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TOWARDS A THEORY OF ECOLOGICALLY UNEQUAL EXCHANGE (EUE) AS A MULTI-TIERED HIERARCHY:

Investigating the interdependence of global and domestic environmental inequalities to explain China's rise to power

Luca Tausch, Jeffrey Althouse[1]

ABSTRACT

The theory of ecologically unequal exchange (EUE) suggests that there exists an asymmetric transfer of biophysical resources from the periphery to the core. Despite ample evidence demonstrating this fact, the theory fails to account for the complex role of the semi-periphery, or how global (inter-country) and domestic (intra-country) environmental inequalities between regions are connected. To fill this gap, we rely on an environmentally extended multi-regional input-output (EEMRIO) model to provide empirical evidence for China's involvement in global (G-EUE) and domestic (D-EUE) ecologically unequal exchange from 1987 to 2017. While being a net exporter of energy to all income groups, we show that China is a net exporter of land, labour, and materials to the core, but a net importer of land, labour, and materials from the periphery and the semi-periphery. On the domestic level, we show that the wealthy East Coast zone is the only net importer of embodied energy and TiVA, while all other economic zones are net exporters of embodied energy to the East Coast zone. While China continues to be exploited by the core, it has fuelled its ascent in the world-system by creating its own peripheries from which it extracts natural resources, as well as by creating extractive peripheries within its borders. Our results suggest the need to move beyond a simple core-periphery dichotomy when studying the world ecological system: EUE arises through a multi-tiered hierarchy that depends on uneven biophysical flows between regions both domestically and globally.

[1] Luca Tausch and Jeffrey Althouse: Université Sorbonne Paris Nord.
Corresponding author: Luca Tausch, luca.tausch@edu.univ-paris.fr.

Towards a theory of ecologically unequal exchange (EUE) as a multi-tiered hierarchy:

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Luca Tausch[1] & Jeffrey Althouse[2]

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Abstract: *The theory of ecologically unequal exchange (EUE) suggests that there exists an asymmetric transfer of biophysical resources from the periphery to the core. Despite ample evidence demonstrating this fact, the theory fails to account for the complex role of the semi-periphery, or how global (inter-country) and domestic (intra-country) environmental inequalities between regions are connected. To fill this gap, we rely on an environmentally extended multi-regional input-output (EEMRIO) model to provide empirical evidence for China's involvement in global (G-EUE) and domestic (D-EUE) ecologically unequal exchange from 1987 to 2017. While being a net exporter of energy to all income groups, we show that China is a net exporter of land, labour, and materials to the core, but a net importer of land, labour, and materials from the periphery and the semi-periphery. On the domestic level, we show that the wealthy East Coast zone is the only net importer of embodied energy and TiVA, while all other economic zones are net exporters of embodied energy to the East Coast zone. While China continues to be exploited by the core, it has fuelled its ascent in the world-system by creating its own peripheries from which it extracts natural resources, as well as by creating extractive peripheries within its borders. Our results suggest the need to move beyond a simple core-periphery dichotomy when studying the world ecological system: EUE arises through a multi-tiered hierarchy that depends on uneven biophysical flows between regions both domestically and globally.*

Keywords: Ecologically unequal exchange, China, Embodied trade flows, Environmentally extended multi-regional input-output analysis, Inter- and Intra-Country Inequality, International Trade, Structural Decomposition Analysis

JEL Codes: Q56, Q57

[1] Corresponding author (luca.tausch@edu.univ-paris.fr); Université Sorbonne Paris Nord
[2] Université Sorbonne Paris Nord

1. Introduction

While the human origins of the present environmental crisis are undeniable, it would be misguided to attribute the same level of responsibility to all of humanity. Those regions that have historically contributed the most to the global stock of carbon emissions and environmental degradation continue to accumulate the vast majority of the global economic, social and material surplus. In doing so, they tend to displace much of the associated environmental burdens to those that have historically been the most socially and economically marginalized (Muradian & Martinez-Alier, 2001) and remain today the most vulnerable to deteriorating environmental conditions, including the effects of climate change.

The rapidly devolving ecological crisis must therefore be viewed as both a cause and consequence of the profound imbalances of power that structure the global social fabric. Such a finding presents a profound conundrum for orthodox theories of trade and development, which have traditionally suggested that open borders and free exchange of capital, goods and services would promote growth, sustainability and equality. This perspective neglects the material and energetic dependencies of economic growth (Haberl et al., 2020; Parrique et al., 2019), the displaced biophysical and social harms associated with "green" growth policies (Althouse et al., 2020; Sovacool, 2021), the historical persistence with which resources and labour are transferred from regions with low to high social, economic, legal and military power (Dorninger et al., 2021; Frey et al., 2019; Infante-Amate & Krausmann, 2019; Magalhães et al., 2019), and the irreversibility of continued social and ecological devastation.

This highlights the need for greater theoretical and empirical research that takes into account the biophysical foundations of industrial production, as well as the inequalities embedded in multiple levels of the world system. In particular, it begs for a greater understanding of the role of power in shaping and restructuring socio-ecological relations.

As such, researchers are increasingly turning to the theory of ecologically unequal exchange (EUE) to better comprehend the link between unequal power relations, disparities in socioeconomic development and ecological degradation at the level of the world-system (Frey et al., 2019; Hornborg, 1998, 2009, 2011, 2019; Jorgenson, 2009, 2016a). The theory of ecologically unequal exchange (EUE) posits that global trade privileges the asymmetric net flow of biophysical resources and labour time from low-income ("peripheral") to high-income ("core") countries (Dorninger et al., 2021).

EUE suggests that peripheral countries are characterised by specialization in low value-added sectors (e.g., primary commodity extraction and processing) that are also the most resource- and pollution-intensive. Meanwhile, high-income (core) countries capture the final stages of value-added production (e.g., high-end technologies and finished products, marketing and financial services, and ownership rents) which imply low domestic impacts and high returns (Althouse & Svartzman, 2022). In this way, the core maintains domestic environmental quality, high standards of living, and access to peripheral environments by capturing the largest share of global purchasing power. Meanwhile, peripheries are driven to suffer the increasing degradation of their local environments, weak access to necessary material and financial resources, and the disintegration of community well-being as they continue to export materials, energy and labour to the core (Rice, 2007).

Despite growing empirical evidence for EUE and its impressive explanatory potential for understanding the present global predicament (Dorninger et al., 2021; Hickel et al., 2022), the theory has been criticised on numerous levels. Some have argued, for example, that EUE theory does not capture the diverse experiences of countries that do not easily fit into the mould of "core" or "periphery" (e.g., China) (Frame, 2019). This can leave research blind to the particular role(s) of the semi-periphery as both purveyors of resources to the core, and as dominant regional powers, in their own right (El Tinay, 2024). Moreover, EUE tends to miss how inequalities between regions *domestically* can reinforce harmful environmental dynamics on the national level. As a result, EUE theory does not make an explicit link between global processes and domestic environmental power struggles (Malm, 2012). Yet globally uneven exchanges might be better understood as the *symptom* of interdependent dynamics taking place at multiple levels - both within and between countries (Althouse & Svartzman, 2022; Costantini et al., 2022).

This paper attempts to respond to some of these arguments by building upon previous work that has studied the uneven flow of resources and labour between countries using environmentally-extended multi-regional input-output (EEMRIO) (Dorninger et al., 2021). First, we add a new regional category to EUE studies - the semi-periphery - in order to study the ambiguous role of middle-income countries in the core-periphery divide. We do so by accounting for the material and resource flows between the rest of the world and China from 1990 - 2015 for a new perspective on global ecologically unequal exchanges ("G-EUE").

Second, we delve deeper into the internal experience of China in order to highlight the presence of domestic ecologically unequal exchange ("D-EUE") as an important dynamic to explain the accumulation dynamics within rapidly emerging semi-peripheral countries. We test this by measuring trade in value added (TiVA) and embodied energy flows via EEMRIO and structural decomposition analysis (SDA) for four major Chinese regions from 1987-2017. This allows us to pinpoint the key dynamics that drive EUE between regions, domestically.

Finally, we attempt to understand more how domestic and global EUE might be related in order to provide additional support to EUE theory by relating our empirical findings to a historical analysis of Chinese internal politics and foreign relations.

This methodology allows for a more nuanced and complex understanding of EUE. Our study suggests that EUE should be understood as the outcome of a multi-tiered hierarchy that links peripheral, semi-peripheral and core regions, both internally and externally. Semi-peripheral states, like China, appear to have risen to global prominence not only by supplying the core with key manufacturing and resource exports, but by generating the conditions to appropriate resources from other peripheral states across the world. This dynamic allows a small export-oriented domestic elite to capture the economic and material surplus by exploiting peripheral zones domestically. These findings both support and expand upon EUE theory, particularly by identifying the ways that EUE manifests between and within (semi-peripheral) countries.

The rest of this paper is structured as follows: Section 2 briefly presents EUE as an important theory for understanding present global imbalances, yet which suffers from a number of ambiguities. Section 3 presents our methodology for overcoming these ambiguities, in particular by using an EEMRIO to study the interdependent processes driving environmental inequalities at the global level, and domestically, within China. Section 4 briefly presents the case study of China to understand the stark rise in regional inequalities over the last decades within the country. Section 5 then presents the results of our study of China and its role in global and domestic ecologically unequal exchanges (G-EUE and D-EUE). Section 6 discusses the results, drawing the connections between G-EUE and D-EUE, as well as the curious role of the semi-periphery within EUE theory. Section 7 then summarizes and concludes, drawing additional insights about the limits of "green" development within a hierarchical world system.

2. (Re)Considering ecologically unequal exchange

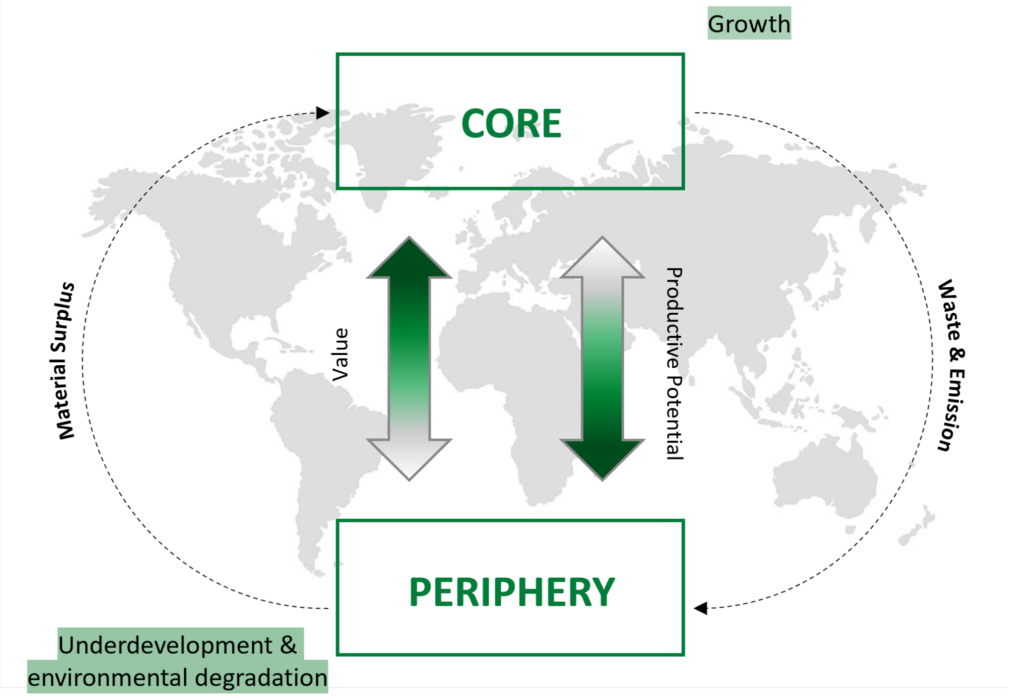
Background of the theory of ecologically unequal exchange

The theory of ecologically unequal exchange emerged from the work of Latin American structuralists, and dependency and world-system theorists, who maintained that the colonial hegemony persisted well into the post-colonial period (Amin, 1974; Frank, 1966, 1979; Furtado, 1959, 1971; Prebish, 1950; Wallerstein, 1974, 1983). From this perspective, the "unequal exchange" of labour (Amin, 1974; Emmanuel, 1972), alongside the forceful appropriation of - and "cheap" access to - natural resources (Moore, 2015), has not only been critical for the economic development of colonial powers, but stands at the root of the present global inequalities (Hickel et al., 2022; Hornborg & Jorgensen, 2010; Ross, 2017).

EUE posits that there is a systematic and asymmetric transfer of biophysical resources (including energy, land, labour and materials) from low-income ("periphery") to high-income ("core") countries. It argues that countries with economic, technological, and military power are uniquely positioned to gain access to a greater share of the world's material and energetic resources (Dorninger et al., 2021).This greater access facilitates the core's over-utilisation of environmental space, and concentrates socio-environmental impacts (destruction of ecosystems, loss of biodiversity, pollution, etc.) in the periphery (Hornborg & Martinez-Alier, 2016). Such a pattern tends to exacerbate existing social disparities in the periphery and entrenches their position as an exporter of environmentally harmful commodities, while simultaneously suppressing their own resource use and material consumption (Rice, 2007).

As shown in Figure 1, EUE theory is based partially on the thermodynamic foundations of industrial production (Georgescu-Roegen, 1971), wherein each step along the production chain implies an irreversible transformation of energy and matter from a state of higher productive potential (low entropy), to lower productive potential (high entropy). Those sectors at the beginning of global production chains (e.g., extractive sectors and materials processing) are systematically valued less than processes further along the chain, yet are by far the most polluting and environmentally damaging (IRP, 2020).

Figure 1: Ecologically Unequal Exchange: Material and productive inequalities between the Core and Periphery



From this perspective, environmental inequalities can be seen as a near-inevitable consequence of the global capitalist mode of production: core countries are characterised by their export of high-value commodities (with low remaining productive potential) and services, while the periphery exports low value commodities, including raw materials and energy resources, at lower world market prices (with high remaining productive potential). The periphery must therefore export far more of its own raw materials (e.g., iron ore) to access the core's finished goods (e.g., cars).

In essence, the "mindless cybernetics of the market" (Hornborg, 2016, p. 154) deprive the poorest and most vulnerable regions of socio-economic and biophysical stability by concentrating the bulk of the world's purchasing power and biophysical potential within the wealthiest and most technologically advanced regions. This vicious cycle enables the core to further accumulate productive infrastructure, while the periphery is left to suffer underdevelopment and environmental degradation, cleaving an ever-widening gap between the core and the periphery.

Empirical evidence and literature gaps

The theoretical propositions put forward by EUE are increasingly supported by empirical evidence. This includes studies documenting the long history of colonial plunder in peripheral sites (Magalhães et al., 2019), as well as regional (Infante-Amate et al., 2022; Infante-Amate & Krausmann, 2019) and more global analyses (Hickel et al., 2022). Further research has looked at more specific indicators to explain the presence of EUE, including a country's position within global value chains (Althouse et al., 2021), inflows of FDI (Doytch & Ashraf, 2022; Jorgenson, 2016b), foreign indebtedness and subsequent structural adjustment programs (Culas, 2006; Shandra et al., 2011). Still other empirical analyses have focused on how EUE opens peripheral countries up to worse environmental outcomes in terms of biodiversity (Jorgenson, 2006, 2012; Prell & Sun, 2015; Shandra et al., 2009; Tasmim et al., 2022), water quality (Fitzgerald & Auerbach, 2016; Shandra et al., 2008) and forest-cover (Shandra et al., 2020; J. M. Sommer et al., 2021, 2023). Importantly, these empirical analyses consistently find evidence for a systematic transfer of resources and labour from the periphery to the core, and a worsening of peripheral environments over time.

Despite the overwhelming evidence for the structural presence of EUE in the world-system, there are several aspects inherent to the theory that remain either understudied or fully overlooked in empirical tests of EUE. First, EUE is primarily concerned with the asymmetric transfer from the periphery to the core, essentially ignoring the important role of the semi-periphery. This core-periphery dichotomy misses the complex environmental dynamics of the semi-periphery, especially the burgeoning role of China, India and other regional powers (Frame, 2019; Prell et al., 2014; Tasmim et al., 2022). In particular, the semi-periphery appears to play multiple roles in the world-system (El Tinay, 2024), that can both challenge and feed into the traditional core-periphery split.

