Ecologically unequal exchange and uneven development patterns along global value chains

Althouse, Jeff; Cahen-Fourot, Louison; Carballa Smichowski, Bruno; Durand, Cédric; Knauss, Steven

DOI:
10.57938/f3897e92-1d98-4954-ad91-081b33aa93bb

Published: 01/01/2022

Document Version:
Publisher's PDF, also known as Version of record

Document License:
Unspecified

WIRTSCHAFTS UNIVERSITÄT WIEN VIENNA UNIVERSITY OF ECONOMICS AND BUSINESS

Jeff Althouse
Bruno Carballa Smichowski
Louison Cahen-Fourot
Cédric Durand
Steven Knauss

Ecologically unequal exchange and uneven development patterns along global value chains

Working Paper Series
42/2021

INSTITUTE FOR ECOLOGICAL ECONOMICS

Ecologically unequal exchange and uneven development patterns along global value chains[1]

Jeff Althouse[1], Bruno Carballa Smichowski[1], Louison Cahen-Fourot[2], Cédric Durand[3], Steven Knauss[4]

[1]Centre d'Économie de Paris-Nord, Sorbonne Paris Nord University; [2]Department of Social Sciences and Business, Roskilde University; [3]Department of History, Economics and Society, University of Geneva & Centre d'Économie de Paris-Nord, Sorbonne Paris Nord University; [4]Institute for Ecological Economics, WU Vienna University of Business and Economics

Abstract

The ecologically unequal exchange (EUE) literature has provided ample empirical evidence for asymmetric transfer of material and energy resources from low-income to high-income countries. However, research has not been able to clearly specify the causal mechanisms driving these processes. This paper relates participation in global value chains (GVCs) to development patterns and ecologically unequal exchange. We conduct a principal components analysis and a clustering analysis along six dimensions (GVC participation, GVC value capture, investment, socioeconomic development, domestic environmental impact and international environmental balance) for 133 countries between 1995 and 2015. We find three social, ecological, productive development and GVC insertion patterns: "*curse of GVC marginalization*", "*ecologically perverse upgrading*" and "*reproduction of the core*". While our results confirm the asymmetry in ecological degradation between high-income and low-income economies shown by EUE, they support the existence of alternative mechanisms to account for it. We argue that environmental asymmetries are driven in large part by differences in how countries articulate within GVCs, and therefore cannot be ascribed to relations of ecologically unequal exchange, alone. Countries with a higher capacity to capture value from GVC participation ("*reproduction of the core*") are able to displace environmental impacts to countries facing a trade-off between the positive socio-economic impacts of rapid GVC integration and ecological degradation ("*ecologically perverse upgrading*"). GVC marginalization, in turn, constitutes a barrier to socio-economic benefits and to imported ecological degradation. However, the lack of diffusion of more ecologically-efficient processes through GVCs has a negative impact on domestic ecological degradation for countries of the "*curse of GVC marginalization*" group.

Key words: Global Value Chains; Ecologically unequal exchange; Development patterns

JEL Classification: F18; O11; Q27; Q37; Q56

[1] Louison Cahen-Fourot and Steven Knauss acknowledge support of the Austrian National Bank Anniversary Fund (Österreichische Nationalbank Jubiläumsfonds project number 18651).

1 Introduction

While ecological degradation is a global phenomenon, its driving causes and consequences are far from universal. Despite growing recognition that environmental risks and responsibilities are unevenly distributed across the planet, however, research bridging global political economy and ecological economics remains underdeveloped.

Applied political economy literature, particularly those investigating the changing structure of productive relations through global value chains (GVCs), still poorly account for ecological dynamics in capitalist globalization at the macro level. In particular, they have not sufficiently grappled with the extensive material flows that underpin valorization processes at the global scale. Pioneering research mobilizing the concept of ecologically unequal exchange (EUE) has proposed important steps in this direction (Clark & Foster, 2009; Dorninger et al., 2021; Foster & Holleman, 2014; Givens et al., 2019; Hornborg, 1998, 2009; Magalhães et al., 2019; Piñero et al., 2019a).

Highlighting the highly differentiated historical and current national responsibilities in the global ecological crisis, EUE emphasizes the asymmetric transfer of material and energy resources from low-income to high-income countries. Importantly, the EUE literature demonstrates the need to move beyond the fetish of price indicators in order to account for the geographically uneven distribution of the environmental degradation. However, while EUE research provides ample empirical evidence for this crucial issue, the causal mechanisms driving these processes of ecologically unequal exchange are not fully articulated.

This paper aims at contributing to overcome this limitation by relating participation in global value chains (GVCs) to development patterns and ecologically unequal exchange. To do so, it proposes a relational perspective that draws on GVC research and insights from the ecologically unequal exchange framework. We distinguish GVC participation – as a key feature of contemporary globalization – from the more general dynamic of international trade (Carballa Smichowski et al., 2021). GVCs can then be understood as a dynamic that is predicated on the drive towards control over production processes under the hegemony of the profit motive. This drive co-evolves within a diverse geography of economico-institutional-ecological contexts, yet results in predictable patterns of social development and environmental degradation that tend to fall along traditional Core-Periphery lines.

We draw on these theoretical insights and the corresponding methodological developments to explore at the country level the economic, social, and ecological dimensions of a limited set of development patterns in relation to their integration in GVCs. Further, we aim to articulate the inter-country compossibility of these patterns; that is, we highlight their "*structural coupling, co-evolution and mutual complementarities-exclusivities and their impact on differential accumulation at a world scale*" (Jessop, 2014, p. 54).

