occur mostly in extreme deciles, not so much in the middle range, as we can see in Figure 8. Using the relay race analogy, there are a few fast runners and a few slow runners, and the majority runs at average speed. Looked at this way, the amounts of net-imports and net-exports are even more extreme: from +9.8 Gt at the top and -8.5 Gt at the bottom in 2024 (compared to +6.3 Gt for HICs and -5.1 Gt for UMICs).

Our analysis reveals that countries tend to remain within their respective deciles for some time. Notably, high-income countries (HICs) consistently appear in the top net-importing decile (see appendix, Table A. 3), aligning with classic EUE arguments. If trends persist some other countries will eventually join or replace countries the deciles. Interestingly, looking at Figure 7, China seems on a path towards joining the top (net-importing) decile. However, its historical average means that it remains part of the bottom (net-exporting) decile (Table A. 3).

Figure 8: Decile Clustering (1970–2024)



Contrary to a classic interpretation of EUE, low-income countries (LICs) do not consistently occupy the bottom decile. The bottom decile is much more mixed in terms of income clusters, but we do not see LICs in there. Also, some HICs are there, but these are the expected cases: Australia, Canada, Chile, and Saudi Arabia. It is important to note that LICs do not appear in the most net-exporting cluster because in absolute terms, other countries export much greater amounts. However, we know that relative to domestic extraction, the exports of net-exporting LICs are significant.

Underpaid

What makes EUE unequal? To explore this question, we calculate the monetary compensation per unit of biophysical resources exported, or Domestic Value Added per unit of RME, by dividing value-added with exports of RME (see appendix, Table A. 4). For example, HIC's monetary compensation amounts to 1100.9 $/t and LIC's to 183.8 $/t. In 2022, the average LIC must therefore export 6 tons of RME to earn what the average HIC earns on 1 ton (1100.9 divided by 183.8). LMIC (including India) must export 5.1 ton and UMIC (including China) 2.5 ton (Table A. 4).

However, we know that net-importing (or -exporting) clusters can include net-exporter (or -importer) countries, we can further categorize by focusing only on comparing net-exporting LICs and net-importing HICs. We find that net-exporting LICs must export 12.7 tons to earn what net-importing HICs earn on one ton (see appendix, Table A. 4).

Finally, we can also apply this logic to the above decile clustering. The bottom (net-exporting) decile has a slightly lower value-added, and a much larger tonnage of export compared to the top (net-importing) decile (see appendix, Table A. 5). This means that the bottom decile must export 7.63 tons of RME to earn what the top decile earns on 1 ton. Zooming further in on the poorest countries within the bottom decile—Egypt, Iran, Ukraine, and India (see appendix, Table A. 3)—we find EUE to be even more "unequal." These LMICs must export 14 tons to earn what the top earns on 1 ton. This suggests the need for a combined approach to assessing how "unequal" EUE is, using deciles as well as income clusters.

Conclusions

From 1970 to 2024, global resource extraction soared from 31 to 106 gigatons, with about 30 percent steadily used for traded goods. This extraction is marked by inequalities and has become a zero-sum game: greater resource allocation to the centers reduces resource availability for the peripheries, a phenomenon supported by empirical research on ecological unequal exchange.

Adding to the evidence, we found deeply uneven patterns of resource consumption. In 2022, LICs, LMICs, and India averaged 3.1, 7.3, and 5.0 tons per capita, while UMICs, HICs, and China hit 11.6, 24.7, and 24.8. Since 1992, all groups saw per capita increases, but LICs the least (16 percent) and China the most (290 percent). HICs form the only cluster with accumulated net imports, totaling 290 Gt from 1970 to 2024. All other groups were net exporters, with LICs exporting a total of 9.6 Gt. The gap between net-importing and net-exporting countries becomes starker when sorted by RTB deciles, showing 400 Gt accumulated by the top decile and 331 Gt drained from the bottom.