Secondly, despite the fact that prominent scholars of EUE argue that ecologically unequal exchange between countries is often preceded by core-periphery-like areas within nations (Bunker, 1984; Martinez-Alier et al., 2016), most empirical analyses testing EUE theory have been conducted at the regional or global level. While this offers important insights into the global dynamics, this singular focus on the interactions between nation-states misses important *domestic* asymmetries that can only be captured by an analysis of biophysical and social patterns within nation-states (Godar et al., 2015; Piñero et al., 2020).[3]

Finally, the connections between global and domestic EUE remain elusive. While the theory of EUE, as proposed by (Hornborg, 1998, 2019), makes precise descriptive and predictive statements about the flow of resources and their compensation, research has not been able to clearly specify how global and local processes, policies and regulations impact the dynamics of ecologically unequal exchange.[4] EUE theory can therefore be bolstered by quantitative and qualitative methods that can suggest its driving forces and causal mechanisms. This includes more granular analyses via decomposition methods that can determine the contribution of different factors to the emergence of EUE (Hickel et al., 2022), beyond simply market exchanges and technological advancements (Althouse et al., 2023; Jiborn et al., 2018).

In order to fill in these research gaps, we propose a case study of China. Numerous studies have already pointed out China's special place within the framework of EUE, including its "semi-peripheral" role, exhibiting both core and peripheral characteristics (Frame, 2019; Prell et al., 2014; Yu et al., 2014). Importantly, Dorninger et al. (2021) further found that China and India are the only two world regions that were not net exporters of all types of embodied resources towards high-income countries between 1990 and 2015.[5] There is also an increasingly large literature, discussing China's presence in the periphery, in particular related to the exploitation of natural resources in those regions (Abegunrin & Manyeruke, 2020; M. Li, 2021; Meng et al., 2018).

Previous analyses on China's coal-fired economic development, as well as its energy-intensive industrial structure, imply that it is not only especially susceptible to the dynamics of ecologically unequal exchange due to its export-intensive trade relations with the core, but that its rapid growth has implied a massive redistribution of environmental burdens both internally (to domestic resource-exporting regions) and externally (to other peripheries across Asia, Africa and Latin America) (Malm, 2012; Svartzman & Althouse, 2020). Lastly, there is a growing literature assessing China's intra-country asymmetries in economic and ecological endowment, providing a large empirical base for our study (Zhuang et al., 2022, 2023). Nevertheless, only a limited number of studies has assessed these asymmetries within the framework of

[3] While a number of studies increasingly look at environmental inequalities resulting from China's internal domestic trade dynamics, these have generally been limited by study time-frame (Wang et al., 2022; Zhuang et al., 2022, 2022)

[4] Though not specifically studied here, EUE theory can also be criticized for lacking a more specific understanding of how institutional power, including power in financial networks and the global monetary architecture, relate to uneven ecological outcomes (Althouse & Svartzman, 2022).

[5] More specifically, China and India were shown to be net importers of embodied land. China was also found to have the largest accumulated net trade in value added amongst all regions over the study period (Dorninger et al., 2021).

ecologically unequal exchange (W. Zhang et al., 2018; Y. Zhang et al., 2018), and none have empirically connected China's domestic environmental inequalities to structural forces driving EUE at the global level.

3. Materials and Method

We propose a three-fold quantitative case study of China's involvement in global and domestic ecologically unequal exchange between 1987 and 2017. The analysis is conducted using environmentally extended multi-regional input-output (EEMRIO) tables to study both domestic and global resource flows. As indicated above, we put forward the terms "G-EUE" (Global EUE) to refer to ecologically unequal exchange *between* nation-states at the level of the world system, and "D-EUE" (Domestic EUE) to refer to ecologically unequal exchange taking place *within* the nation-state – in this case, between regions within China.

To determine China's involvement in global, G-EUE, we rely on a global EEMRIO, assessing the biophysical net trade of China from 1990-2015 in the resource flows "raw material equivalents'' (Schaffartzik et al., 2015), "embodied energy" (B. Chen et al., 2018), "embodied land" (Bruckner et al., 2015), and "embodied labour" (Alsamawi et al., 2014). Furthermore, we decide to integrate the value-added deriving from international trade over time using TiVA (Dorninger et al., 2021; Johnson & Noguera, 2012; Timmer et al., 2014) in constant international 2010 US-American dollars (USD).

To provide a full account of China's involvement in G-EUE, we choose to measure its biophysical net trade with three different country groupings, including a core, semi-periphery, and periphery grouping. Our country grouping builds on previous analyses by Dorninger et al. (2021) and Hickel et al. (2022), such that 'high income' (HI) countries map onto core, 'upper middle income' (UMI) map onto semi-periphery, while 'lower-middle income' and 'low income' countries represent the periphery (see Appendix 1, Table 1.1 for country groupings).[6]

Secondly, to determine China's involvement in D-EUE, we rely on a series of regional EEMRIO tables measuring China's net trade of embodied energy and TiVA between the four primary regions of China from 1987-2017. These four regions are subsequently mapped according to population size and income levels to represent the domestic core (Eastern China Zone), semi-periphery (North Zone) and periphery (Western Zone and Central Zone).[7]

[6] Note that we chose to include India in the periphery, which gives the Periphery a much larger population size. However, given India's relatively small biophysical net trade with China, this choice does not significantly affect the results of this study. See Appendix 1, Table 1.1 for details on the country groupings.

[7] As indicated below and in Appendix 1, Table 1.2 and 1.3, we choose to diverge slightly from the official economic zones to achieve even population groupings among four zones. A subsequent analysis revealed that this alternative regional grouping tends to underestimate how ecological inequalities evolve between the regions in China, when compared to the grouping based on "official" economic zones (e.g., Western Zone, East Coast Zone, Central Zone).

Finally, to determine the mechanisms behind China's involvement in D-EUE, we employ a structural decomposition analysis (SDA) (Dietzenbacher & Los, 1998; Miller & Blair, 2009) in order to assess the driving forces of China's regional energy consumption between 1997 and 2015.

Environmental input-output analysis

Input-output (IO) analysis was initially conceived by Nobel Prize Laureate Wassily Leontief (1936) to analyse the interdependence of industries within and across economies (Miller & Blair, 2009). Multi-Regional Input-Output analysis (MRIO) allows for the study not only the interdependence between sectors within a country, but between sectors of different regions or countries, including the interdependence of global supply chains and the accounting for multilateral trade (Wiedmann et al., 2011).

EEMRIO models extend these monetary input-output tables by including biophysical and non-monetary flows such as land, labour, energy, water or materials, allowing us to create consumption-based pressure indicators that can capture the displacement effects of international and inter-regional trade (Wiedmann & Lenzen, 2018). Thus, EEMRIO analysis has proven to be highly effective for studying the distribution of human footprints, tracking material flows within global supply chains, and determining the environmental responsibility attributed to producers and consumers in a globalized world (Guilhoto, 2021; Peters, 2008).

For the present study, suppose there are *n* sectors and *m* regions. r and s represent exporting and importing regions, while i and j represent exporting and importing sectors, respectively.[8] Following the literature on IOA, bold capital and minor letters denote matrices and column vectors respectively, the prime indicates transposition, hats (^) indicate the diagonalisation of vectors, $\hat{\mathbf{x}}^{-1}$ denotes matrix inversion of $\hat{\mathbf{x}}$. Let **Z** (*nm* × *nm*) denote the matrix of interindustry trade, where each element z_{ij}^{rs} represents the interindustry sales of sector i in region r, consumed by sector j in region s. Furthermore, let **x** (*nm* × 1) represent the gross output vector for which its element x_i^r represent the output of sector i in region r, while x_i^s represent the output of sector i in region s ; **f** (*nm* × 1) represents final demand vector with its element f_i^{rs} indicating the products of sector i from region r consumed finally in region s; **v** denotes the vector of total value added, where each element v_j^s (1 × *nm*) represents the total value added for industry j in region s.[9] **A** = $\mathbf{Z}\hat{\mathbf{x}}^{-1}$ (*nm* × *nm*) represents the matrix of direct technical input coefficients, where each element $a_{ij}^{rs} = z_{ij}^{rs}/x_i^s$ represents the direct input requirement from sector i in region r per unit of total output for sector j in region s. Total output (**x**) equals total sales for intermediary production plus total final demand (**f**), namely that **x = Zi + f**. Total inputs (**x′**) equal total intermediary purchases plus

[8] Note that for the global analysis m, r and s refer to different countries, while for the national study, m, r and s represent different regions of China.

[9] Note here, for both regional and global analysis, the total value-added vector is composed of compensation of employees, depreciation of fixed capital, profits plus taxes minus subsidies.

value-added, namely **x´= i´Z + v**. Note here that **i** is a summation vector such that **Zi** represents the row sums of the transaction matrix, while **i´Z** represents the column sums of the transaction matrix. Hence, we can estimate the accounting balance of the demand driven monetary MRIO table as

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f} = \mathbf{Lf} \qquad (1)$$

Note that **I** represents the identity matrix, while **L =** $(\mathbf{I} - \mathbf{A})^{-1}$ is the 'Leontief inverse', whose element l_{ij}^{rs} denotes the direct and indirect consumption of products of sector i in region r needed by sector j in region s to produce on unit of industry output of final demand.

For both global and national analysis, the present study applies an environmental extension, recording non-monetary flow associated with economic activities. Denoting the production-based environmental extension vector as **q**, where each element q_j^s represents the total physical input of sector j in region s, we can estimate the consumption-based accounts by $\mathbf{C} = \hat{\mathbf{e}}\mathbf{L}\hat{\mathbf{f}}$. Note that $\mathbf{e} = \mathbf{q}\hat{\mathbf{x}}^{-1}$ is an intensity vector where each element e_i^r represents the direct physical input ***q*** of industry i in region r per unit of total output of industry i in region r. Let further denote element c_{ij}^{rs} the amount of non-monetary flows ***q*** that are embodied in the total upstream inputs from industry i in region r, required to satisfy the final demand for the output of industry j in region s. Hence, in our IO framework consumption-based accounts (**C**) add up to the total production-based accounts (E) such that all non-monetary flows are allocated to final demand without any double-counting involved. Furthermore, we use the TiVA concept to assess the monetary footprints. The TiVA indicator (**B**) is calculated by **B =** $\hat{\mathbf{p}}\mathbf{L}\hat{\mathbf{f}}$, where $\mathbf{p} = \mathbf{v}\hat{\mathbf{x}}^{-1}$ is an intensity vector for which each element p_i^r represents the amount of value added (***v***) of industry i in region r per unit of total output of industry i in region r. As above, b_{ij}^{rs} denotes the amount of value added ***v*** that is embodied in the total upstream inputs from industry i in region r, required to satisfy the final demand for the output of industry j in region s. b_{ij}^{rs} can thus be interpreted as an indicator showing how much of final demand expenditure for the output of industry j in region s is directly and indirectly captured by the production activity of industry i. Considering the basic IO accounting identity, the column sums of **B** summed to a scalar adds up to final demand (***f*** **=i´B**), while the sum of the row elements as a scalar adds up to total value added (***v*** **= Bi**). Hence, for the global analysis global value added (***v***) adds up to global final demand (***f***) and for the national analysis, national value added (***v***) adds up to national final demand (***f***); no double counting involved.[10]

[10] Note that the national IO tables include international exports and imports as inputs, which make the table slightly different from the international tables. For the first part of the analysis, we chose to ignore exports and imports and calculate the final demand vector based on the assumption that x = Zi + f. This allows us to fulfil the accounting identity that total v = y, in line with the global analysis. However, for the SDA, we choose to include international exports. Unfortunately, the MRIO tables are not clearly labelled or in Chinese such that there remains uncertainty on how imports are expressed in the table. We choose to subtract imports from the FD vector and thus from gross

Structural Decomposition Analysis

While input-output analysis is useful for describing the flows of energy and materials or analysing the displacement of environmental impacts, it is unable to provide any indication as to the forces behind these phenomena. To this end, decomposition techniques have been put forward to study the driving factors of changes in some chosen aggregate indicator over time (Dietzenbacher & Los, 1998; R. E. Miller & Blair, 2009). The most popular decomposition techniques are the index composition analysis (IDA) and the structural decomposition analysis (SDA). These techniques are already widely used to study driving factors behind energy consumption and emission changes (Feng et al., 2012; D. Guan et al., 2009; Peters et al., 2007; H. Zhang & Lahr, 2014).

SDA's are often used in conjunction with MRIO analyses in order to better track the driving forces behind economic phenomena and distinguish a wide range of final demand and production effects, as well as direct and indirect effects along the entire supply chain (R. E. Miller & Blair, 2009). In this study, the application of a SDA allows us both to substantiate the claims and predictions made by this study, and provides additional empirical grounding for EUE by providing evidence for its driving forces (Althouse et al. 2023). As Hickel et al. (2022, p. 10) point out, in order to empirically test for the presence of EUE, it is necessary to conduct an SDA-type analysis to determine the role of different potential variables in driving environmental inequalities. Here, the SDA provides a more granular picture of the factors driving energy consumption between regions in China by disaggregating the total change in regional energy consumption into the contributions made by its various components (Guan et al., 2009; Zhang & Lahr, 2014).

For the purpose of this study, we closely follow the decomposition approach presented by Dietzenbacher et al. (2000) and Zhang & Lahr (2014). As previously noted, let *m* represent the number of regions and *n* the number of industries, we have the following variables:

E: aggregated energy consumption (scalar),
e: vector with q_i^r as energy input per unit of output of industry i in region r (*nm* × 1 vector),
I: identity matrix (*nm* × *nm* matrix),
L: Leontief-inverse matrix:matrix of total input requirements (*nm* × *nm*), **L** = $(\mathbf{I} - \mathbf{A})^{-1}$,
f: vector with f_i^r giving the final demand for output of industry i in region r (*mn* × 1 vector),

output, such that v = y. While this can be considered a slight modification of the original MRIO tables, it was ensured that the difference between the two final demand vectors is minimal, hence any limitation associated with this modification can be reasonably accepted.

Knowing that energy consumption can be defined as $E = \hat{\mathbf{e}}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{f}} = \hat{\mathbf{e}}\mathbf{L}\hat{\mathbf{f}}$, we can denote its change, with indices as time indicators, where 0 represents 1997 and 1 represents 2015 as

$$\frac{E_1}{E_0} = \frac{\mathbf{e}_1\mathbf{L}_1\mathbf{f}_1}{\mathbf{e}_0\mathbf{L}_0\mathbf{f}_0} = \frac{\mathbf{e}_1\mathbf{L}_1\mathbf{f}_1}{\mathbf{e}_0\mathbf{L}_1\mathbf{f}_1} \times \frac{\mathbf{e}_0\mathbf{L}_1\mathbf{f}_1}{\mathbf{e}_0\mathbf{L}_0\mathbf{f}_1} \times \frac{\mathbf{e}_0\mathbf{L}_0\mathbf{f}_1}{\mathbf{e}_0\mathbf{L}_0\mathbf{f}_0} \quad (2)$$

where the first factor indicates the effect of changes in energy requirements (**e**), the second denotes the effect of changes in the production structure (**L**), and the last factor denotes the effect of changes in final demand (**f**). Note that here, we only represent the left-to-right polar decomposition. In our analysis, we conduct both polar decompositions and use the geometric average of the corresponding elements of the two polar decompositions to obtain Fisher indices, which were then used to analyse the results. We follow Dietzenbacher et al. (2000) and Zhang & Lahr (2014) by decomposing the final two factors to analyse the effects of changing interregional trade. Consequently, we can rewrite the Leontief inverse as $\mathbf{L} = (\mathbf{I}-\mathbf{A})^{-1} = (\mathbf{I}-\mathbf{A}^* \circ \mathbf{T}^{\mathbf{A}})^{-1}$ and final demand as **f = Fh,** where ∘ denotes the Hadamard product (element-by-element multiplication of matrices).

$\mathbf{A}^*$**:** matrix constructed by stacking *m* identical *n* × *nm* matrices of aggregate intermediate inputs per unit of gross output by industry by region[11] (*nm* × *nm* matrix), $\forall r\colon [a^*] = \sum_{r=1}^{m} a_{ij}^{rs}$;

$\boldsymbol{T}^{\mathbf{A}}$**:** intermediate trade coefficients indicating the input shares of each region in aggregated inputs by industry by region (*nm* × *nm* matrix), $[t^{\mathrm{A}}]_{ij}^{rs} = a_{ij}^{rs}/[a^*]_{ij}^{rs}$, note that $\sum_{i=1}^{m} a_{ij}^{rs} = 1$;

F: matrix of final demands for each region of destination [*mn* × (*m* + 5)]. Element f_i^{rs} denotes the final demand for commodity i produced in r by region s; s = 1,...,m, m+1,...,m+5, where m+1 denotes the final demand to changes of urban consumption for commodity i produced in region r, m+2 denotes the final demand changes to changes of rural consumption for commodity i produced in region r, R+3 the final demand to changes of government expenditure for commodity i produced in region r, m+4 denotes the final demand to changes of capital investment[12] for commodity i produced in region r, R+4 denotes the export of commodity i produced in region r; note that **F** results from **f** = **Fh**, where **h** is the (R+5) × 1 summation vector consisting of ones and **f** thus represents the row sum vector of matrix **F**.