Empirically, these different patterns are identified via a geometric data analysis for 133 countries in 1995 and 2015. We use data from well-established international databases along six dimensions (GVC participation, GVC value capture, investment, socioeconomic development, domestic environmental impact and international environmental balance).

The rest of the paper is structured as follows: section 2 reviews the literature, acknowledging the limited engagement of the GVCs literature with ecological issues at the macro level. Section 3 engages with the contribution of the EUE perspective to the understanding of uneven development and exposes our hypotheses. Section 4 details the methodology and data of our empirical investigation. Section 5 presents and discusses the results of the analysis, focusing particularly on how our paper nuances findings from within EUE. Section 6 concludes and offers opportunities for further investigation.

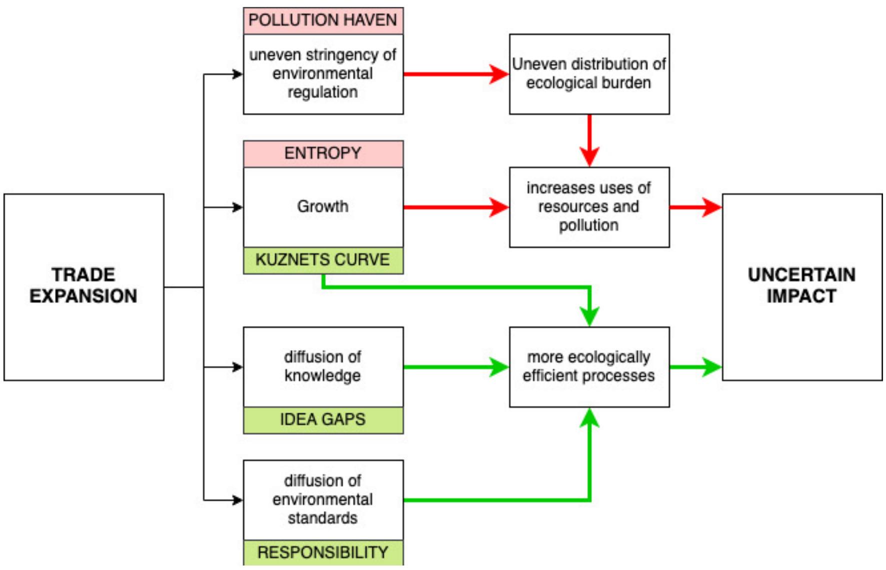
2 Engagement with ecological issues in macro GVCs literature

Rising awareness of the ecological crisis has led international economic organizations to assess how deepening trade relations are impacting the environment. Despite an overall positive assessment of the environmental leadership of lead firms (Bair et al., 2021, p. 14), the World Bank explains (World Bank, 2020, p. 4):

> *"GVCs can also have harmful effects on the environment. The main environmental costs of GVCs are associated with the growing, more distant trade in intermediate goods compared with standard trade. This leads to higher carbon dioxide (CO2) emissions from transportation (relative to standard trade) and to excess waste (especially in electronics and plastics) from the packaging of goods. The growth generated by GVCs can also strain natural resources, especially if accompanied by production or energy subsidies, which encourage excess production."*

The OECD assessment is more ambiguous. Its website affirms that "*trade can have both positive and negative effects on the environment*", suggesting an uncertain impact of trade expansion on the environment and the distribution of the ecological burden (*Trade and the environment - OECD*, 2021). It acknowledges five distinctive mechanisms at stake. Figure 1 summarizes these mechanisms and identify them under five labels, referring to their theoretical underpinnings.

Figure 1. Channels driving the uncertain global ecological impact of trade expansion (Authors' elaboration freely adapted from the OECD)



1) Entropy: First, the OECD argues that "*Economic growth resulting from trade expansion*" can directly negatively affect the environment by "*increasing pollution or degrading natural resources*". Implicitly, the underlying argument here refers to the consequences of the *entropy* law as a result of the expansion of economic processes (Georgescu-Roegen, 1971).
2) Pollution Haven Hypothesis: They also contend that "*trade liberalization may lead to specialization in pollution-intensive activities in some countries*" with less stringent

regulation. This is reminiscent of the so-called *pollution haven* hypothesis (Copeland & Taylor, 1994). One could add that trade liberalization is then likely to imply an increase in overall ecological degradation. To the extent that the benefits of economic activities are geographically disconnected from negative ecological impacts, these impacts are not able to hamper locally the expansion of economic activities and their far-away immediate negative ecological consequences.

3) Environmental Kuznets Curve: Next, following the Environmental *Kuznets Curve* (EKC) hypothesis (Grossman & Krueger 1991), the OECD considers that trade relations, "*by supporting economic growth, development, and social welfare, contribute to a greater capacity to manage the environment more effectively*".
4) Idea Gaps: Moreover, open markets "*can improve access to new technologies that make local production processes more efficient*" in terms of resources uses and pollution reduction". This is an extension to environmental issues of the *idea gaps* argument advanced in the nineties by the proponents of endogenous growth theory to designate some gains of trade and foreign investment for low-income countries related to their interaction with corporations from high-income countries (Romer, 1993).
5) Corporate Responsibility: Finally, there is an argument in terms of diffusion of corporate *responsibility*. Under the pressure of ecological awareness of citizens from rich countries and to evade the risk of tougher regulations, corporations communicate on their responsibility. Although this phenomenon goes back at least to the 1970s (Chamayou, 2021), it has taken more prominence in the past decade under the label of Voluntary Sustainability Standards (de Bakker et al., 2019; Lambin & Thorlakson, 2018). The adoption of ecologically sounder practices is supposed to trickle down on higher environmental requirements along their supply chains. This is a reason why the OECD advances that integration in the global economy stimulates "*the use of cleaner production processes and technologies*" in low-income countries.