This increasing body of knowledge debunks the notion of "green capitalism" or "ecological modernization," which claims that economic growth can "decouple" from resource usage. Instead, a consumption-based analysis reveals that as their wealth increases, HICs rely more on international trade rather than domestic extraction. Over time, their RMC per capita exceeds their DMC per capita because they import products that require more resources than are directly incorporated within them. Meanwhile, the other income clusters provide raw materials, energy, land, and water, resulting in significant gains for the HICs who can avoid the costs and impacts of domestic production. These studies suggest that ecological unequal exchange is a fundamental feature of global capitalism.

Our paper adds important supplements and enhancements to existing evidence of ecological unequal exchange. First, while LICs have the smallest net exports among income groups, their drains are considerable when compared to domestic extraction. Over time, LICs consumed 13.3 percent less raw materials than they extracted, with the rest going to global markets. Meanwhile, HICs used 24.1 percent more than they extracted, relying on imports to cover the gap. We argue that such a relative measure is important in discussions about local implications of ecological unequal exchange than the more commonly used absolute measures.

Second, the classic EUE argument claims that HICs benefit by draining resources from the rest of the world. While most net importers are indeed HICs and UMICs (66 percent), some HICs are also net exporters (15 percent). However, these HICs are not dependent; they capture over 17 times the value-added captured by net-exporting LICs. Conversely, some LICs are also net importers, but they capture just 1/106th of the value-added that net importing HICs do.

These important distinctions suggest that ecological unequal exchange arises more from structural differences than from the types of commodities traded. HICs benefit more from both net-importing and net-exporting compared to LICs. We find a significant positive relationship between absolute RTB and value-added ($R = 0.8$), meaning the more a country exploits the environment, whether domestically or abroad, the more value-added it captures.

Strengthening this conclusion, we found a strong positive correlation between net trade balance and the size of trade flows, indicating that countries with near-zero net trade balances also have low import/export flows ($R = 0.79$). Countries more integrated into global trade thus tend to exploit domestic or foreign environments more and gain in value-added. In other words, highly integrated countries rarely maintain a balanced trade position (where imports and exports are roughly equal).

Given humanity's reliance on finite natural resources, systemic extraction to satisfy the material demands of a wealthy minority deprives the rest of the world. This alone makes ecological unequal exchange "unequal." Moreover, countries in the lower-income clusters are drained and underpaid, reinforcing long-term patterns of uneven development. Our estimates reveal that in 2022, the average LIC must export 6 tons of RME to earn what an HIC earns on one ton. More strikingly, a net-exporting LIC must export 12.7 tons to match the income from one ton in a net-importing HIC.

Traditional trade accounts depict a simple exchange of money for resources, but both material and monetary gains flow in the same direction. Our paper supports this and adds the nuance that the HICs can also benefit from net-exporting RMEs—increasing both their monetary gains and per capita consumption levels. Several LICs also net-import RMEs but fail to gain in the same way.

Future research should investigate these inequalities by considering the direction of the trade flows (e.g., ratios of exports from LICs to HICs). This could shed light on further inequalities driven by price differences (Köhler 1998; Ricci 2023). Moreover, ecological unequal exchange research could benefit from the original unequal exchange theory, and vice versa (Brolin 2007; Ricci 2023; Olk 2024; Theis et al. 2024). The unequal exchange theory explains why periphery exports are cheaper and why their prices are low compared to their value (socially necessary labor-time). Unequal exchange occurs when privileged buyers get underpriced commodities (price < value), and impoverished buyers overpay (price > value). Wage disparities, in turn, drive ecological unequal exchange (Emmanuel 1972), favoring extractive sectors in peripheries (Warlenius 2016). These sectors, marked by imbalances, low value-added, and debt, perpetuate cheap resource drains. Although ecological unequal exchange didn’t originate from this theory, future research would benefit from their connections.

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Appendices

Appendix A. Additional Tables

Table A. 1: Net-importer and net-exporter income clusters (2022), showing net-importer (with RTB>0) and -exporter clusters (RTB<0); relative size of the income clusters in each category (based on number of countries and population sizes); and their average RTBs and Domestic Value Added.