The final decomposition of aggregated energy consumption change can thus be written as

---

[11] Note that this explanation is taken from Zhang & Lahr (2014) who follow Dietzenbacher et al. (2000). In detail, it means aggregating the A matrix by sector, resulting in a n × nm matrix, which is then stacked identically below each other m times, resulting in a matrix of nm × nm.

[12] Note that capital investment here excludes changes in inventory.

$$\frac{E_1}{E_0} = (3) \times (4) \times (5) \times (6) \times (7)$$

$$\frac{\mathbf{e}_1 \mathbf{L}_1 \mathbf{f}_1}{\mathbf{e}_0 \mathbf{L}_1 \mathbf{f}_1} \quad (3)$$

$$= \frac{\mathbf{e}_0 \left(\mathbf{I} - \mathbf{A}^*{}_1 \circ \mathbf{T}^{\mathbf{A}}{}_1\right)^{-1} \mathbf{f}_1}{\mathbf{e}_0 (\mathbf{I} - \mathbf{A}^*{}_0 \circ \mathbf{T}^{\mathbf{A}}{}_1)^{-1} \mathbf{f}_1} \quad (4)$$

$$= \frac{\mathbf{e}_0 \left(\mathbf{I} - \mathbf{A}^*{}_\mathbf{0} \circ \mathbf{T}^{\mathbf{A}}{}_1\right)^{-1} \mathbf{f}_1}{\mathbf{e}_0 (\mathbf{I} - \mathbf{A}^*{}_\mathbf{0} \circ \mathbf{T}^{\mathbf{A}}{}_\mathbf{0})^{-1} \mathbf{f}_1} \quad (5)$$

$$= \frac{\mathbf{e}_0 \mathbf{L}_0 \mathbf{F}_1 \mathbf{h}}{\mathbf{e}_0 \mathbf{L}_0 \mathbf{F}_0 \mathbf{h}} \quad (6)$$

$$= \frac{\mathbf{e}_0 \mathbf{L}_0 \mathbf{f}_1}{\mathbf{e}_0 \mathbf{L}_0 \mathbf{f}_0} \quad (7)$$

Therefore, energy consumption changes are decomposed into five partial effects.

$\Delta\mathbf{e}$: effect of changes in energy requirements per unit of output (Eq. 3)

$\Delta\mathbf{A}^*$: effect of changes in the production structure (Eq. 4)

$\Delta\mathbf{T}^{\mathrm{A}}$: productivity effect of changed regional trade structures of interm. inputs (Eq. 5)

$\Delta\mathbf{F}$: effect of changes in final demand composition (Eq. 6)

$\Delta\mathbf{f}$: effect of changes in total final demand (Eq. 7)

We further decide to employ an additive decomposition method to decompose final demand into its various components (H. Zhang & Lahr, 2014). This allows us to assess in more detail, what parts of final demand (e.g., exports, capital investment, or government expenditure) have been driving regional energy consumption and thus the domestic ecologically unequal exchange. It provides yet another, more granulated assessment of the driving forces of EUE on a regional level, allowing us to move substantially beyond what is common within the literature on EUE (see Appendix 2 for details on the method and Appendix 4 on the associated limitations with MRIO analysis).

Data

For the first part of the empirical analysis – assessing China's ecologically unequal exchange with the rest of the world (G-EUE) – we rely on a dataset compiled by Dorninger et al. (2021) in their most recent time-series study on global ecologically unequal exchange. The dataset was constructed using the global MRIO database Full Eora (Lenzen et al., 2012, 2013) and entails data for biophysical trade flows between

173 countries, accounting for more than 99% of the global population in 2015. China's exports, imports and domestic trade[13] were extracted from the dataset and China's total exports of four biophysical resources (raw material equivalents, energy, land, and labour) were subtracted from all imports, calculating the net trade of these resources, as well as TiVA with each country or income group. Positive net trade indicates Chinese net appropriation of biophysical resources (or TiVA) from the respective region, while negative net trade indicates net provision of biophysical resources (or TiVA) from China to the respective country or income group.

For the national analysis - assessing ecologically unequal exchange between regions within China (D-EUE) - we rely on Chinese regional MRIO tables for the years 1987 (Ichimura & Wang, 2003), 1997, 2002, 2007 (S. T. Li, 2016; S. T. Li et al., 2010; Xu & Li, 2008), 2012, 2015 and 2017 (Y. Guan et al., 2021; Shan et al., 2018, 2020; H. Zheng et al., 2020).[14] The MRIO tables are extended by energy data sourced from the CEADS website and available by sector and region for each year from 1997 to 2017 (Y. Guan et al., 2021; Shan et al., 2018, 2020; H. Zheng et al., 2020). Similar to the global analysis, positive net trade indicates the region's net appropriation of biophysical resources, while negative net trade indicates net provision of the respective region.

4. Case Study: China

Following its economic reforms starting in 1978, China has experienced unprecedented economic growth, industrialisation and rapid urbanisation. This astounding social transformation coincided with a massive rural exodus towards urban centers, and almost 800 million people exiting poverty (J. Chen, 2007). China's GDP increased from $149.54 in 1978 to $1.34 trillion in 2001. After joining the WTO in 2001, its GDP increased exponentially to $17.73 trillion in 2021, with an average annual growth rate of 8.7% in the same period (Bruton et al., 2021; World Bank, 2023c). The nation's rapid economic development was largely led by its rapidly increasing international trade with an export volume increase from $44.93 billion USD in 1990 to $272.05 billion in 2001 and $3.55 trillion in 2021(World Bank, 2023b).

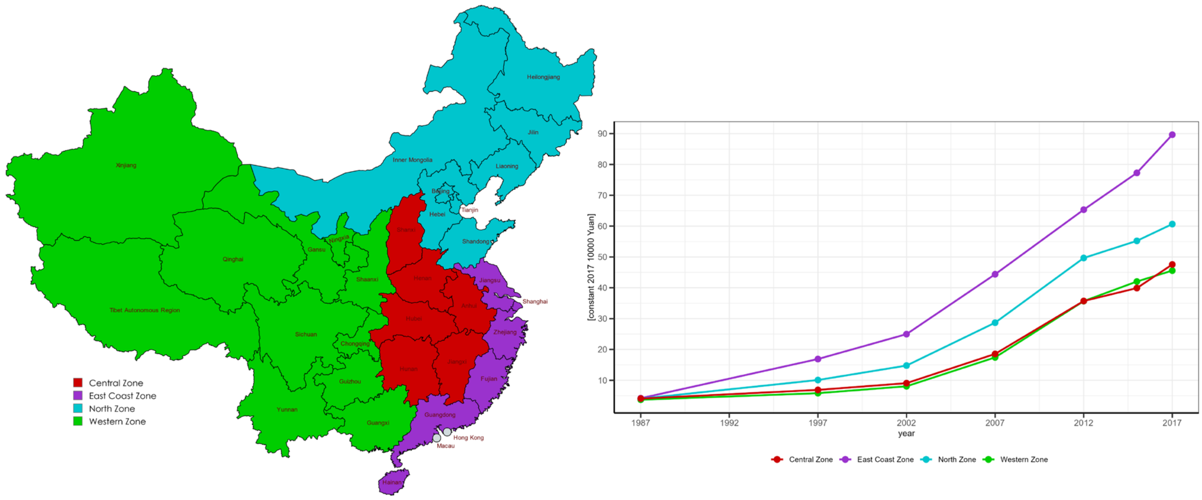
China's increased presence in the world system, alongside successful government plans to attract foreign capital, including an undervalued Yuan have led to large amounts of foreign-direct investment (FDI) inflows, including a surge in foreign-invested enterprises (FIE), concentrated in the Southern and Eastern parts, marking China's rise to one of the largest manufacturers and exporters in the world (Malm, 2012; Svartzman & Althouse, 2020; Yu et al., 2014; Y. Zhang et al., 2023).

[13] Note that "domestic" refers to monetary and biophysical flows between regions within China. For the global analysis, we include Taiwan, Hong Kong, and Macao in our classification of China. Hence, trade flows between these countries and China or within these countries were classified as "domestic" (see Appendix 1, Table 1.1 for further details on the country grouping).

[14] For details on the MRIO tables and their differences, see Appendix 1.

China’s rapid ascendance in the world-system has also substantially increased its consumption of natural resources, including the pollution of the local, national, and global environment. In 2001 China’s carbon emissions were nearly half that of the US. However, by 2006 it had overtaken the US as the world’s largest emitter of CO2, and now emits roughly twice as much (Muntean et al., 2018; World Bank, 2023a). It has been repeatedly noted that the increase in CO2 emissions has been largely driven by China’s substantial hunger for energy after 2001, which was mainly satisfied by coal (Ciccantell, 2019; Malm, 2012; Muradian et al., 2012). The country now consumes almost 50% of the world's coal and nearly 70% of the world’s primary energy (Svartzman & Althouse, 2020).

Figure 2: Four Chinese regions and their respective growth rates



Despite China’s impressive economic growth, the fruits of its economic expansion were shared highly unequally between the different regions within China, culminating in substantial domestic income inequalities. Figure 2 shows GDP per capita across four main economic zones of roughly equal population size from 1987 to 2017: Central Zone (SCZ), North Zone (NZ), East Coast Zone (ECZ) and Western Zone (WZ).[15] While this figure shows that the tide of income has risen for all economic zones, income disparity across the four regions increased substantially in recent years (excluding the similar trajectory of the Central Zone and the Western Zone). The ratio of GDP per capita between the richest zone (ECZ) and the poorest zones (WZ and CZ) almost doubled from 1.1 in 1987 to 1.9 in 2017.

This rise in regional economic disparities can be partly explained by China’s economic reforms, starting in 1978 (C. C. Fan, 1997; Y. Li & Wei, 2010), which divided China into distinct economic zones for national development (see Appendix 3, Figure 3.6) (State Council of China, 1986). The East Coast was supposed to develop export-oriented industries, foreign trade and be the target of FDI inflows and foreign-held companies.

[15] Note that our regional classifications diverges from the official classification, which divides China into three main zones. As explained in Appendix 1, it is likely that our results underestimate regional inequalities and thus the extent of ecologically unequal exchange between economic zones in China.

The massive expansion of transport infrastructure in China in the 1990s (Leung, 2010; McKay & Song, 2010), alongside the substantial increases in FDI inflows (D. Guan et al., 2018; Malm, 2012; Whalley & Xin, 2006; S. X. B. Zhao & Zhang, 2007) quickly transformed the East Coast from an agricultural backwater into a vibrant export center, enjoying sustained economic growth.

The North Zone - particularly the North East - is characterised by its historical reliance on both mineral resources and heavy industry, particularly coal, steal, petrochemicals and machinery. The North Zone was traditionally considered the industrial heartland of the country, but the dynamism of the region slowly deteriorated in the latter part of the 20th century, particularly after the restructuring of state-owned industries by a series of new legislation in the 1990s (Chung et al., 2009). While a new revitalization programme for the Northeast was launched in 2005, the region never quite regained its original prominence. GDP per capita in the region fell to below that of even the Central and Western Zones in the last five years (Zeping et al., 2021).

On the other hand, the Central Zone was largely led by its agriculture and energy industry, while the Western Zone was mainly characterized by animal husbandry and mineral exploitation (State Council of China, 1986). Development planning in these zones was nonetheless complemented with massive investments in infrastructure, particularly to supply produce to the rest of the country.

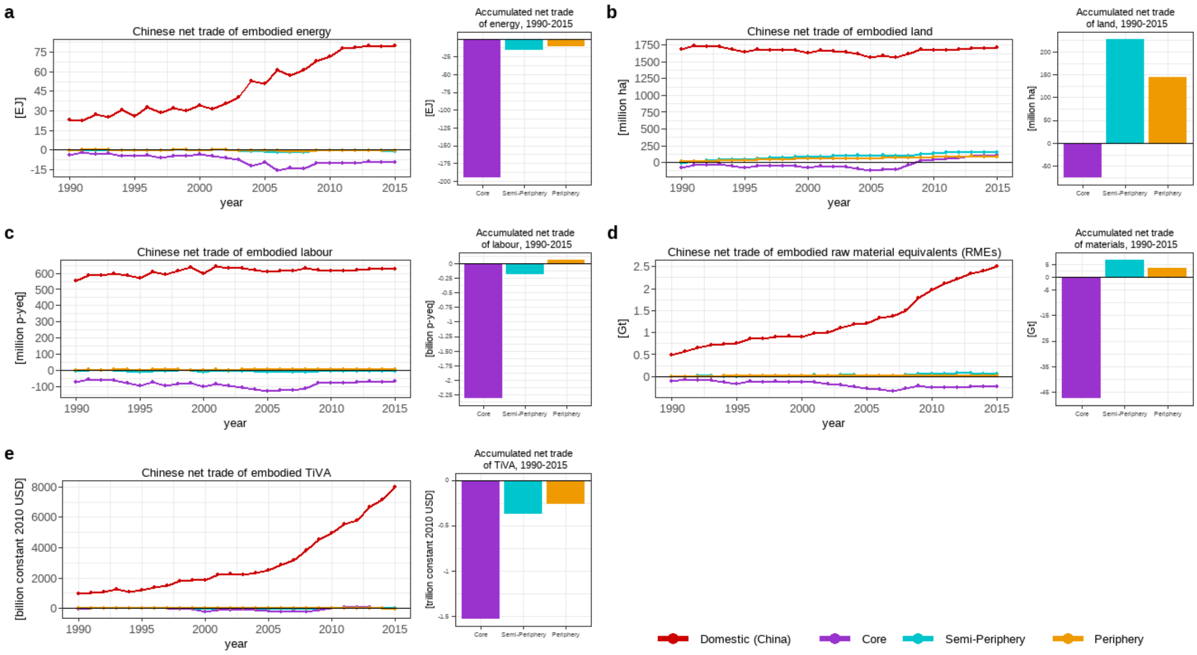
Consequently, the East Coast Zone, led by tax abatements, infrastructural investments and state funding became the growth pole of China with very few positive spillovers recorded to the other regions. Following the divergent income levels and the respective productive structures, we argue that the East Coast Zone can be described as the domestic core, while the North Zone corresponds roughly to the domestic semi-periphery and the Western Zone and Central Zone correspond to the domestic periphery.

A key factor of these regional inequalities - and the underdevelopment of peripheral regions - in China has been their relative endowment of natural resources and the unequal distribution of environmental impacts. Studies consistently note substantial asymmetries in energy consumption (J. Chen et al., 2017; Huang et al., 2021; B. Zhang et al., 2016), water and land usage (X. Fan et al., 2022; Guo et al., 2020; J. Liu et al., 2022; Long et al., 2022), as well as CO2 emissions (Wang et al., 2022; Wiedenhofer et al., 2017; H. Zheng et al., 2020; J. Zheng et al., 2019) between the different regions in China. In fact, W. Zhang et al. (2018) show that in 2012 almost 80% of consumption-based air-pollutant emissions of the richer regions were outsourced to poorer regions, while most of the value-added was retained within the richer areas. Moreover, Y. Zhang et al. (2018) show that embodied resources flew from resource-rich but economically-poor to resource-poor and economically-rich regions accompanied by regional underdevelopment in the resource-rich regions.

5. Results

5.1 Global Ecologically Unequal Exchange (G-EUE): Evaluating environmental inequalities between China and the rest of the world

Figure 3: China's Involvement in Global Ecologically Unequal Exchange (G-EUE) from 1990-2015: Chinese net trade and accumulated net trade position with the core, semi-periphery and periphery



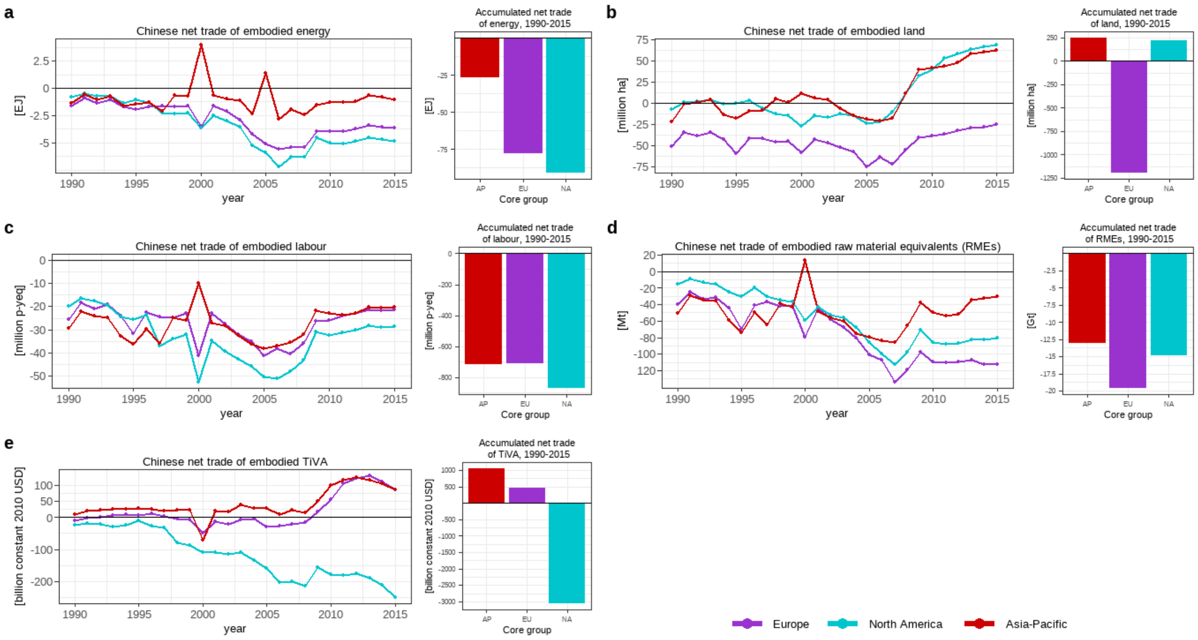
Note: China's net trade of resources with the three-level country-grouping over time and accumulated appropriation and supply as bar plots, 1990–2015. Top left: embodied energy [EJ]; top right: embodied land [billion ha]; middle left: embodied labour [million p-y_{eq}]; middle right: raw material equivalents (RMEs) [Gt]; and bottom left: trade in value added (TiVA) [bn constant 2010 USD]. Positive values represent a net appropriation of resources by China. Note also that China is removed from the accumulated bar plots for ease of reading the graphs.