In the context of global value chains literature at the macro level, empirical research has focused mostly on the *environmental Kuznets curve,* the *idea gaps*, the corporate *responsibility* and the *pollution haven* hypotheses. Interestingly, the *entropy* hypothesis, which directly confronts the growth paradigm to the best of our knowledge, has not been addressed in the literature. In this section, we assess the main findings of this literature on these four channels.

2.1 The environmental Kuznets curve following the gains of trade

The environmental Kuznets curve (EKC) hypothesis states that as incomes grow, environmental damage also tends to increase, before reaching a tipping point (Dinda, 2004; Sarkodie & Strezov, 2019). It is assumed that after a certain level of per capita income, growth becomes positively related to environmental quality and declining resource use. EKC theory holds that at higher levels of material security, households begin to desire improved environmental quality, and governments will be more institutionally and financially capable of protecting the environment.

In the broader literature, the empirical and theoretical evidence for an Environmental Kuznets Curve are highly contested (Padilla, 2017; Stern, 2004). First, it is problematic to treat environmental quality as a luxury good that can only be attained after a certain level of industrial development (Jorgenson, 2016). Second, econometric studies find only weak evidence for an EKC. Results often depend on the time period used, the type of pollution under scrutiny, and even the statistical method of analysis (Hoffman, 2017; Kearsley & Riddel, 2010; Nahman & Antrobus, 2005). Most importantly for the purposes of this paper, empirical investigations of the EKC study emissions dynamics of individual countries as evolving in isolation from the rest of the world. This abstracts heavily from the dynamics of globalization; global growth regimes are interdependent and co-evolve through trade. As such, studies linking the EKC and GVC participation fail to consider the global material flows that constitute the world economy and their impact on bio-chemical cycles, biodiversity, and overall planetary health. Since a large share of the energy and material transformations may originate in other countries, for example, focusing on domestic environmental aggregates masks the true consequences of a given level of economic activity (Dorninger et al., 2021; Frey, 2019).

In the part of this literature that is directly linked to GVCs, studies have empirically sought to establish a link between trade, income growth and decline of some specific environmental impacts. Wang et al. (2019) estimate the effect of participation in GVCs on per capita CO2 emissions, using panel data from 1995–2011 for 62 countries. The authors find that participation in GVCs follows the hypothesized inverted U-shaped relationship with per capita CO2 emissions. However, per capita GDP showed an N-shaped relationship with per capita CO2 emissions, implying that after a given level of income, emissions begin rising again. Their study suggests that greater participation in GVCs and upgrading through investments in R&D can technically reduce carbon emissions within a nation's borders, yet this relationship may only hold up to a certain threshold.

Assamoi et al. (2020) also find that a greater degree of participation brings about a reduction of emissions, for eleven Asian countries over the period of 1995-2014. Furthermore, Yasmeen et al. (2019) study various indicators of air pollution and their association with value-added trade within 39 countries from 1995-2009. By looking only at emissions associated with domestic production, the authors find that greater trade and higher levels of income are associated with lower levels of pollution.

If no universal relation between decrease in environmental impacts, growth and trade can be identified, an interesting question is how various growth regimes and modes of insertion within global trade generate diverse environmental outcomes (Cahen-Fourot, 2020; Cahen-Fourot & Durand, 2016; Piñero et al., 2019a).

2.2 Closing "idea gaps" to diffuse knowledge in terms of ecological efficiency

More recently, some studies have begun investigating how the changing geography of global production might also provide opportunities for countries to upgrade both their income potential and environmental efficiency (De Marchi & Di Maria, 2019; Khattak & Pinto, 2018). In this view, participating in global value chains offers a newfound means for low-income countries to adopt new technologies, meet the more stringent standards of chain leaders, all while raising incomes. De Marchi et al. (2013), for example, claim that integration within GVCs can "transform environmental constraints into new drivers of competitive advantage" that provide opportunities for increased efficiency along the chain. From this perspective, GVCs allow firms to transfer knowledge, technology and expertise up the chain, with major potential for positive spillovers. This is supposed to help to make processes and products more efficient and allows for low-income countries to upgrade their overall level of technological acumen and thereby reduce environmental impacts.

Several empirical studies have attempted to investigate the potential for environmental upgrading as a result of GVCs. Song and Wang (2017), for example, study the extent to which GVC participation in China could support greater technological upgrading and efficiency. By isolating differences in firm ownership, scale, and R&D inputs, they found that firm-level participation in GVCs came with marked improvements in spillovers in different industries. However, since Chinese firms tend to specialize in primarily low-value products, the potential for country-wide benefits was limited. This suggests that future technological upgrading would come from “transformation of the growth model and adjustments to the trade structure” (Song & Wang, 2017).