	Income cluster	Share of countries (%)	Share of population (%)	Mean RTB (Million ton)	Mean DVA (Million US$)
Net-importer countries and clusters	Low	10%	5%	16.1	2.5
	Lower middle	23%	22%	50.8	16.8
	Upper middle	14%	5%	21.8	40.2
	High	52%	28%	270.0	265.0
	China	1%	39%	1788.3	3424.3
Net-exporter countries and clusters	Low	21%	12%	-25.3	7.6
	Lower middle	29%	22%	-102.6	26.1
	Upper middle	34%	28%	-183.8	65.4
	High	15%	4%	-305.7	132.0
	India	1%	33%	-553.1	481.9

Table A. 2: Top net-importer and net-exporter countries (2022), showing top net-importer (with RTB>0) and -exporter countries (RTB<0); their income clusters; and their RTBs, RMCs and Domestic Value Added.

	Country	Cluster	RTB (Mt)	RMC (t/c)	DVA (Million US$)
Top net-importers	United States of America	H	2701	31.80	3184
	China	CHN	1788	24.81	3424
	Japan	H	1437	17.66	819
	Germany	H	985	23.51	934
	South Korea	H	658	23.59	456
	Italy	H	532	15.72	417
	United Kingdom	H	518	17.02	563
	Netherlands	H	398	31.58	290
	France	H	396	16.46	518
	Belgium	H	337	43.34	160
Top net-exporters	Indonesia	UM	-458	7.66	225
	South Africa	UM	-475	6.21	73
	Iran	LM	-476	6.27	114
	Egypt	LM	-553	4.24	57
	India	IND	-553	5.02	482
	Chile	H	-673	17.95	66
	Canada	H	-958	41.15	399
	Brazil	UM	-1248	17.29	255
	Russia	UM	-1248	13.54	428
	Australia	H	-1775	34.07	299

Table A. 3: Top and bottom deciles, showing which countries (and their income cluster) belong to the top and bottom deciles.

Countries in top decile:		Countries in bottom decile:	
Country	Cluster	Country	Cluster
Austria	H	Australia	H
Belgium	H	Brazil	UM
France	H	Canada	H
Germany	H	Chile	H
Hong Kong. SAR	H	China	CHN
Israel	H	Egypt	LM
Italy	H	India	IND
Japan	H	Indonesia	UM
Netherlands	H	Iran	LM
Singapore	H	Kazakhstan	UM
South Korea	H	Peru	UM
Spain	H	Russia	UM
Switzerland	H	Saudi Arabia	H
United Kingdom	H	South Africa	UM
United States of America	H	Ukraine	LM

Table A. 4: Exports units needed to match HIC unit earnings (2022). India is recombined with the LMIC cluster and China with the UMIC cluster. The monetary compensation per unit of biophysical resources exported, or Domestic Value Added per unit of RME, is calculated by dividing value-added with exports of RME. The last column represents how many units of raw material equivalent (RME) the different income clusters would need to export in order to earn what the HIC cluster earns on selling one unit of RME. The two final rows focus on net-exporting LICs and net-importing HICs.

Income cluster	DVA (Billion US$)	Exports (Gt, in RME)	DVA per unit of RME ($/t)	Export units needed to match HIC unit earnings
Low	154	0.84	184	5.99
Lower middle, plus India	1412	6.56	215	5.11
Upper middle, plus China	5733	12.89	445	2.48
High	11576	10.51	1101	1.00
Net-exporting “Low”	136	0.77	176	12.66
Net-importing “High	9806	4.39	2233	1.00

Table A. 5: Exports units needed to match top decile unit earnings (2022). As in Table A.4, but applied to decile clusters instead of income clusters.