To start, Figure 3 plots China's accumulated net trade with the three regional income groupings (core, periphery, and semi-periphery) over the period from 1990 to 2015. Across the embodied flows of energy, land, labour and raw materials, China's production-based footprint[16] (red line), namely the part of the embodied resource required for China's consumption provided and produced by China was significantly larger than their net trade with any of the five income regions. We can immediately observe that across all four embodied biophysical flows, the core was the largest net appropriator of resources from China. Most importantly, not only is the core a net appropriator of materials, energy, land, and labour from China, it simultaneously generates a monetary surplus from those net appropriations, being by far the largest net importer of embodied TiVA (58.8/a billion constant 2010 USD). Moreover, while

[16] Note that for the purpose of this analysis, we choose to diverge from the common definition of the term and refer to the production-based footprint as the part of China's energy consumption provided by China themselves. This definition excludes exports and solely includes net trade.

China is positioned as a net provider of energy (8.4 EJ/a) and TiVA (83.2/a billion constant 2010 USD) to all country groups, it is also a significant net importer of land (14.5 million ha/a) and materials (402.3 Mt/a) from both the semi-periphery and the periphery.

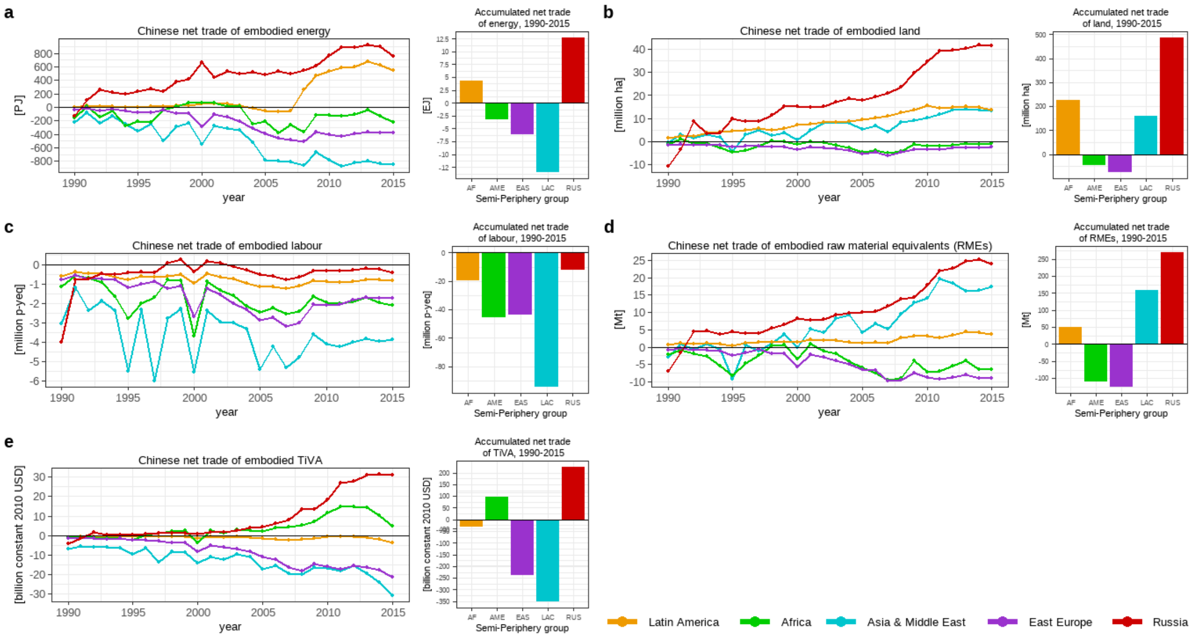
Figure 4: G-EUE between China and core countries 1990-2015: Chinese net trade and accumulated net trade position with respect to core regions



Note: China's net trade of resources with the core over time and accumulated appropriation and supply as bar plots, 1990–2015. Top left: embodied energy [EJ]; top right: embodied land [million ha]; middle left: embodied labour [million p-y_{eq}]; middle right: raw material equivalents (RMEs) [Mt]; and bottom left: trade in value added (TiVA) [bn constant 2010 USD]. Positive values represent a net appropriation of resources by China. Note also that China is removed from both time-series and the accumulated bar plots for ease of reading the graphs.

We further group net trade flows according to core, semi-periphery and periphery, by disaggregating each income grouping into various economic regions. This allows for a more detailed understanding of where resources and value flow between the different regions and China. As can be seen in Figure 4, we focus first on the core, which we divide into three main economic regions: Asia-Pacific (A-P), North America (NA), and Europe (EUR). The core grouping confirms the findings of the previous analysis: across all embodied biophysical flows, China remains a net provider to the core group over the entire period. The only exceptions being China's relatively small net appropriation of land from the Asian-Pacific (A-P) region (9.3 million ha/a) and North America (8.2 million ha/a), as well as the small net appropriation of TiVA from A-P (40.1 billion constant USD/a) and Europe (17.9 billion constant USD/a), particularly after 2010. This appropriation is largely due to the increase in net appropriation of land and TiVA by China after 2006. Such a finding is coherent with the general trend that China's net provision of physical resources to the core started to stagnate or slow down after 2006.

Figure 5: G-EUE between China and Semi-Peripheral countries 1990-2015: Chinese net trade and accumulated net trade position with respect to semi-peripheral regions

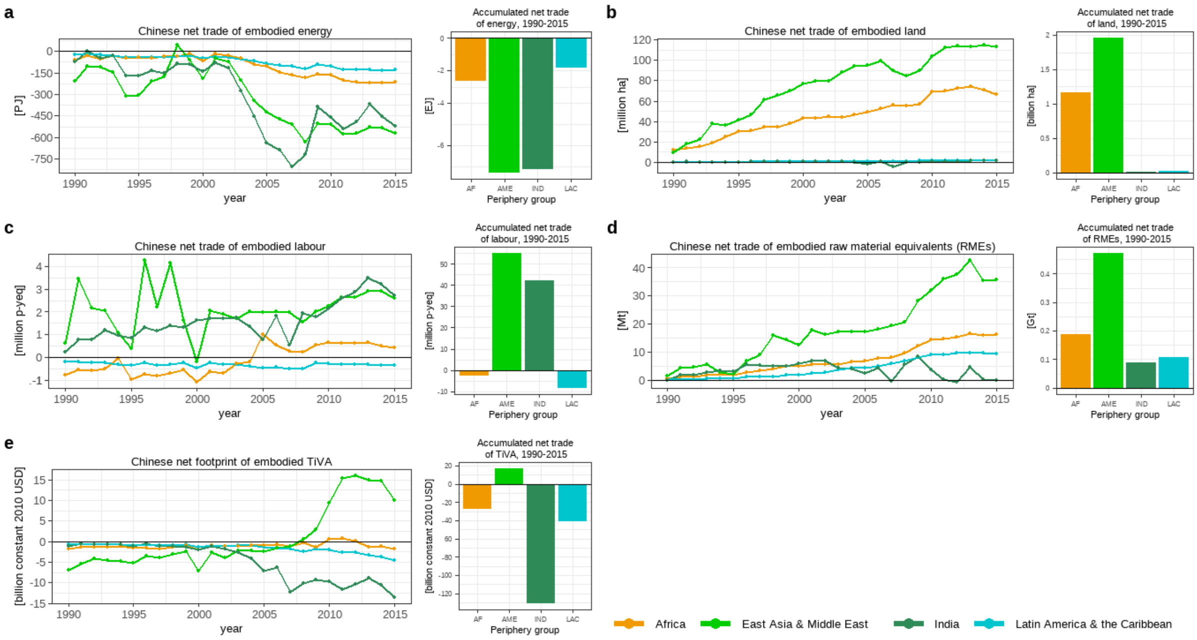


Note: China's net trade of resources with the semi-periphery over time and accumulated appropriation and supply as bar plots, 1990–2015. Top left: embodied energy [PJ]; top right: embodied land [million ha]; middle left: embodied labour [million p-y_{eq}]; middle right: raw material equivalents (RMEs) [Mt]; and bottom left: trade in value added (TiVA) [bn constant 2010 USD]. Positive values represent a net appropriation of resources by China. Note also that China is removed from both time-series and the accumulated bar plots for ease of reading the graphs.

Second, we analysed China's trade with the semi-periphery, characterized by upper-middle income and middle-income countries in Latin America, Africa, Asia and Middle East, Eastern Europe, and Russia. As can be seen in Figure 5, coherent with the ambiguous characteristics of the semi-periphery, China's biophysical net trade with the semi-periphery is more complex. Overall, our results indicate that China is a net importer of RMEs (18.4 Mt/a), land (33.6 million ha/a) and TiVA (12.3 million constant USD/a) from the semi-periphery, in particular from Russia (60.4%), Africa (12.2%), and Latin America (27.4%) all with substantial increases after 2001.[17] Note for example that between 1990-2001 net appropriation of land was 4.6 million ha/a compared to 17.2 million ha/a between 2001 and 2015, while for materials it increased from 1.6 Mt/a to 8.7 Mt/a for the same period. However, China is also an important exporter of embodied labour to other semi-peripheral countries. Interestingly, Asian and the Middle Eastern countries were the largest net appropriators of Chinese embodied energy, labour, and TiVA compared to other semi-peripheral countries.

[17] Percentages are based on accumulated net trade.

Figure 6: G-EUE between China and Peripheral countries 1990-2015: Chinese net trade and accumulated net trade position with respect to peripheral regions



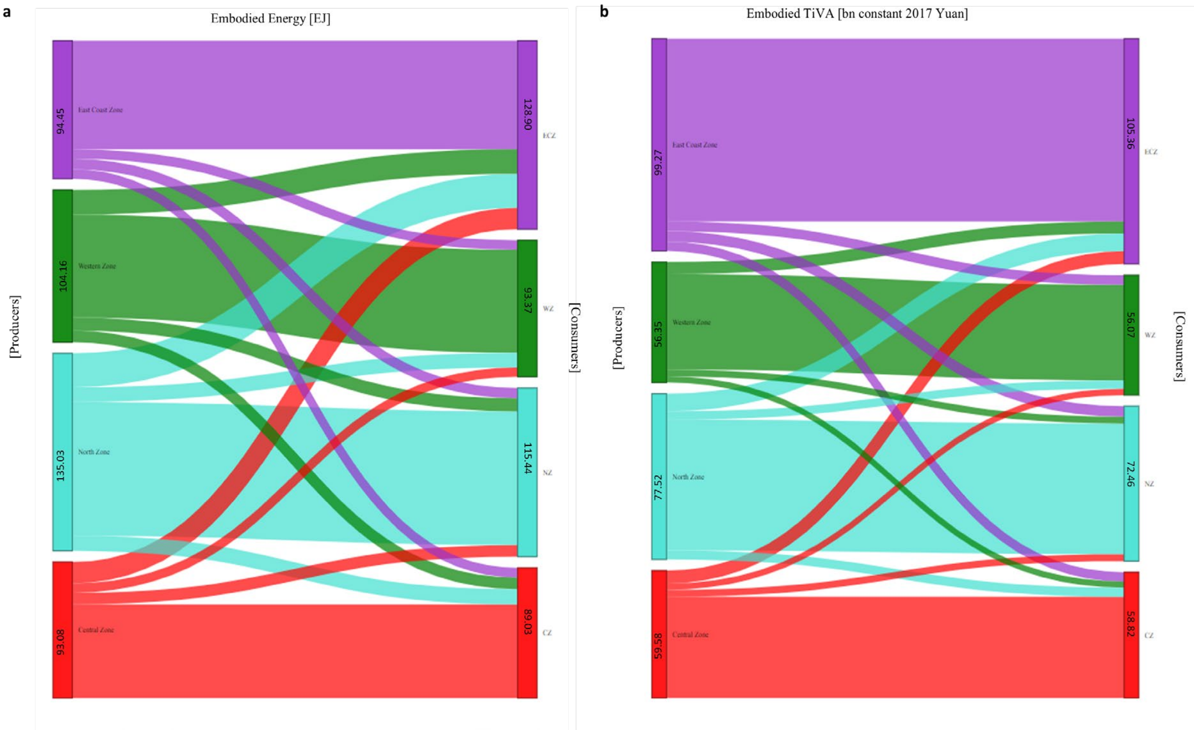
Note: China's net trade of resources with the periphery over time and accumulated appropriation and supply as bar plots, 1990–2015. Top left: embodied energy [EJ]; top right: embodied land [million ha]; middle left: embodied labour [million p-y_{eq}]; middle right: raw material equivalents (RMEs) [Mt]; and bottom left: trade in value added (TiVA) [bn constant 2010 USD]. Positive values represent a net appropriation of resources by China. Note also that China is removed from both time-series and the accumulated bar plots for ease of reading the graphs.

Last, we focused on the China's trade with peripheral (low-income) countries in Africa, East Asia & Middle East, Latin America & the Caribbean, and India (Figure 6). With respect to China's net trade with the periphery, it is clear that China is a net appropriator of embodied land (121.8 million ha/a), labour (3.7 million p-yeq/a) and materials (32.9 Mt/a) from the periphery. Importantly, this trend accelerated substantially over the analysed period. On the contrary, we can observe that for embodied energy, China remains a net exporter of embodied energy to the periphery over the entire period with a yearly 800 PJ/a provided to the periphery, confirming the findings above that China is a net exporter of embodied energy to all country groupings.

5.2 Domestic Ecologically Unequal Exchange (D-EUE): Evaluating environmental inequalities between regions within China

MRIO Analysis of Chinese Domestic Ecologically Unequal Exchange (D-EUE)

Figure 7: Exploring D-EUE between regions in China



Note: Sankey diagrams exhibiting accumulated production and consumption of embodied energy and TiVA in each economic zone (East Coast zone (ECZ), Western Zone (WZ), Central Zone (CZ), Central China (CC)) from 1987-2017. Flows represent the redistribution of resources through trade. Note that money (as consumer expenditures) and resources flow in opposite directions in trade relations, i.e., money flows from consumers to producers. However, embodied value added (TiVA) is aligned in the same direction as embodied resources (q).