Costantini et al. (2017) find further evidence that there is room for eco-innovations to increase sectoral-level efficiency within GVCs, but pollution reductions are dependent of the type of pollution under scrutiny and the kinds of technology adopted. Finally, Wang et al. (2021) find that environmental outcomes and the potential for upgrading depend on the degree of participation within a value chain. In their study of five middle income countries from 1995 to 2009, they show that below a certain threshold of participation, greater levels of technological progress result in increased pollution. Conversely, at higher levels of participation, technological progress is associated with reduced emissions.

However, comprehensive reviews of the literature urge caution when considering the possibilities for successful environmental upgrading amongst firms and countries in low-income countries (Golgeci et al., 2021; Navarrete et al., 2020). Empirical studies have tended to obscure the uneven impacts across different sectors and between countries, specifically by focusing on technology spillovers and efficiencies at the firm- or sectoral- level. There is reason to believe that environmental upgrading within GVCs requires active regulatory intervention in order to be successful (Navarrete et al., 2020). Indeed, even the World Bank (2020) is doubtful that GVC participation will lead to greener or more equitable outcomes. The benefits of GVCs are unlikely to be widely shared unless countries can enhance social and environmental protections, implying that “all countries need to ensure that the growth associated with trade does not lead to environmental degradation” (ibid, p. 20)

The fragmentation of global production can also have an impact on the environment through the diffusion of voluntary standards. In the meantime, this can turn environmental upgrading into a tool of power, as the literature on voluntary standards in globalization to which we now turn shows.

2.3 Voluntary sustainability standards and the globalization of responsibility

Related to the view that participation in GVCs offers technological opportunities to close the idea gaps in terms of ecological efficiency, some literature advances that trade and GVCs can have a positive macro ecological impact through the diffusion of voluntary sustainability standards (VSS) among private actors (horizontally and vertically in GVCs), civil society organizations and governments (Lambin & Thorlakson, 2018).

VSS is an extension at the macro level of the Corporate Social Responsibility (CSR) literature, management practices and policy debate. Some authors consider that the incorporation of concerns of consumers via CSR can be a source of competitive advantage for businesses, allowing for “win-win-win business strategies” reconciliating financial, ecological and social dimensions in firms performance (Elkington, 1994; Porter & Kramer, 2006). Others insist that firms, governments and civil society actors are engaged in continuous struggles over the governance of global value chains. In this view, the standards implemented for chain governance result from the contestation of corporate power and the attempt by corporations to respond and anticipate these critics through their CSR policies and practices (Bair & Palpacuer, 2015; Levy, 2008). In any case, the implementation of social and environmental standards by corporations takes place on a voluntary basis, these are commitments under the auspices of a “soft” law, not the rigorous imperative of “hard” law (Supiot, 2016).

This is this logic that is pursued in VSS agreements. Their voluntary nature ensures that they do not run afoul of WTO rules and multilateral free trade agreements, while at the same time limiting the role of government enforcement. To develop and sustain the consistency of such standards, "meta-governance" institutions are formed, such as the International Social and Environmental Accreditation and Labelling Alliance (ISEAL) promoting agricultural sustainability standards (Fransen, 2015). In order to remain a good standing member of such a meta-governance alliance, firms are incentivized to upgrade their sustainability standards and to diffuse best practices to their suppliers.

Additionally, the more recent phenomenon of including environmental, social, and governance (ESG) criteria in capital markets could be seen as a variation on this VSS mechanism, possibly with more bite than ordinary VSS to the extent that central banks could, if they have the willingness to do so, effectively intervene to align firms' access to credit with their adherence to ESG standards (Barmes & Livingstone, 2021; Dafermos et al., 2020).

The verdict is still out on the impact of voluntary sustainability standards. While improvements have been noted at the micro or meso levels, larger scale objectives have been more difficult to reach (Brandi, 2017). The World Bank, for example, comments that although the cocoa industry is particularly well placed to implement such standards due to the domination of just six large companies at the downstream level of production, in practice the results have been disappointing. As a result, "Despite the strong incentives to work together to improve the social and environmental footprint of the upstream operations, the private sector commitments are not translating into improved sustainability of the supply chain in the absence of regulatory change" (World Bank, 2020, p. 128)

One explanation of this poor outcome has been proposed and tested in the context of the coffee sector. It advances that the competition between certification schemes incentivizes standard-setting organizations to expand their coverage and define substantive criteria. However, due to the lack of resources to raise standards on the ground and control implementation, the transformative capacity of VSS is very limited (Dietz & Grabs, 2021).

Furthermore, independent of any ecological impact, the push toward targeting ecological outcomes through private voluntary corporate responsibility may in certain cases end up pitting an environmental logic against an economic one for suppliers in lower value-added segments of GVCs. It's in this light that Ponte (2019, 2020) warns against what he terms a "sustainability-driven supplier squeeze," where lead firms take advantage of VSS to gain more information about suppliers' cost structure and operations that increases the lead firms' market power and ability to extract value. In his view, VSS create a trade-off between environmental upgrading and economic benefits / social standards for suppliers. Indeed, lead firms tend to leverage environmental issues to manage brand image and supply risks, while extracting 'green value' from their suppliers in low-income countries (Khan et al., 2020). As such, the implementation of specific ecological standards may go along without any overall improvement for the environment. As Ponte (2019) writes, "*In supplier jurisdictions where regulatory monitoring is poor or difficult, this can lead to* pro forma *compliance with buyer demands and certifications, while further limiting the actual impact on environmental sustainability."* If suppliers quietly cut corners, this is likely to cause long-term environmental downgrading over time. Moreover, the expansion of green standards and certified production processes may result in cleaner operations in some cases and for some environmental variables, while contributing to broader negative impacts. For example, efficiency-certified food production may still depend upon monoculture cultivation and land intensification, which continues to contribute to soil degradation and biodiversity loss.