Decile	DVA (Billion US$)	Exports (Gt, in RME)	DVA per unit of RME ($/t)	Export units needed to match top unit earnings
Top (net-importers)	8617	3.22	2678	1.00
Bottom (net-exporters)	6250	17.81	351	7.63
Bottom (net-exporters & LMIC)	682	3.58	191	14.06

Appendix B. Correlation Graphs

Figure B. 1: **Correlation (absolute) RTB and Domestic Value Added.**

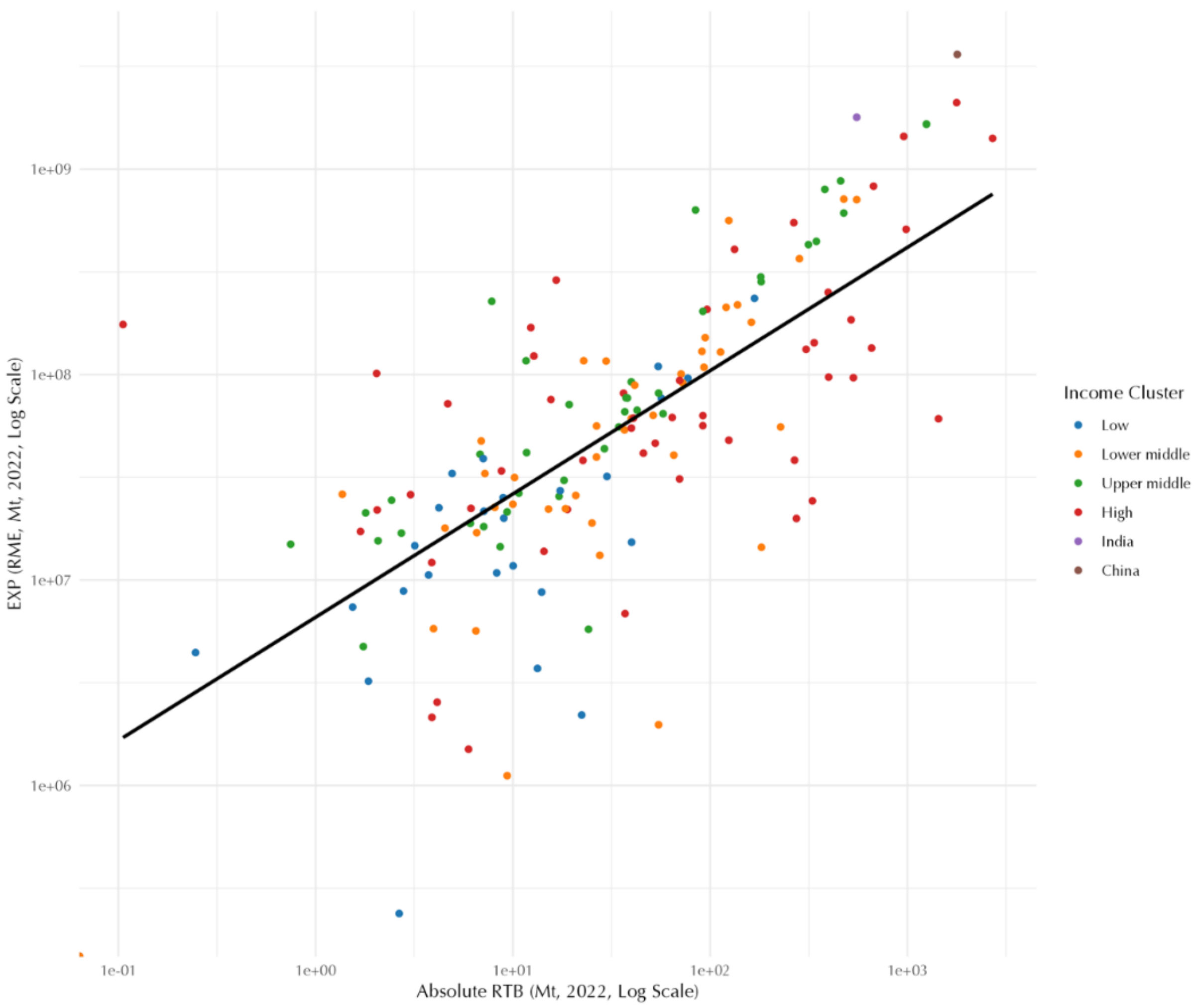

Figure B. 2: **Correlation between (absolute) RTB and EXP$_{RME}$.**