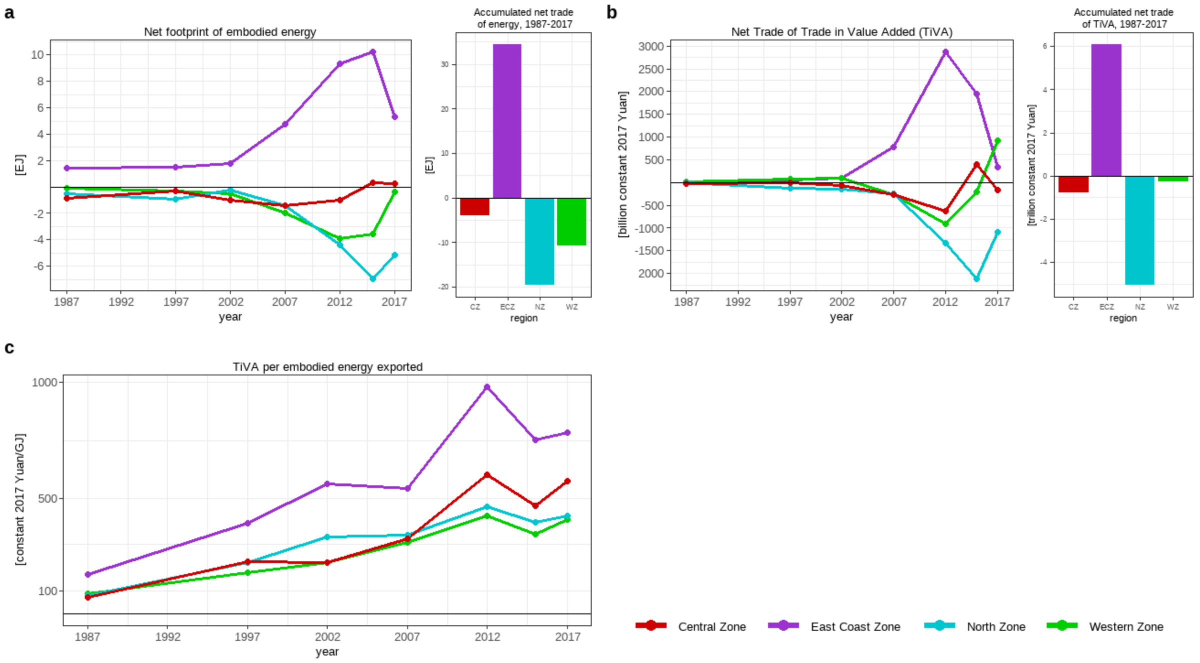
With respect to our analysis of domestic ecologically unequal exchange (D-EUE), we are able to see how China's semi-peripheral status, its bilateral trade of embodied biophysical resources with the rest of the world, and its growing economic power, relates to observable trends of environmental load displacement, domestically. We divide China into four major regions of roughly equal population size, corresponding broadly to the domestic core (Eastern China Zone), semi-periphery (North Zone) and periphery (Western Zone and Central Zone).[18] Our analysis shows that with respect to embodied energy, only the East Coast Zone (ECZ) used more resources from a consumption perspective than they provided through production, as their final demand was associated with energy requirements exceeding their domestic extraction by 34.45 EJ (see Figure 7 & Figure 8). The largest producer of embodied energy is the North Zone (135.03 EJ) which is also the largest net provider of

[18] As adhered to above, the classification is based on the population and income levels described in Appendix 1.

embodied energy with their domestic extraction exceeding their energy requirements by 20.59 EJ.

With respect to TiVA, we observe that only the ECZ is achieving a net monetary surplus (in terms of value-added), reaching 6.09 trillion Yuan over the study period. This is far above other Chinese regions, particularly the North Zone (CZ), which was a major net exporter of TiVA . Moreover, the ECZ was also the highest appropriator of value-added compared to the other economic zones, reaching 105.36 trillion Yuan versus 58.82, 72.46, and 56.07 trillion Yuan for the Central Zone, the North Zone and the Western Zone, respectively.

Figure 8: Domestic Ecologically Unequal Exchange (D-EUE) between regions in China



Note: Top left: Net trade of embodied energy over time, accumulated appropriation and supply as bar plots [in EJ]; top right: Net trade of embodied TiVA over time, accumulated appropriation and supply as bar plots [in million constant 2017 Yuan]; top left: TiVA per energy exported over time [constant 2017 Yuan/GJ]. Positive values represent net appropriation.

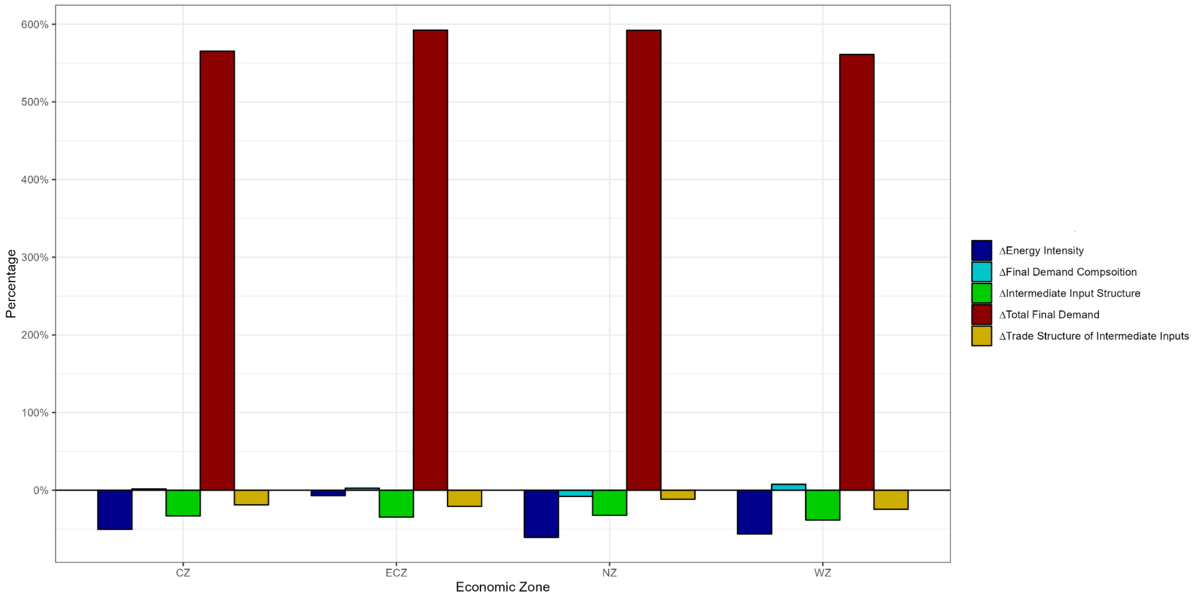
Given the results of our time-series analysis, we observe a substantial increase in disparities of embodied energy in net regional trade after 2002. While the ECZ was a net importer of just 1.57 EJ/a of embodied energy between 1987 and 2002, this number increased by a factor of almost 5, to 7.4 EJ/a, between 2007 and 2017. Similarly, while the net provision of embodied energy from the Western zone (WZ) was 0.3 EJ/a and 0.5 EJ/a for the Central zone (CZ) between 1987 and 2002, this rose to 2.5 EJ/a and 5.4 EJ/a respectively between 2007 and 2017. Note, however, that we can observe a convergence of both net embodied energy and net TiVA by 2017, in particular between the East Coast Zone and the Central and Western Zone.

The asymmetric flows between the economic zones of China becomes even more apparent when considering the net trade of embodied TiVA. While disparities between the regions are very small between 1987 and 2002, they rise to unprecedented heights between 2002 and 2015. We can also observe that between 2002 and 2017, the ECZ is the largest net appropriator of TiVA (1483.3 billion constant 2017 Yuan), appropriating about 84% of its value-added from the CZ. Similar to the net trade of embodied energy, we observe a convergence after 2012, with the Western zone even appropriating a higher share of Chinese value-added than the ECZ.

The asymmetry in the distribution of monetary value added becomes even more visible when analysing the value added per unit of exported embodied energy. Over the entire 30-year period, the ECZ gained on average double the amount of TiVA per energy unit embodied in exports than the rest of the countries combined.

Structrual Decomposition Analysis of Chinese energy inequality

Figure 9: Assessing the drivers of energy inequality between regions in China



We then attempt to understand the structural drivers of uneven ecological flows between regions using a Structural Decomposition Analysis (SDA). Our SDA shows that during the 18-year period, most of the increase in consumption-related energy use in all regions in China was due to rapidly rising final demand (Figure 9 above, and Table 1 below). Improvements in energy efficiency ($\Delta\mathbf{e}$) slightly offset the rapidly rising demand for energy in all regions. Interestingly enough, these energy efficiency improvements were by far the lowest in the ECZ (7%) compared to an average of 56% for the other three regions. Furthermore, changes in final demand composition ($\Delta\mathbf{F}$) had almost no effect on energy use in most regions. On the contrary, the changing structure of intermediate inputs ($\Delta\mathbf{A}^*$), as well as the changes in trade structure of intermediate inputs ($\Delta\mathbf{TA}$) reduced the rising trend of energy use in all regions by 35%

and 19% respectively. Nevertheless, these two effects were small compared to the effects of changes in final demand (Δ**f**).

Table 1: The role of drivers of unequal energy consumption in China

Economic Zone	Energy Consumption						Final Demand					
	Δ**e** (%)	Δ**A*** (%)	Δ**T**$^{\mathbf{A}}$ (%)	Δ**F** (%)	Δ**f** (%)	Total (%)	Δ**rc** (%)	Δ**uc** (%)	Δ**g** (%)	Δ**i** (%)	Δ**ex** (%)	Total (%)
ECZ	-7	-35	-21	3	592	533	9	57	15	76	108	265
WZ	-56	-38	-24	8	561	449	20	56	23	146	26	272
NZ	-61	-32	-12	-8	592	480	12	52	24	105	42	235
CZ	-50	-33	-19	2	565	465	17	58	20	152	20	267
China	-44	-35	-19	1	578	482	15	56	20	120	49	260

From the analysis above, it is evident that changes in final demand (Δ**f**) played a major role in driving up energy demand in all of the zones between 1997 and 2015. To investigate some of the reasons behind this, we take a closer look at the different categories of final demand by breaking it up into its five respective components: rural consumption (**rc**), urban consumption (**uc**), government expenditure (**g**), capital investment (**i**) and international exports (**ex**).

Figure 10: Breaking down the components of final demand in driving energy inequalities

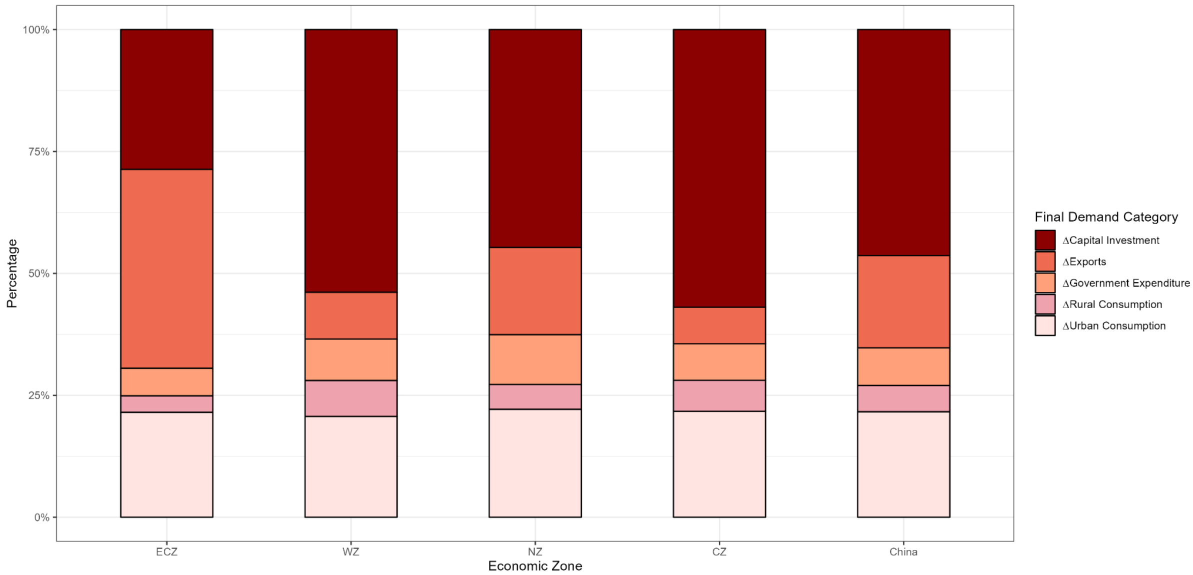


Figure 10 demonstrates the respective contributions of each final demand category to the change in intermediate energy use for the different income groups, including the national average. Overall, capital investment (**i**) played the most important role in raising intermediate energy use (46%). Furthermore, urban consumption (**uc**) (22%) and exports to the rest of the world (**ex**) (19%) were the other important drivers of intermediate energy use growth. On a national level, rural consumption (**rc**) and government expenditure (**g**) only played minor parts. It is noteworthy to mention that, with respect to regional differences, our results suggest that while exports were an almost negligible driver of energy consumption in the NZ (18%), CZ (7%) and the WZ (10%), they accounted for almost half of the final demand effect of the ECZ (41%). In fact, exports were the largest driver of total energy consumption, only in the ECZ. On a reverse note, we can retrieve that final demand contributions accounted for by capital investment were significantly more important for all the other regions as a driver of energy consumption. They accounted for more than 50% of the final demand effect for the WZ, CZ and NZ, while accounting for less than one-third of the final demand effect of the East Coast zone.

5.3 Summary of Results

To summarize, given China's semi-peripheral status in the world-system, we find its role within global (inter-country) EUE to be ambiguous, while its involvement in domestic (intra-country) EUE is indisputable. With respect to China's involvement in G-EUE, our results suggest that China is a net exporter of embodied energy to both core, periphery, and semi-periphery. Moreover, while China is a net exporter of materials, land, and labour to the core, it is a net importer of materials, land and labour from the periphery. China's net trade with the semi-periphery is more complex, exhibiting both core and peripheral characteristics.

Regarding China's involvement in D-EUE, our results suggest that the domestic core, namely the East Coast Zone, is a net importer of embodied energy and TiVA from all other regions. Conversely, the periphery (Central Zone and Western Zone) and the semi-periphery are net exporters of both energy and TiVA, with the semi-periphery (North Zone) being the largest net exporter of embodied energy and TiVA to the core. Moreover, the results of our SDA suggest that overall, the increases in domestic energy consumption are largely driven by changes in final demand and in particular by increases in capital (infrastructural) investments and exports to the rest of the world. Interestingly, exports were the main driver of energy consumption only in the core. Capital investment was the main driver of energy consumption in both periphery and semi-periphery, while exports played only a negligible role in these regions.

6. Discussion

The theory of ecologically unequal exchange posits that there exists an asymmetric transfer of biophysical resources from the core to the periphery. However, conventional representations of EUE have too often relied on a core-periphery dichotomy, failing to describe ecologically unequal exchange as a multi-tiered hierarchical dynamic (Althouse & Svartzman, 2022; El Tinay, 2024; Frame, 2019). Our case study of China transcends the theory of EUE providing the first global, empirical time-series assessment, incorporating the role of the semi-periphery, as well as the role of intra-country asymmetries in the context of ecologically unequal exchange. We further show that ecologically unequal exchange can be better conceived as a multi-tiered hierarchichal dynamic largely driven by a combination of external and internal dynamics.

China's involvement in Global Ecologically Unequal Exchange (G-EUE)

As a result of its semi-peripheral position in the world-system, China displays a complex mixture of both core and peripheral characteristics in the context of EUE. China continues to transfer large amounts of embodied biophysical resources to the core, while simultaneously appropriating embodied biophysical resources from the periphery. Therefore, our analysis provides evidence for China's ascent in the world's economic and ecological hierarchy and its transition from a peripheral to semi-peripheral country as a two-fold exploitative relationship. It highlights how China has fuelled its economic development by siphoning natural resources from poorer regions - relying on peripheries both domestically and abroad- while simultaneously suffering from the material exploitation of the world's core powers. In particular, we confirm that China relies heavily on the periphery (particularly Africa, Asia and Latin America) for its natural resources, including land, labour, and materials. These findings are consistent with an increasingly rich literature that has highlighted China's increased economic and political ties with major resource exporting nations throughout the periphery (Abegunrin & Manyeruke, 2020; Diab, 2023; Frame, 2019; Gulley et al., 2019; Wang et al., 2022).

High-income core countries are not only net-importers of- China's biophysical resources, they also capture the majority of value-added in their trade with China. Hence, while standardized accounting assumes that money and materials flow in opposite directions (Feenstra, 2015; Odum, 2007), we confirm the findings of EUE theory that embodied resource and monetary flows are aligned in the same direction (Dorninger et al., 2021). Most importantly, our study shows that value capture and capital accumulation in the core is fundamentally dependent on this persistent appropriation of natural resources from China.

China's Dependence on Domestic Ecologically Unequal Exchange (D-EUE)

China's ascent in the world system is frequently understood through two simplistic narratives: On the one hand, China's rapid development is often considered a direct result of the Chinese state's strategic investments in (increasingly "green") productive activity, innovation and R&D to compete at the higher levels of global value production (Gereffi et al., 2022; IEA, 2022). On the other, China is sometimes painted as a rising neo-colonial power that has expanded its productive and financial strength by exploiting the natural resources in earlier peripheral countries (Rapanyane, 2021). Our results paint a much more complex narrative, wherein China is both exploiter and exploited: its rise in the global hierarchy comes with great material and socio-economic rewards as well as heavy burdens.

Our results affirm that China's rise to global power must be viewed at the intersection of China's external dynamics of ecologically unequal exchange with the rest of the world and its deliberate internal strategy of 'resource-self-exploitation' to serve its productive power. Fuelled by the rising international demand for energy and China's corresponding net provision of embodied energy to the core, we show that there is an asymmetric exchange of embodied energy in the form of ecologically unequal exchange within and between China's main economic zones. In particular, it is shown that this asymmetric biophysical exchange between zones in China has fuelled economic growth in the benefitting regions, while perpetuating underdevelopment in the poorer regions.