Overall, sustainability governance through GVCs tends to reinforce the relative power of lead firms by erecting barriers to competition, forcing production risks upstream and increasing price pressures on suppliers. This severely limits the potential for local firms to benefit from participating in GVCs and reduces the capacity positive spillovers. Indeed, lead firms are more likely to focus on ways of "using the environment to appropriate value, pass on risk and costs, and position themselves commercially and politically" (Havice & Campling, 2017) relative to suppliers in low-income countries. From this perspective, the 'greening' of supply chains is more likely to reinforce uneven development dynamics and degradation than to promote sustainability and knowledge-sharing and technology upgrading (Baglioni & Campling, 2017).

The effect of the diffusion of pro-ecological standards through GVCs by means of corporate responsibility should not be completely discounted, particularly as these can likely be improved by more targeted public policy. However, such a process may bring contradictory socio-ecological impacts will not necessarily override the other diverse impacts of trade and GVC relations on the global environmental crisis.

2.4 Trade fragmentation driven by pollution haven appeal

Another strand of research advances that the pollution motive is a driving force of global trade as pollution-intensive industries are bound to relocate to "pollution havens" where environmental regulations are lax, principally in relatively low-income regions (Copeland & Taylor, 1994). The pollution haven hypothesis (PHH) contends that (i) stringent environmental standards harm growth prospects in high-income countries by sending jobs and investment overseas and (ii) strict regulations do not necessarily reduce environmental harms, but instead displace them (Cole, 2004; Karp, 2011). In the context of global capitalism where firms have improved capabilities to fragment production processes along GVCs, one should expect an increase in the displacement of polluting activities to pollution havens. Declining pollution-intensity in high-income countries, may then be associated with more pollution-intensive production in low-income countries where regulations are less strict.

It should be highlighted that the PHH remains theoretically weak and empirically debated (Gill et al., 2018; Kearsley & Riddel, 2010; Millimet & Roy, 2011) in particular because the notion that firms relocate production due primarily to the costs associated with environmental regulations is difficult to verify.

However, a growing literature has provided some corroboration for the PHH. Ederington et al. (2005) show that most studies are likely to underestimate the effects of environmental costs on trade with low-income and low-standard countries. This is especially the case because many of the most polluting industries are based in extractive production and are relatively immobile. They show that pollution abatement costs are much larger for exports produced within low-income counties even for « footloose » industries.

Many of the most recent empirical analyses increasingly show how GVCs are part of a new dynamic of production which is driving global pollution and resource use by displacing production elsewhere (Duan et al., 2021; Hertwich, 2020; Wang & Zhang, 2021; Zhang et al., 2021; Zhong et al., 2021).

Duan and Jiang (2021), for example, look at inter-industry emissions production of multinational and non-multinational enterprises. Their work confirms that the emissions-intensity of MNEs is higher than non-MNEs, suggesting that more globalized firms are more heavily polluting. Moreover, they show that a hypothetical strong reduction in global production (reshoring) would also reduce emissions: in a scenario analysis wherein (i) MNEs were replaced by the domestic counterparts in the host economies and (ii) that domestic firms in the MNEs' parent economies indicated a global reduction of carbon emissions 278 Mt. (−3.17%) and 1170 Mt. (−13.34%), respectively.

Some studies use a multi-regional input–output analysis to calculate the PHH by focusing on trade in intermediate goods, which attribute emissions to final consumers (López et al., 2013, 2018; Z. Zhang et al., 2017, 2019). Meng et al. (2018) estimate the emissions per unit of value-added within GVCs along 41 economies in 35 sectors from 1995 to 2009 and show a marked increase in emissions transferred from high-income to low-income countries as a result of GVC-related trade, noting the role of China in trade-related emissions in particular. They find that low-income countries increasingly tend to integrate within GVCs in ways that gears domestic production towards fulfilling final consumer demand in high-income countries.

The majority of available studies calculate the amount of displaced emissions using a Balanced Embodied Emissions in Trade (BEET), a statistical aggregate that measures the difference between emissions embodied in exports minus emissions embodied in imports. As it would be expected, low-income countries are shown to be net exporters of environmental impacts, while high-income countries are shown to be net importers. Moreover, these studies show that as pollution-intensive production has increasingly concentrated in havens like China and other low-income countries, global production is becoming more pollution-intensive. However, by using aggregate-level statistics like the BEET, these studies can misrepresent both the forces driving displaced emissions and the amount displaced. In particular, they would fail to take into account how technological differences can be a key determinant of relative emissions intensities (Douglas & Nishioka, 2012).

Duan et al. (2021) find the most robust causal evidence to date for the PHH within GVCs by isolating the effects of technology and using value-added trade data. Their study covers 40 economies between 1995 and 2009 to test the determinants of multiple types of air pollution. They show that the gap between emissions intensity of production in high-income countries and in low-income countries increases over time. In fact, the larger the per capita income gap between importing and exporting countries, the more pollution-intensive the value-added exports of low-income countries. The expansion of GVC-related trade appears thus to enable greater levels of trade-related pollution displacement along what the authors call “global pollution chains”.

One important issue in this literature is that many studies, including those explicitly covered here, tend to simply assume a direct correlation between regulation stringency and income. By not directly testing for environmental regulations, the authors are actually examining the link between income level (or position within value-added production) and environmental impacts embedded in trade. For this reason, positive findings for displaced pollution do not necessarily demonstrate any “comparative disadvantage” caused by environmental regulations. Rather, they indicate the systematic displacement of environmental degradation according to a country’s position within global value production. Those countries specializing in production stages at the bottom of the value hierarchy will likely have low incomes and high environmental impacts, while those at the end of the chain will appropriate the greatest share of global income and appear to have the least direct environmental impacts (Piñero et al. 2019). As such, the PHH hints at the dynamics described by ecologically unequal exchange, to which we turn in the following section.

3 The contribution of ecologically unequal exchange to uneven development

The theory of ecologically unequal exchange posits that global trade privileges the asymmetric net flow of biophysical resources and labor time from low-income to high-income countries (Dorninger et al., 2021). According to EUE, different regions occupy distinct positions within a hierarchically organized world-system wherein material inequalities are reinforced through international exchanges. Low-income (Peripheral) countries are said to concentrate in low value-added and extractive sectors, a function for which they are poorly remunerated. Although this configuration of the World Economy-Ecology is forcefully documented by the EUE, the mechanisms at stake are still poorly understood.

3.1 Polarizing the world economy through ecologically unequal exchange

EUE describes a vicious circle whereby Peripheries are driven to export a greater share of embodied resources and labor time in exchange for less resource-intensive imports from the high-income (Core) countries. Peripheries therefore suffer the increasing degradation of their home environments, weak access to necessary material and financial resources, and the disintegration of community well-being (Rice, 2007). Moreover, the concentration of extractive, resource- and pollution-intensive production in low-income countries is said to undermine the functioning of natural systems in Peripheries, thereby reinforcing inter- and intra-country inequalities (Althouse et al., 2020). As such, EUE is posed as a significant driver of uneven development, in its own right (Bunker, 1985).

In the EUE perspective, global development is a zero-sum game that favors Core countries. The Core specializes in conceptualization, logistic and marketing services and final production stages. These activities are generally less tangibles-intensive and have lower ecological impact, yet are rewarded with the greatest portion of global income. According to the EUE literature, high-income countries are therefore capable of preserving domestic environmental quality through their ability to capture global purchasing power. With a greater share of global income, they have enhanced power to use low-income countries as waste sinks or resource pools.

The empirical literature on EUE forcefully demonstrates these profound divisions. In a study of regions classified according to their relative share of world income, Dorninger et al. (2021) found that every region not classified as high-income between 1990 and 2015 served as net providers of raw materials to global production. Moreover, the value-added per ton of exported goods was shown to be eleven times higher in high-income countries than in those with the lowest income. More generally, the literature has shown that environmental impacts, including emissions (Jorgenson, 2012; Prell & Sun, 2015), water pollution (Shandra et al., 2008), biodiversity loss (Shandra et al., 2009), and deforestation (Jorgenson, 2006) are overwhelmingly concentrated in Peripheral zones.

3.2 Emphasizing imbalances do not suffice to understand causation

EUE theory offers an important analysis of the imbalances at the heart of the "world-ecological" system (Hornborg, 2003). By highlighting the environmental foundations of Center-Periphery dynamics, EUE scholars point to the injustices born of endless positional competition among private firms and nation-states (Andersson & Lindroth, 2001), exacted through improved technology (Hornborg, 2016), "green" efficiency (Bonds & Downey, 2012) or military prowess (Jorgenson, 2016). EUE theory is a reminder that on a finite planet - bound by the laws of thermodynamics - economic growth and increasing cross-border integration may reinforce patterns of underdevelopment and environmental predation, rather than alleviate them (Bunker & Ciccantell, 2005; Hornborg, 2016).

Despite its many strengths, however, EUE research has fallen short of a convincing account of how environmental inequalities arise and are perpetuated within global capitalism. Empirical work tends to measure aggregate material and pollution flows between countries to describe a generalized asymmetric relationship between high-income and low-income countries. EUE literature thus presents evidence of a generalized trend as a technical fact. As such, EUE theory does not sufficiently engage with the power, institutional and historical dynamics underpinning this trend (Infante-Amate & Krausmann, 2019) and sidesteps more specific explanations of its driving forces. After all, the observation, everything else equal, that high-income countries trade more sophisticated goods and services against more resource-intensive goods exported by low-income is an important but not necessarily surprising empirical fact (e.g., high GDP per capita is related to the production of sophisticated products that have lower remaining productive potential).

In this respect, the limitations of EUE mirror those that plagued the older Marxian discussions of economic unequal exchange. This should not be surprising, since it has long been noted that "*Marxist and ecological approaches to unequal exchange (conceptualized as underpayment of labor and energy, respectively) are analytically identical*" (Hornborg 2014: 15).