Centred around the idea of making the East Coast zone the growth pole of China and driven by the international demand for Chinese exports, China's regional policies opted for an opening up of capital frontiers, which led to a surge in FDI inflows and foreign-held enterprises in the East Coast zone (Malm, 2012; S. X. B. Zhao & Zhang, 2007). Along with large-scale, mainly export-oriented, infrastructural investments and favourable policies such as tax abatements and subsidies for capitalist enterprises (H. Zhang & Lahr, 2014), China channelled economic, financial, and political power to the East Coast zone, creating a small, export-oriented, capitalist elite.

Conversely, given the world's rising demand for energy, China's regional economic policies increasingly centred on its resource-rich peripheries in the Central and Western zone. Driven by its supposed 'Western Development Strategies' (H. Zhang & Lahr, 2014) designed to improve infrastructure, technology and human capital in these underdeveloped zones in the late 1990s and early 2000s (W. Zhang et al., 2018) China, liberalized interregional trade and promoted the commodification of natural resources in the Central and Western zone.

China's growth strategy and rising demands for steel and chemical products for development fueled the energy-intensive heavy manufacturing industries in the North Zone. The North therefore became the primary exporter of embodied energy over time to the East Coast zone, even as it enjoyed relatively higher income levels than the Central and Western zones, for much of the study period.

Simultaneously, with China's entry into the WTO in 2001, international trade and thus China's net provision of natural resources, including embodied energy and materials to the rest of the world surged. Therefore, our analysis suggests that D-EUE in China was largely driven by a combination of external dynamics (e.g., changes in international demand that affect exports, increased net provision of embodied energy to the rest of the world) and internal dynamics, including deliberate regional economic policies, followed by the subsequent local reorganisation of modes of production and extraction (e.g., large infrastructural investments, liberalisation of interregional trade, capital inflows, creation of export centres).

This complementary dynamic created an export-oriented capitalist elite in the East Coast zone which was able to treat the peripheral regions of China as empty frontiers from which profits and energy could be extracted and to which socio-economic and environmental impacts could be shifted through a process of intra-country ecologically unequal exchange. In other words, the combination of granting political and economic power to large, often foreign-owned capitalist-enterprises, while liberalising, deregulating and privatising the extraction of natural resources in its own peripheries, China created a situation in which "groups of private entrepreneurs control both the economic and political [power] to appropriate" (Bunker, 1984, p. 1039) natural resources while allowing a small capitalist elite to reap the profits from the "exploitation and exportation" (Brand et al., 2016, p. 126) of nature.

However, China's rise to prominence and the exploitation of domestic peripheries was not uniform over time. Our study noted a surprising convergence of net TiVA and net embodied energy between regions - beginning after 2012, and particularly after 2015. While this study could not precisely define the reasons for this shift, a few factors may be at root. First, much of the reversal stemmed from the decline in relative appropriation from the Western Zone. This may be due, in part, to the increasingly successful development strategy to turn the Western Zone from a primarily extractive frontier into a more balanced and diversified economy (Kong, 2021; Z. Liu et al., 2021). Second, since exports to the rest of the world were a major driving force of D-EUE, it is important to note that there was a brief but noticeable decline in Chinese exports after 2015, which only recovered after 2017. Third, our study on China's involvement in G-EUE suggests that between 2012-2015, its net provision of embodied energy to both core, periphery, and semi-periphery plateaued. Moreover, its production-based accounts, namely the part of the embodied energy required for China's consumption provided and produced by China stagnated after 2012. Given China's coal-intensive energy production, this may also be related to the drastic fall in coal prices after 2012 (BP, 2023; Clark, 2016), which may have alleviated some of the inequalities in value-added and as a consequence in the asymmetric compensation of embodied energy. An alternative explanation for this convergence results from more targeted and successful regional policies conducted by the Chinese government, as the price of oil, natural gas, and electricity are being reformed in attempts to internalize environmental costs (W. Zhang et al., 2018). A further dive into the possible causes and consequences of this convergence is out of the scope of this paper.

Towards a multi-tiered hierarchy of ecologically unequal exchange

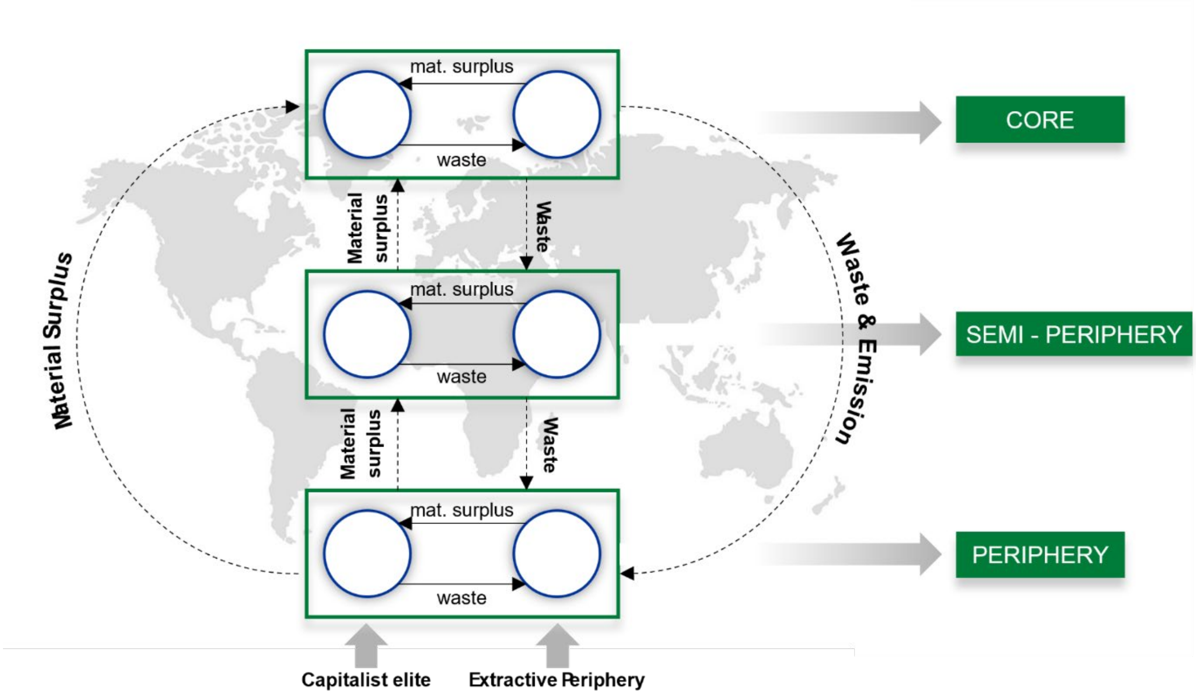
Conventional representations of ecologically unequal exchange theory have focused primarily on the asymmetric exchange of biophysical resources between countries.

Underdevelopment is viewed as a consequence of the asymmetric transfer of biophysical resources and labour from the periphery to the core of the world system. Our analysis has shown that this core-periphery dichotomy is insufficient to explain the complexities of global capital accumulation, particularly given the ambiguous role of semi-peripheries in the context of EUE. Using the case study of China, we further demonstrate that any globally traded commodity must ultimately emerge from local modes of transformation, transportation and ultimately extraction that provide these commodities to the world market. Acknowledging this fundamental fact, allows us to understand how economic processes rest upon an asymmetric exchange of biophysical resources within a multi-tiered hierarchy.

Ecologically unequal exchange is therefore not only a matter of asymmetric material exchanges between core and periphery but a complex dynamic encapsulating a multitude of biophysical appropriation and exploitation that occur between the extraction of resources and the final consumption at many levels. Uneven environmental outcomes at the global level are preceded by similar processes that reinforce unevenness domestically, particularly within the nations that extract, produce, and supply commodities to the international market. In this way, ecologically unequal exchange not only perpetuates inequalities between the periphery and the core, but also relies upon intra-country inequalities that can intensify divisions between the export-oriented capitalist elites benefitting from the 'exploitation and exportation' of nature and the extreme extractive peripheries which are locally dependent on the extraction of these resources.

Consequently, the world-system is not only structured between core, semi-periphery, and periphery, but comprised of a complex dynamic of multiple core-periphery relationships. Ultimately, ecologically unequal exchange must be viewed as embedded within a multi-tiered hierarchy in which global and regional dynamics of underdevelopment are complementary, inexorably related and constantly reshape their own materialization.

Figure 11: Towards a theory of ecologically unequal exchange as a mult-tiered hierarchy



Note: For illustration purposes, we do not integrate the "domestic" semi-periphery in the graphic. However, given the arguments put forward in this study, it is evident that such a category is also a key variable determining the flow of monetary and biophysical resources within and between regions.

Figure 11 aims to provide a more nuanced framework of the ecologically unequal exchange that incorporates the inter- and intra-country dynamics of EUE. It allows us to view the unequal material flows not only as an asymmetric transfer between the core, the semi-periphery, and the periphery, but as a holistic framework that incorporates the local reorganisation of modes of production and extraction, as well as the unequal material flows on the regional level within the socio-metabolic environments that produce and extract these globally traded commodities. It displays ecologically unequal exchange as a multi-tiered hierarchical system resting on a multitude of core-periphery constellations characterized by complex dynamics of exploitation, domination and underdevelopment.

Limitations and Opportunities for Further Research

Despite the robustness of the findings of this study, there were some limitations in the present analysis that could be addressed in future research.[19] For example, we were unable to conduct a structural decomposition analysis on the global level to determine the driving forces of EUE on the global level. It is argued that a more granular assessment of potential drivers on the global level could substantially enhance the

[19] See Appendix 4 for a detailed explanation on the limitations.

predictions made by this study (Hickel et al., 2022). Furthermore, given the backward-looking design of our study, we are unable to predict future developments of ecologically unequal exchange. Additional research could take a more dynamic approach to determine how policy changes on a global or national level (e.g., an expansion of China's belt-and-road initiative, the American Inflation Reduction Act) could affect how monetary and biophysical imbalances may increase or stagnate across regions (Magacho et al., 2022, 2023). Lastly, by relying on a positivist epistemological approach and prioritizing the empirical assessment of the complex dynamics of ecologically unequal exchange, we fail to account for cultural, ethnic, racial and gender related aspects that are inherent to the dynamics of capital accumulation and resource exploitation (Crenshaw, 1989; Grosfoguel, 2002; Harding, 2002; Hill-Collins, 1991). Future research within the field of EUE could ideally take into account not only the epistemological limitations of assessing complex social phenomena based on solely quantitative testing, but also to engage in a critical dialogue with de-colonial and cultural perspectives including thinkers from the periphery and with peripheral perspectives (Gonzalez Casanova, 1965; Grosfoguel, 2011).

7. Conclusion

The theory of ecologically unequal exchange postulates that there exists an asymmetric exchange of biophysical resources between economically powerful and less-powerful regions. Our analysis provides substantial evidence for this asymmetric biophysical exchange on a global and domestic level, and further demonstrates the importance of studying the particular role of semi-peripheral countries in the EUE process. On the global level (G-EUE), we show that China as a semi-peripheral country takes on a two-fold role by increasingly exploiting natural resources in peripheral countries, while simultaneously acting as a net provider of biophysical resources to the core. On the domestic level (D-EUE), we demonstrate the existence of ecologically unequal exchange between different economic zones of China, largely driven by the interdependence between global dynamics and China's targeted regional economic policies, including its planned self-exploitation of domestic natural resources.

These results confirm the hypothesis that any attempt to describe the world-system as a simple core-periphery dichotomy is inevitably incomplete (Frame, 2019). On the contrary, we show that the world system, characterized by a capitalist mode of production, must be viewed as a multi-tiered hierarchical system, accounting for the unequal distribution of wealth and the biophysical foundations of economic flows. Following our SDA, we are able to offer a more precise assessment of the drivers of ecologically unequal exchange on a regional level: We show that D-EUE is driven by a combination of internal and external dynamics, including a strong link between global demand (e.g., demand for Chinese exports) and domestic policy (e.g., massive build-up of trade infrastructure and the liberalization of intra-regional trade).

The temporal persistence, its global and regional occurrence, as well as its applicability to all biophysical indicators, suggests that ecologically unequal exchange is not temporary or coincidental, but systemic, persistent and should be viewed as a structural feature of the global economy (Dorninger et al., 2021). Our results indicate that the accumulation of wealth and power in some regions - whether globally or domestically - is fuelled and sustained by asymmetric biophysical exchanges with other, less wealthy and less powerful regions. Economic growth in the former rests on the appropriation and use of natural resources from the former.

The capitalist world system has historically evolved through struggles to appropriate and extract the social and ecological surplus in peripheral regions from which "cheap" resources can be extracted and appropriated (Bhambra, 2017; Galeano, 1997; Moore, 2015). As such, the transition from periphery to semi-periphery or from semi-periphery to core should therefore be understood along with the creation of new peripheral zones of extraction. In fact, our study highlights that China's 'catching-up' to traditional Western powers has been accompanied by an increasingly exploitative relationship concerning the utilisation of natural resources and enhanced material control over both "external" and "internal" peripheries.

Such findings raise additional questions about the value of policies in pursuit of "green" forms of economic growth - whether in the periphery, semi-periphery or core. "Green growth" strategies ultimately arise through the hierarchical organization of capitalist production. As such, they are predicated on an endless positional competition marked by environmental burden-shifting (Althouse et al., 2020). Indeed, our study suggests that even China's massive investment efforts to mitigate climate-change, decouple economic growth from material and energy throughput, and establish itself as an industry leader for renewables and efficient technologies (Z. Liu et al., 2021; Wu et al., 2018; X. Zhao et al., 2022) are likely to occur at great expense to peripheral regions. Green development in the former perpetuates underdevelopment and environmental degradation in the latter, without truly addressing the global sustainability challenges that can protect the future of our planet (Bonds & Downey, 2012; Harlan, 2021).

This suggests a number of key insights: First, green accumulation strategies should be re-considered for their impacts on intra- and inter-generational justice, since they cannot be sustained indefinitely or adopted universally, on shared planet with finite resources (Cumming & von Cramon-Taubadel, 2018). Second, sustainability may have little or nothing to do with the *quantity* of investment for "green" projects and technologies, but the quality of socio-ecological relations that are practiced and institutionalized (Althouse & Svartzman, 2022, 2024). Third, economic theory must acknowledge the biophysical foundations of economic flows, their subjectivity to power relations and the structural inequalities of the world system, in order to understand why increasingly desperate attempts to "escape" the environmental crisis have failed to meaningfully change the global trajectory (Hornborg, 2019). Finally, it highlights the potential for an inherently contradictory relationship between capitalism and nature (Altvater, 1990; Foster et al., 2010; O'Connor, 1998), as the perpetual drive to accumulate - whether in "green" or "brown" forms - appears to systematically deplete the very "sources of all wealth—the soil and the worker." (Marx, 2004, p. 472).

Bibliography

Abegunrin, O., & Manyeruke, C. (2020). *China's power in Africa : A new global order*. Palgrave Macmillan.

Alsamawi, A., Murray, J., & Lenzen, M. (2014). The Employment Footprints of Nations : Uncovering Master-Servant Relationships. *Journal of Industrial Ecology*, *18*(1), 59-70. https://doi.org/10.1111/jiec.12104

Althouse, J., Cahen-Fourot, L., Carballa-Smichowski, B., Durand, C., & Knauss, S. (2023). Ecologically unequal exchange and uneven development patterns along global value chains. *World Development*, *170*(106308). https://doi.org/10.1016/j.worlddev.2023.106308

Althouse, J., Guarini, G., & Gabriel Porcile, J. (2020). Ecological macroeconomics in the open economy : Sustainability, unequal exchange and policy coordination in a center-periphery model. *Ecological Economics*, *172*, 106628. https://doi.org/10.1016/j.ecolecon.2020.106628

Althouse, J., Smichowski, B. C., Cahen-Fourot, L., Durand, C., & Knauss, S. (2021). *Ecologically unequal exchange and uneven development patterns along global value chains* (Working Paper Series 42/2021). Vienna University of Economics and Business: Institute for Ecological Economics.

Althouse, J., & Svartzman, R. (2022). Bringing subordinated financialisation down to earth : The political ecology of finance-dominated capitalism. *Cambridge Journal of Economics*, *46*(4), 679-702. https://doi.org/10.1093/cje/beac018

Althouse, J., & Svartzman, R. (2024). Prospects and roadblocks to a « sustainable » international monetary and financial system. In J. Jäger & E. Dziwok (Éds.), *Understanding Green Finance* (p. 182-198). Edward Elgar Publishing. https://doi.org/10.4337/9781803927558.00022

Altvater, E. (1990). The Foundations of Life (Nature) and the Maintenance of Life (Work) : The Relation between Ecology and Economics in the Crisis. *International Journal of Political Economy*, *20*(1), 10-34. https://doi.org/10.1080/08911916.1990.11643788

Amin, S. (1974). Accumulation and development : A theoretical model. *Review of African Political Economy*, *1*(1), 9-26. https://doi.org/10.1080/03056247408703234

Bhambra, G. K. (2017). Our island story' : The dangerous politics of belonging in austere times. In S. Jonsson & J. Willén (Éds.), *Austere histories in European societies : Social exclusion and the contest of colonial memories*. Routledge, Taylor & Francis group.