3.3 From unequal exchange to uneven development or *vice versa* ?

Early in the Marxian discussion it was acknowledged that underpayment could not be conceptualized merely as the exchange of more for less embodied labor. As Arghiri Emmanuel put it early on: "*prices corresponding to (labor) values would put a premium on non-mechanization. Technological progress would be held up*" (Emmanuel, 1972, p. 163). As a result, the literature came to largely agree on a definition of unequal exchange as "*the exchange of products whose production involves wage differentials greater than those of productivity*" (Amin, 1977, p. 211), or, put in more formal terms, where the double factoral terms of trade are not equal to unity (Raffer, 1987, pp. 92–93).

The clarity concerning the definition of unequal exchange allowed for a more straightforward discussion of its status as a cause or a mere reflection of uneven development. Emmanuel (1972) made the former case, arguing that wage differences between regions were an independent causal variable that brought about deteriorating double factor. The objection to this argument, advanced most notably by Bettelheim (1972a, 1972b), was that it was the historically-formed differences in national productive structures and capital intensities, which explained non-equivalent exchanges in terms of embodied labour. Here wage differences are a reflection of those differences in productive structures rather than a cause of them. This latter point continues to be disputed (Hickel et al., 2021).

In contrast, due to a lack of a comparable consensus over what would constitute an ecologically *equal* exchange, it has been difficult to define whether EUE is a cause or reflection of uneven development. Hornborg (2014) distinguishes between what he terms neo-physiocrat and non-reductionist schools of ecological economics. Neophysiocrats believe that ecologically equal exchange is possible as long as embodied energy / resources are not underpaid, leaving only the appropriate value metric that would determine a just payment in question. Non-reductionists, on the other hand, deny the very possibility of an ecologically equal exchange. In this view, technologies are always supported by uneven material and energy flows. The very existence of a given technology demands that lower-value, lower-entropy inputs are transformed to produce higher-value, higher-entropy outputs. Technologies are therefore considered to be an index of global purchasing power which necessarily drive unsustainable outcomes. Hornborg (2016), for example, writes that when viewing technology through the lens of the international transfers of embodied labour time, materials and energy,

> "*modern technology is always and everywhere a matter of uneven distribution in global society. This means that the extent to which a given technology is adopted hinges on the distribution of money in the world-system, and that the technology itself represents an unequal exchange of resources between different economic segments of global society.*" (Hornborg, 2016, p. 115)

In other words, as soon as any technological progress anywhere on earth has repercussions on trade flows, these flows become more asymmetrical in terms of embodied natural space.

EUE is said to occur, by definition, because more sophisticated products have lower remaining productive potential than less sophisticated products (Hornborg, 2014).

This latter conception may be true as a matter of accounting. However, it also runs the risk of conflating such accounting matters with causal ones. This can be seen in the empirical work. On the one hand, Dorninger et al. (2021, p. 8) acknowledge that their "*results stem – at least partly – from underlying differences in labour productivity, which are, in turn, contingent on the unequal availability of technological infrastructure, i.e. industrial technology and machinery*". That is to say, differences in national productive structures *à la* Bettelheim. Yet elsewhere, the authors seem to invert causality and consider EUE as "*arguably one of the main sources of inequalities in our modern world"* and that *"relationships of ecologically unequal exchange are a prerequisite for the seamless functioning of modern technology*" (Dorninger et al., 2021, p. 10).

3.4 The ambiguities of unequal exchange

One upshot of this ambiguity is the conversion of technological progress into a zero-sum game, something without precedent in the original unequal exchange literature. Yet Table 1 shows the difficulty of interpreting imbalances in embodied ecological impact, or EUE in an accounting sense, as necessarily zero-sum for the environment.

By standard accounting definitions of EUE (Dorninger et al., 2021; Moran et al., 2013; Rivera-Basques et al., 2021), everything being equal, increasing offshoring from Core regions to the Periphery will lead to greater unequal exchange and higher global footprint, while reshoring will foster less unequal exchange and reduce the global footprint. Improved efficiency in the Periphery will also both reduce unequal exchange and the global footprint. However, the dynamic is less straightforward when one considers the impact of greater efficiency in the use of resources in Core countries. Indeed, much like in the PHH research, the effect of both different levels of efficiency and that of progressive technological changes are overlooked in the aggregate statistics accounting for embodied material and energy flows (Duan et al., 2021). More efficiency may increase EUE (as an accounting matter) at the same time as it helps economize on planetary resource use, assuming the rebound effect is smaller than efficiency gains.

For example, all else equal, increases in domestic technical efficiency in a high-income country would result in a *reduction of emissions embodied in exports*. This would imply an apparent greater overall pollution displacement, despite being disconnected from trade. Additionally, given that low-income countries tend to have less efficient energy infrastructures and production systems, aggregate statistics will show that they are net-exporters of embodied pollution, even when exchanging the exact same commodity with a trading partner. This will then be mis-attributed to greater emissions displacement (PHH) or an increase in ecologically unequal exchange (EUE).[2] For this reason, Jiborn et al. (2018) propose a more demanding definition of EUE than the mere exchange of more embodied energy for less : studies would have to show both (i) that there is a reduction in domestic environmental impacts through trade and (ii) this reduction is linked to rising environmental impacts elsewhere, compared to a no-trade scenario.

Yet the conflation of such distinct mechanisms, with different implications for the global environment, under the EUE accounting-based framework demonstrates that looking into exchange relations alone are insufficient to grasp virtuous and perverse developmental and

[2] According to Kander et al (2015), this situation can even hold when a highly energy-efficient country specializes in exporting more energy-intensive production than what it imports. While such an exchange would reduce aggregate global emissions, as well as the emissions of the trading partner, aggregate accounting methods are likely to label this as an increase in EUE.

ecological dynamics in different regions. A more multi-dimensional approach is needed that can set the stage for a more precise identification of mechanisms underpinning socio-ecological development patterns, which is the objective of this contribution.