Bonds, E., & Downey, L. (2012). Green Technology and Ecologically Unequal Exchange : The Environmental and Social Consequences of Ecological Modernization in the World-System. *Journal of World-Systems Research*, *18*(2), 167-186. https://doi.org/10.5195/JWSR.2012.482

BP. (2023). *Statistical Review of World Energy*. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Brand, U., Dietz, K., & Lang, M. (2016). Neo-Extractivism in Latin America – one side of a new phase of global capitalist dynamics. *Ciencia Política*, *11*(21). https://doi.org/10.15446/cp.v11n21.57551

Bruckner, M., Fischer, G., Tramberend, S., & Giljum, S. (2015). Measuring telecouplings in the global land system : A review and comparative evaluation of land footprint accounting methods. *Ecological Economics*, *114*, 11-21. https://doi.org/10.1016/j.ecolecon.2015.03.008

Bruton, G. D., Ahlstrom, D., & Chen, J. (2021). China has emerged as an aspirant economy. *Asia Pacific Journal of Management*, *38*(1), 1-15. https://doi.org/10.1007/s10490-018-9638-0

Bunker, S. G. (1984). Modes of Extraction, Unequal Exchange, and the Progressive Underdevelopment of an Extreme Periphery : The Brazilian Amazon, 1600-1980. *American Journal of Sociology*, *89*(5), 1017-1064. https://doi.org/10.1086/227983

Chen, B., Li, J. S., Wu, X. F., Han, M. Y., Zeng, L., Li, Z., & Chen, G. Q. (2018). Global energy flows embodied in international trade : A combination of environmentally extended input–output analysis and complex network analysis. *Applied Energy*, *210*, 98-107. https://doi.org/10.1016/j.apenergy.2017.10.113

Chen, J. (2007). Rapid urbanization in China : A real challenge to soil protection and food security. *CATENA*, *69*(1), 1-15. https://doi.org/10.1016/j.catena.2006.04.019

Chen, J., Wu, Y., Wen, J., Cheng, S., & Wang, J. (2017). Regional differences in China's fossil energy consumption : An analysis for the period 1997–2013. *Journal of Cleaner Production*, *142*, 578-588. https://doi.org/10.1016/j.jclepro.2016.05.135

Chung, J. H., Lai, H., & Joo, J.-H. (2009). Assessing the « Revive the Northeast » (zhenxing dongbei) Programme : Origins, Policies and Implementation. *The China Quarterly*, *197*, 108-125.

Ciccantell, P. S. (2019). Ecologically Unequal Exchange and Raw Materialism : The Material Foundations of the Capitalist World-Economy. In R. S. Frey, P. K. Gellert, & H. F. Dahms (Éds.), *Ecologically Unequal Exchange* (p. 49-73). Springer International Publishing. https://doi.org/10.1007/978-3-319-89740-0_3

Clark, P. (2016, juin 8). Coal use plunges as China cuts back and US turns to gas. *Financial Times*.

Costantini, V., Morando, V., Olk, C., & Tausch, L. (2022). Fuelling the Fire : Rethinking European Policy in Times of Energy and Climate Crises. *Energies*, *15*(20), 7781. https://doi.org/10.3390/en15207781

Crenshaw, K. (1989). Demarginalizing the Intersection of Race and Sex : A Black Feminist Critique of Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics. *University of Chicago Legal Forum*, *1989*(1), 139-167.

Culas, R. J. (2006). Debt and Deforestation : A Review of Causes and Empirical Evidence. *Journal of Developing Societies*, *22*(4), 347-358. https://doi.org/10.1177/0169796X06071524

Cumming, G. S., & von Cramon-Taubadel, S. (2018). Linking economic growth pathways and environmental sustainability by understanding development as alternate social–ecological regimes. *Proceedings of the National Academy of Sciences*, *115*(38), 9533-9538. https://doi.org/10.1073/pnas.1807026115

Diab, O. (2023). Africa's unequal balance. *Review of African Political Economy*, 1-9. https://doi.org/10.1080/03056244.2023.2190453

Dietzenbacher, E., Hoen, A. R., & Los, B. (2000). Labor Productivity in Western Europe 1975–1985 : An Intercountry, Interindustry Analysis. *Journal of Regional Science*, *40*(3), 425-452. https://doi.org/10.1111/0022-4146.00182

Dietzenbacher, E., & Los, B. (1998). Structural Decomposition Techniques : Sense and Sensitivity. *Economic Systems Research*, *10*(4), 307-324. https://doi.org/10.1080/09535319800000023

Dorninger, C., Hornborg, A., Abson, D. J., von Wehrden, H., Schaffartzik, A., Giljum, S., Engler, J.-O., Feller, R. L., Hubacek, K., & Wieland, H. (2021). Global patterns of ecologically unequal exchange : Implications for sustainability in the 21st century. *Ecological Economics*, *179*, 106824. https://doi.org/10.1016/j.ecolecon.2020.106824

Doytch, N., & Ashraf, A. (2022). The Ecological Footprints of Greenfield FDI and Cross-border M&A Sales. *Environmental Modeling & Assessment*, *27*(6), 935-951. https://doi.org/10.1007/s10666-021-09777-3

El Tinay, H. (2024). The semi-periphery and ecologically unequal exchange : Carbon emissions and recursive exploitation. *Environmental Sociology*, *0*(0), 1-13. https://doi.org/10.1080/23251042.2024.2309407

Emmanuel, A. (1972). *Unequal Exchange : A Study of the Imperialism of Trade*. Monthly Review Press.

Fan, C. C. (1997). Uneven development and beyond : Regional development theory in post-Mao China. *International Journal of Urban and Regional Research*, *21*(4), 620-639. https://doi.org/10.1111/1468-2427.00105

Fan, X., Liu, H., & Wang, M. (2022). Study on the Agricultural Land Transfer Embodied in Inter-Provincial Trade in China. *Land*, *11*(5), 656. https://doi.org/10.3390/land11050656

Feenstra, R. C. (2015). *Advanced International Trade : Theory and Evidence*. Princeton University Press.

Fitzgerald, J., & Auerbach, D. (2016). The Political Economy of the Water Footprint : A Cross-National Analysis of Ecologically Unequal Exchange. *Sustainability*, *8*(12), 1263. https://doi.org/10.3390/su8121263

Foster, J. B., Clark, B., & York, R. (2010). *The Ecological Rift : Capitalism's War on the Earth*. NYU Press.

Frame, M. (2019). The Role of the Semi-Periphery in Ecologically Unequal Exchange : A Case Study of Land Investments in Cambodia. In R. S. Frey, P. K. Gellert, & H. F. Dahms (Éds.), *Ecologically Unequal Exchange* (p. 75-106). Springer International Publishing. https://doi.org/10.1007/978-3-319-89740-0_4

Frank, A. G. (1966). The Development of Underdevelopment. *Monthly Review*, *18*(4), 17. https://doi.org/10.14452/MR-018-04-1966-08_3

Frank, A. G. (1979). *Dependent accumulation and underdevelopment*. Monthly Review Press.

Frey, R. S., Gellert, P. K., & Dahms, H. F. (2019). *Ecologically Unequal Exchange : Environmental Injustice in Comparative and Historical Perspective* (1st ed. 2019). Springer International Publishing : Imprint: Palgrave Macmillan. https://doi.org/10.1007/978-3-319-89740-0

Furtado, C. (1959). *Formação Econômica do Brasil*. Fundo de Cultura.

Furtado, C. (1971). *Development and underdevelopment*. Univ. of California Press.

Galeano, E. (1997). *Open veins of Latin America : Five centuries of the pillage of a continent* (25th anniversary ed). Monthly Review Press.

Georgescu-Roegen, N. (1971). *The Entropy Law and the Economic Process*. Harvard University Press. https://doi.org/10.4159/harvard.9780674281653

Gereffi, G., Bamber, P., & Fernandez-Stark, K. (Éds.). (2022). *China's New Development Strategies : Upgrading from Above and from Below in Global Value Chains*. Springer Nature. https://doi.org/10.1007/978-981-19-3008-9

Godar, J., Persson, U. M., Tizado, E. J., & Meyfroidt, P. (2015). Towards more accurate and policy relevant footprint analyses : Tracing fine-scale socio-environmental impacts of production to consumption. *Ecological Economics*, *112*, 25-35. https://doi.org/10.1016/j.ecolecon.2015.02.003

Gonzalez Casanova, P. (1965). Internal colonialism and national development. *Studies in Comparative International Development*, *1*(4), 27-37. https://doi.org/10.1007/BF02800542

Grosfoguel, R. (2002). Colonial Difference, Geopolitics of Knowledge, and Global Coloniality in the Modern/Colonial Capitalist World-System. *Review (Fernand Braudel Center)*, *25*(3), 203-224.

Grosfoguel, R. (2011). Decolonizing Post-Colonial Studies and Paradigms of Political-Economy : Transmodernity, Decolonial Thinking, and Global Coloniality. *Transmodernity: Journal of Peripheral Cultural Production of the Luso-Hispanic World*, *1*(1). https://doi.org/10.5070/T411000004

Guan, D., Meng, J., Reiner, D. M., Zhang, N., Shan, Y., Mi, Z., Shao, S., Liu, Z., Zhang, Q., & Davis, S. J. (2018). Structural decline in China's CO2 emissions through transitions in industry and energy systems. *Nature Geoscience*, *11*(8), 551-555. https://doi.org/10.1038/s41561-018-0161-1

Guan, Y., Shan, Y., Huang, Q., Chen, H., Wang, D., & Hubacek, K. (2021). Assessment to China's Recent Emission Pattern Shifts. *Earth's Future*, *9*(11). https://doi.org/10.1029/2021EF002241

Guilhoto, J. J. M. (2021). Input–Output Models Applied to Environmental Analysis. In J. J. M. Guilhoto, *Oxford Research Encyclopedia of Environmental Science*. Oxford University Press. https://doi.org/10.1093/acrefore/9780199389414.013.573

Gulley, A. L., McCullough, E. A., & Shedd, K. B. (2019). China's domestic and foreign influence in the global cobalt supply chain. *Resources Policy*, *62*, 317-323. https://doi.org/10.1016/j.resourpol.2019.03.015

Guo, S., Wang, Y., Shen, G. Q. P., Zhang, B., & Wang, H. (2020). Virtual built-up land transfers embodied in China's interregional trade. *Land Use Policy*, *94*, 104536. https://doi.org/10.1016/j.landusepol.2020.104536

Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., Hausknost, D., Krausmann, F., Leon-Gruchalski, B., Mayer, A., Pichler, M., Schaffartzik, A., Sousa, T., Streeck, J., & Creutzig, F. (2020). A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II : Synthesizing the insights. *Environmental Research Letters*, *15*(6), 065003. https://doi.org/10.1088/1748-9326/ab842a

Harding, S. (2002). Rethinking Standpoint Epistemology : What is Strong « Objectivity »? In K. B. Wray (Éd.), *Knowledge and Inquiry : Readings in Epistemology*. Broadview Press.

Harlan, T. (2021). Green development or greenwashing? A political ecology perspective on China's green Belt and Road. *Eurasian Geography and Economics*, *62*(2), 202-226. https://doi.org/10.1080/15387216.2020.1795700

Hickel, J., Dorninger, C., Wieland, H., & Suwandi, I. (2022). Imperialist appropriation in the world economy : Drain from the global South through unequal exchange, 1990–2015. *Global Environmental Change*, *73*, 102467. https://doi.org/10.1016/j.gloenvcha.2022.102467

Hill-Collins, P. (1991). *Black feminist thought : Knowledge, Consciousness, and the politics of empowerment* (Repr. d. Ausg. von 1990). Routledge.

Hornborg, A. (1998). Towards an ecological theory of unequal exchange : Articulating world system theory and ecological economics. *Ecological Economics*, *25*(1), 127-136. https://doi.org/10.1016/S0921-8009(97)00100-6

Hornborg, A. (2009). Zero-Sum World : Challenges in Conceptualizing Environmental Load Displacement and Ecologically Unequal Exchange in the World-System. *International Journal of Comparative Sociology*, *50*(3-4), 237-262. https://doi.org/10.1177/0020715209105141

Hornborg, A. (2011). *Global ecology and unequal exchange : Fetishism in a zero-sum world*. Routledge.

Hornborg, A. (2016). *Global magic : Technologies of appropriation from Ancient Rome to Wall Street*. Palgrave Macmillan. https://doi.org/10.1057/9781137567871

Hornborg, A. (2019). *Nature, Society, and Justice in the Anthropocene : Unraveling the Money-Energy-Technology Complex*. Cambridge University Press.

Hornborg, A., & Jorgensen, A. K. (Éds.). (2010). *International trade and environmental justice : Toward a global political ecology*. Nova Science Publishers.

Hornborg, A., & Martinez-Alier, J. (2016). Ecologically unequal exchange and ecological debt. *Journal of Political Ecology*, *23*(1). https://doi.org/10.2458/v23i1.20220

Huang, W., Li, Y., & Li, H. (2021). Embodied energy in China : Drivers and inequality at a regional level. *Environmental Science and Pollution Research*, *28*(45), 64488-64502. https://doi.org/10.1007/s11356-021-15328-w

Ichimura, S., & Wang, H. (2003). Interregional Input-Output Analysis of the Chinese Economy. *World Scientific Pub, Co. Inc.*

IEA. (2022). *World Energy Outlook 2022*. IEA. https://www.iea.org/reports/world-energy-outlook-2022, License: CC BY 4.0 (report); CC BY NC SA 4.0 (Annex A)

Infante-Amate, J., & Krausmann, F. (2019). Trade, Ecologically Unequal Exchange and Colonial Legacy : The Case of France and its Former Colonies (1962–2015). *Ecological Economics*, *156*, 98-109. https://doi.org/10.1016/j.ecolecon.2018.09.013

Infante-Amate, J., Urrego-Mesa, A., Piñero, P., & Tello, E. (2022). The open veins of Latin America : Long-term physical trade flows (1900–2016). *Global Environmental Change*, *76*, 102579. https://doi.org/10.1016/j.gloenvcha.2022.102579

IRP. (2020). *Mineral Resource Governance in the 21st Century : Gearing extractive industries towards sustainable development*. [A Report by the International Resource Panel]. United Nations Environment Programme.

Jiborn, M., Kander, A., Kulionis, V., Nielsen, H., & Moran, D. D. (2018). Decoupling or delusion? Measuring emissions displacement in foreign trade. *Global Environmental Change*, *49*, 27-34. https://doi.org/10.1016/j.gloenvcha.2017.12.006

Johnson, R. C., & Noguera, G. (2012). Accounting for intermediates : Production sharing and trade in value added. *Journal of International Economics*, *86*(2), 224-236. https://doi.org/10.1016/j.jinteco.2011.10.003

Jorgenson, A. K. (2006). Unequal Ecological Exchange and Environmental Degradation : A Theoretical Proposition and Cross-National Study of Deforestation, 1990-2000. *Rural Sociology*, *71*(4), 685-712. https://doi.org/10.1526/003601106781262016

Jorgenson, A. K. (2009). The Sociology of Unequal Exchange in Ecological Context : A Panel Study of Lower-Income Countries, 1975-2000. *Sociological Forum*, *24*(1), 22-46. https://doi.org/10.1111/j.1573-7861.2008.01085.x

Jorgenson, A. K. (2012). The sociology of ecologically unequal exchange and carbon dioxide emissions, 1960–2005. *Social Science Research*, *41*(2), 242-252. https://doi.org/10.1016/j.ssresearch.2011.11.011

Jorgenson, A. K. (2016a). Environment, Development, and Ecologically Unequal Exchange. *Sustainability*, *8*(3), 227. https://doi.org/10.3390/su8030227
Jorgenson, A. K. (2016b). The sociology of ecologically unequal exchange, foreign investment dependence and environmental load displacement : Summary of the literature and implications for sustainability. *Journal of Political Ecology*, *23*(1). https://doi.org/10.2458/v23i1.20221
Kong, T. Y. (2021). *China's Western Region Development Strategy : Promises And Challenges* (EAI Background Brief 1596). East Asian Institute, National University of Singapore.
Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012). Mapping the Structure of the World Economy. *Environmental Science & Technology*, *46*(15), 8374-8381. https://doi.org/10.1021/es300171x
Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building Eora : A Global Multi-region Input–output Database at High Country and Sector Resolution. *Economic Systems Research*, *25*(1), 20-49. https://doi.org/10.1080/09535314.2013.769938
Leontief, W. W. (1936). Quantitative Input and Output Relations in the Economic Systems of the United States. *The Review of Economics and Statistics*, *18*(3), 105. https://doi.org/10.2307/1927837
Leung, G. C. K. (2010). China's oil use, 1990–2008. *Energy Policy*, *38*(2), 932-944. https://doi.org/10.1016/j.enpol.2009.10.045
Li, M. (2021). China : Imperialism or Semi-Periphery? *Monthly Review*, 47-74. https://doi.org/10.14452/MR-073-03-2021-07_4
Li, S. T. (2016). China Regional Expansion Input-Output Table in 2007 : Preparation and Application. *Economic Science Press: Beijing*.
Li, S. T., Qi, S. C., & Xu, Z. Y. (2010). China Regional Expansion Input Output Table in 2002 : Preperation and Application. *Economie Science Press: Beijing*.
Li, Y., & Wei, Y. H. D. (2010). The spatial-temporal hierarchy of regional inequality of China. *Applied Geography*, *30*(3), 303-316. https://doi.org/10.1016/j.apgeog.2009.11.001
Liu, J., Xuan, K., Xie, N., Zhang, J., Wang, X., Yu, Z., & Wang, W. (2022). Effects of urbanisation on regional water consumption in China. *Journal of Hydrology*, *609*, 127721. https://doi.org/10.1016/j.jhydrol.2022.127721
Liu, Z., Deng, Z., He, G., Wang, H., Zhang, X., Lin, J., Qi, Y., & Liang, X. (2021). Challenges and opportunities for carbon neutrality in China. *Nature Reviews Earth & Environment*, *3*(2), 141-155. https://doi.org/10.1038/s43017-021-00244-x
Long, H., Xie, R., Gao, C., Sun, M., & Su, B. (2022). Analysis of China's regional differences in water consumption based on spatial structural decomposition analysis model. *Science of The Total Environment*, *848*, 157629. https://doi.org/10.1016/j.scitotenv.2022.157629

Magacho, G., Espagne, E., & Godin, A. (2022). *Impacts of CBAM on EU trade partners : Consequences for developing countries* (AFD Research Papers 2022/238; p. 1-20).

Magacho, G., Espagne, E., Godin, A., Mantes, A., & Yilmaz, D. (2023). Macroeconomic exposure of developing economies to low-carbon transition. *World Development*, *167*, 106231. https://doi.org/10.1016/j.worlddev.2023.106231

Magalhães, N., Fressoz, J.-B., Jarrige, F., Le Roux, T., Levillain, G., Lyautey, M., Noblet, G., & Bonneuil, C. (2019). The Physical Economy of France (1830–2015). The History of a Parasite? *Ecological Economics*, *157*, 291-300. https://doi.org/10.1016/j.ecolecon.2018.12.001

Malm, A. (2012). China as Chimney of the World : The Fossil Capital Hypothesis. *Organization & Environment*, *25*(2), 146-177. https://doi.org/10.1177/1086026612449338

Martinez-Alier, J., Temper, L., & Demaria, F. (2016). Social Metabolism and Environmental Conflicts in India. In N. Ghosh, P. Mukhopadhyay, A. Shah, & M. Panda (Éds.), *Nature, Economy and Society* (p. 19-49). Springer India. https://doi.org/10.1007/978-81-322-2404-4_3

Marx, K. (2004). *Capital : Volume 3*. Penguin Press.

McKay, H., & Song, L. (2010). China as a Global Manufacturing Powerhouse : Strategic Considerations and Structural Adjustment. *China & World Economy*, *18*(1), 1-32. https://doi.org/10.1111/j.1749-124X.2010.01178.x

Meng, J., Mi, Z., Guan, D., Li, J., Tao, S., Li, Y., Feng, K., Liu, J., Liu, Z., Wang, X., Zhang, Q., & Davis, S. J. (2018). The rise of South–South trade and its effect on global CO2 emissions. *Nature Communications*, *9*(1), 1871. https://doi.org/10.1038/s41467-018-04337-y

Miller, R. E., & Blair, P. D. (2009). *Input-Output Analysis : Foundations and Extensions* (2e éd.). Cambridge University Press. https://doi.org/10.1017/CBO9780511626982

Moore, J. W. (2015). *Capitalism in the Web of Life : Ecology and the Accumulation of Capital*. Verso Books.

Muntean, M., Guizzardi, D., Schaaf, E., Crippa, M., Solazzo, E., Olivier, J. G. J., & Vignati, E. (2018). *Fossil CO2 emissions of all world countries—2018 report*. Publications Office of the European Union. 10.2760/30158

Muradian, R., & Martinez-Alier, J. (2001). Trade and the environment : From a ‘Southern’ perspective. *Ecological Economics*, *36*(2), 281-297. https://doi.org/10.1016/S0921-8009(00)00229-9

Muradian, R., Walter, M., & Martinez-Alier, J. (2012). Hegemonic transitions and global shifts in social metabolism : Implications for resource-rich countries. Introduction to the special section. *Global Environmental Change*, *22*(3), 559-567. https://doi.org/10.1016/j.gloenvcha.2012.03.004

O’Connor, J. (1998). *Natural causes : Essays in ecological marxism*. Guilford Press.

Odum, H. T. (2007). *Environment, power, and society for the twenty-first century : The hierarchy of energy*. Columbia University Press.

Parrique, T., Barth, J., Kerschner, C., Kraus-Pol, A., Kuokkanen, A., & Spangenberg, J. H. (2019). *Decoupling debunked – Evidence and arguments against green growth as a sole strategy for sustainability*. European Environmental Bureau.

Peters, G. P. (2008). From production-based to consumption-based national emission inventories. *Ecological Economics*, *65*(1), 13-23. https://doi.org/10.1016/j.ecolecon.2007.10.014

Piñero, P., Pérez-Neira, D., Infante-Amate, J., Chas-Amil, M. L., & Doldán-García, X. R. (2020). Unequal raw material exchange between and within countries : Galicia (NW Spain) as a core-periphery economy. *Ecological Economics*, *172*, 106621. https://doi.org/10.1016/j.ecolecon.2020.106621

Prebish, R. (1950). *The Economic Development of Latin America and its Principal Problems* (United Nations Publication E/CN.12/89/Rev.l). ECLAC - United Nations Department of Economic Affairs.

Prell, C., Feng, K., Sun, L., Geores, M., & Hubacek, K. (2014). The Economic Gains and Environmental Losses of US Consumption : A World-Systems and Input-Output Approach. *Social Forces*, *93*(1), 405-428. https://doi.org/10.1093/sf/sou048

Prell, C., & Sun, L. (2015). Unequal carbon exchanges : Understanding pollution embodied in global trade. *Environmental Sociology*, *1*(4), 256-267. https://doi.org/10.1080/23251042.2015.1114208

Rapanyane, M. B. (2021). Neocolonialism and New imperialism : Unpacking the Real Story of China's Africa Engagement in Angola, Kenya, and Zambia. *Journal of African Foreign Affairs*, *8*(3), 89-112. https://doi.org/10.31920/2056-5658/2021/v8n3a5

Rice, J. (2007). Ecological Unequal Exchange : International Trade and Uneven Utilization of Environmental Space in the World System. *Social Forces*, *85*(3), 1369-1392. https://doi.org/10.1353/sof.2007.0054

Ross, C. (2017). *Ecology and Power in the Age of Empire : Europe and the Transformation of the Tropical World*. Oxford University Press.

Schaffartzik, A., Wiedenhofer, D., & Eisenmenger, N. (2015). Raw Material Equivalents : The Challenges of Accounting for Sustainability in a Globalized World. *Sustainability*, *7*(5), 5345-5370. https://doi.org/10.3390/su7055345

Shan, Y., Guan, D., Zheng, H., Ou, J., Li, Y., Meng, J., Mi, Z., Liu, Z., & Zhang, Q. (2018). China CO2 emission accounts 1997–2015. *Scientific Data*, *5*(1), 170201. https://doi.org/10.1038/sdata.2017.201

Shan, Y., Huang, Q., Guan, D., & Hubacek, K. (2020). China CO2 emission accounts 2016–2017. *Scientific Data*, *7*(1), 54. https://doi.org/10.1038/s41597-020-0393-y

Shandra, J. M., Leckband, C., & London, B. (2009). Ecologically Unequal Exchange and Deforestation : A Cross-National Analysis of Forestry Export Flows.

Organization & Environment, *22*(3), 293-310. https://doi.org/10.1177/1086026609343097
Shandra, J. M., Restivo, M., & Sommer, J. M. (2020). Appetite for Destruction? China, Ecologically Unequal Exchange, and Forest Loss. *Rural Sociology*, *85*(2), 346-375. https://doi.org/10.1111/ruso.12292
Shandra, J. M., Shircliff, E., & London, B. (2011). The International Monetary Fund, World Bank, and structural adjustment : A cross-national analysis of forest loss. *Social Science Research*, *40*(1), 210-225. https://doi.org/10.1016/j.ssresearch.2010.08.004
Shandra, J. M., Shor, E., & London, B. (2008). Debt, Structural Adjustment, and Organic Water Pollution : A Cross-National Analysis. *Organization & Environment*, *21*(1), 38-55. https://doi.org/10.1177/1086026608314759
Sommer, J. M., Restivo, M., & Shandra, J. M. (2021). China, Mining, and Forests : A Cross-National Test of Ecologically Unequal Exchange. *The Sociological Quarterly*, *62*(2), 369-391. https://doi.org/10.1080/00380253.2020.1756519
Sommer, J. M., Zhang, Y., & Shandra, J. (2023). Ecologically unequal exchange, repression, and forest loss : How China's demand for agricultural products impacts the natural environment. *Environmental Development*, *46*, 100866. https://doi.org/10.1016/j.envdev.2023.100866
Sovacool, B. K. (2021). Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. *Energy Research & Social Science*, *73*, 101916. https://doi.org/10.1016/j.erss.2021.101916
State Council of China. (1986). *The Seventh Five Year Plan for national economic and social development of the People's Republic of China, 1986-1990* [Technical Report]. State Council of China.
Svartzman, R., & Althouse, J. (2020). Greening the international monetary system? Not without addressing the political ecology of global imbalances. *Review of International Political Economy*, *29*(3), 844-869. https://doi.org/10.1080/09692290.2020.1854326
Tasmim, S., Sommer, J. M., & Shandra, J. M. (2022). Feed me ! China, agriculture, ecologically unequal exchange, and forest loss in a CROSS-NATIONAL perspective. *Environmental Policy and Governance*, *32*(1), 29-42. https://doi.org/10.1002/eet.1959
Timmer, M. P., Erumban, A. A., Los, B., Stehrer, R., & de Vries, G. J. (2014). Slicing Up Global Value Chains. *Journal of Economic Perspectives*, *28*(2), 99-118. https://doi.org/10.1257/jep.28.2.99
Wallerstein, I. (1974). *The modern world system. 1 : Capitalist agriculture and the origins of the European world-economy in the sixteenth century*. University of California Press.
Wallerstein, I. (1983). *Historical capitalism*. Verso.
Wang, X., Yang, J., Zhou, Q., Liu, M., & Bi, J. (2022). Mapping the exchange between embodied economic benefits and CO2 emissions among Belt and Road

Initiative countries. *Applied Energy*, *307*, 118206. https://doi.org/10.1016/j.apenergy.2021.118206
Whalley, J., & Xin, X. (2006). *China's FDI and non-FDI economies and the sustainability of future high Chinese growth* (NBER Working Paper 12249). https://www.nber.org/system/files/working_papers/w12249/w12249.pdf
Wiedenhofer, D., Guan, D., Liu, Z., Meng, J., Zhang, N., & Wei, Y.-M. (2017). Unequal household carbon footprints in China. *Nature Climate Change*, *7*(1), 75-80. https://doi.org/10.1038/nclimate3165
Wiedmann, T., & Lenzen, M. (2018). Environmental and social footprints of international trade. *Nature Geoscience*, *11*(5), 314-321. https://doi.org/10.1038/s41561-018-0113-9
Wiedmann, T., Wilting, H. C., Lenzen, M., Lutter, S., & Palm, V. (2011). Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis. *Ecological Economics*, *70*(11), 1937-1945. https://doi.org/10.1016/j.ecolecon.2011.06.014
World Bank. (2023a). *CO2 emissions (kt)*. https://data.worldbank.org
World Bank. (2023b). *Exports of goods and services (current US$)*. https://data.worldbank.org
World Bank. (2023c). *GDP (current US$)*. https://data.worldbank.org
Wu, Y., Chau, K. W., Lu, W., Shen, L., Shuai, C., & Chen, J. (2018). Decoupling relationship between economic output and carbon emission in the Chinese construction industry. *Environmental Impact Assessment Review*, *71*, 60-69. https://doi.org/10.1016/j.eiar.2018.04.001
Xu, X. C., & Li, S. T. (2008). China Regional Expansion Input-output table in 1997 : Preparation and Application. *Tsinghua University Press: Beijing*.
Yu, Y., Feng, K., & Hubacek, K. (2014). China's unequal ecological exchange. *Ecological Indicators*, *47*, 156-163. https://doi.org/10.1016/j.ecolind.2014.01.044
Zeping, R., Chai, X., & Jiajun, Y. (2021, janvier 2). Weekend Long Read : Why China's North-South Economic Gap Keeps Getting Bigger. *Caixin Global*. https://www.caixinglobal.com/2021-01-02/weekend-long-read-why-chinas-north-south-economic-gap-keeps-getting-bigger-101645586.html
Zhang, B., Qiao, H., Chen, Z. M., & Chen, B. (2016). Growth in embodied energy transfers via China's domestic trade : Evidence from multi-regional input–output analysis. *Applied Energy*, *184*, 1093-1105. https://doi.org/10.1016/j.apenergy.2015.09.076
Zhang, H., & Lahr, M. L. (2014). China's energy consumption change from 1987 to 2007 : A multi-regional structural decomposition analysis. *Energy Policy*, *67*, 682-693. https://doi.org/10.1016/j.enpol.2013.11.069
Zhang, W., Liu, Y., Feng, K., Hubacek, K., Wang, J., Liu, M., Jiang, L., Jiang, H., Liu, N., Zhang, P., Zhou, Y., & Bi, J. (2018). Revealing Environmental Inequality Hidden in China's Inter-regional Trade. *Environmental Science & Technology*, *52*(13), 7171-7181. https://doi.org/10.1021/acs.est.8b00009

Zhang, Y., Liao, C., & Pan, B. (2023). Ecological unequal exchange between China and European Union : An investigation from global value chains and carbon emissions viewpoint. *Atmospheric Pollution Research*, *14*(2), 101661. https://doi.org/10.1016/j.apr.2023.101661

Zhang, Y., Shao, L., Sun, X., Han, M., Zhao, X., Meng, J., Zhang, B., & Qiao, H. (2018). Outsourcing natural resource requirements within China. *Journal of Environmental Management*, *228*, 292-302. https://doi.org/10.1016/j.jenvman.2018.08.107

Zhao, S. X. B., & Zhang, L. (2007). Foreign Direct Investment and the Formation of Global City-Regions in China. *Regional Studies*, *41*(7), 979-994. https://doi.org/10.1080/00343400701281634

Zhao, X., Jiang, M., & Zhang, W. (2022). Decoupling between Economic Development and Carbon Emissions and Its Driving Factors : Evidence from China. *International Journal of Environmental Research and Public Health*, *19*(5), 2893. https://doi.org/10.3390/ijerph19052893

Zheng, H., Zhang, Z., Wei, W., Song, M., Dietzenbacher, E., Wang, X., Meng, J., Shan, Y., Ou, J., & Guan, D. (2020). Regional determinants of China's consumption-based emissions in the economic transition. *Environmental Research Letters*, *15*(7), 074001. https://doi.org/10.1088/1748-9326/ab794f

Zheng, J., Mi, Z., Coffman, D., Milcheva, S., Shan, Y., Guan, D., & Wang, S. (2019). Regional development and carbon emissions in China. *Energy Economics*, *81*, 25-36. https://doi.org/10.1016/j.eneco.2019.03.003

Zhuang, M., Gao, Z., Geng, Y., & Xiao, S. (2022). Spatial distribution pattern of embodied natural resources use in China and its relationship with socioeconomic development : From an exergetic perspective. *Resources Policy*, *79*, 103090. https://doi.org/10.1016/j.resourpol.2022.103090

Zhuang, M., Gao, Z., Geng, Y., Zhang, C., & Xiao, S. (2023). Exergy analysis of natural resources embodied in China's interregional trade and its implication for regional imbalance. *Environmental Science and Pollution Research*, *30*(39), 90814-90829. https://doi.org/10.1007/s11356-023-28025-7

8. Appendix

Appendix and supplementary data to this article can be found online under this link

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