Table 1. Beyond ecologically unequal exchange: the compossibility of perverse and virtuous dynamic of economic-ecological regimes

	Global Footprint	Core domestic impact	Periphery domestic impact	Unequal Exchange
Offshoring	+	-	+	+
Reshoring	-	+	-	-
Efficiency Core	-	-	=	+
Efficiency Periphery	-	=	-	-

3.5 Hypotheses

A key aspect of the present paper is that we distinguish participation in GVCs, a central feature of contemporary globalization, from the more general dynamic of international trade. This allows us to move beyond an understanding of EUE as reflecting any underlying technical necessity of global exchanges. We hypothesize that by investigating how different countries are environmentally articulated within global production processes, we can both clarify the causal mechanisms and nuance an interpretation of EUE. This allows for a more complete understanding of the development of environmental inequalities, seeing them as a function of diverse socio-technical, institutional and historical power dynamics (Baglioni & Campling, 2017). By investigating GVCs, we provide an important window into how the global division of labor is related to the global division of environmental impacts and responsibilities (Piñero et al., 2019a).

GVCs arise as a new form of industrial organization due to "the second unbundling": "*As the ICT revolution lowered the cost of coordinating complex processes across great distances (…) it [became] possible to separate manufacturing processes internationally*" (Baldwin, 2016, p. 109). Firms with sufficient resources took advantage of this new ability to circulate knowledge and information to project their control capacities over labor processes internationally. In order to minimize their costs and sustain their profitability, they offshore labor-intensive stages of production from high-wage nations to low-wage nations, shift the location of activities as a result of regulatory or fiscal arbitrage, and deploy global sourcing strategies to benefit from the opportunities offered by the expansion of their potential supply base.

In this context, GVCs cannot be conceptualized simply as a new form of trade characterized by increased international fragmentation. What is at stake is a form of international projection of production processes to variegated economico-institutional contexts under the hegemony of the profit motive. A GVC should then be thought of as "*an institutional and economic production and valorization space where one (or a small number of) lead actor(s) exert(s) economic power to (partially) centralize profits and control(s) to some degree the labor process over geographically and often legally dispersed productive units.*" (Carballa Smichowski et al., 2021, p. 275). In such a perspective, the trade of commodities such as primary products should not be considered as GVC trade.

In keeping with this definition, we explore in this paper the ecological consequences of participation in GVCs and the resulting articulation of development patterns. Hypothetically, a "rosy scenario" could be envisaged in which GVCs promote virtuous development patterns for all while simultaneously reducing the global ecological burden. In this case, the dominant mechanisms at play would be the diffusion of knowhow (closing the idea gaps) and sustainability standards (globalization of corporate responsibility) through GVCs. Developing countries most heavily participating in GVCs could expect to capture more value through knowledge spillovers, unleashing a process of productive catching up through linkages with the broader economy. Such countries would also improve socioeconomic conditions for the majority and bring their efficiency in resource use in line with the best global standards, reducing ecologically unequal exchange in the process. If this rosy scenario were to hold, the planet could technically enter the downward phase of an environmental Kuznets curve by means of further GVC expansion. This would be opposed to the scenario in which a downward-sloping EKC in some countries is only possible due to the development of pollution havens and ecologically unequal exchange elsewhere.

In contrast to this rosy scenario, we expect to find complex relational patterns of development and ecological impact associated with GVC trade. The conceptual framework we advance to understand this articulation is represented in Figure 2. It underscores the relational dimension of development patterns associated with increasing (decreasing) participation in GVCs in the Core and the Periphery. Moreover, it proposes three main hypotheses considering the socio-economic, productive and ecological consequences of GVC participation.

3.5.1 H1. Negative productive effect of GVC participation in Core countries, but positive effect in the Periphery

Increased (decreased) participation in GVCs is adverse (favorable) to productive expansion for Core countries as for them increased (decreased) participation in GVCs mostly means offshoring (reshoring) physical production activities.

For Peripheral countries, increased participation in GVCs has a positive effect on productive dynamics as the expansion of foreign demand incentivizes investment. However, the lack of ability to capture value and the lack of internal articulation can nurture a process of immiserizing growth (Kaplinsky, 2000, 2004; Knauss, 2019; Milberg & Houston, 2005) consistent with poor economic achievements in spite of increased productive sophistication. A retreat of globalization could have the same effect in reverse, in terms of lower demand outlets but improved perspective of internal articulation and value capture.

3.5.2 H2: Diversity of socioeconomic effects of GVC participation

Increase (decreased) GVC participation allows for a variety of socioeconomic outcomes both in Core countries and Peripheral countries, depending on the domestic institutional settings and internal balance of social forces. We are inclined to consider that *divide and rule* dynamics should diminish the associational power of labor (Peoples & Sugden, 2000; Wright, 2000). The pressure on wages and labor standards of a *global reserve army* of labour should negatively affect socioeconomic outcomes. However, these factors could be counterbalanced by the distribution of some of the value capture by corporations in Core countries, by productive dynamics in the Periphery, and by diverse national institutional configurations.

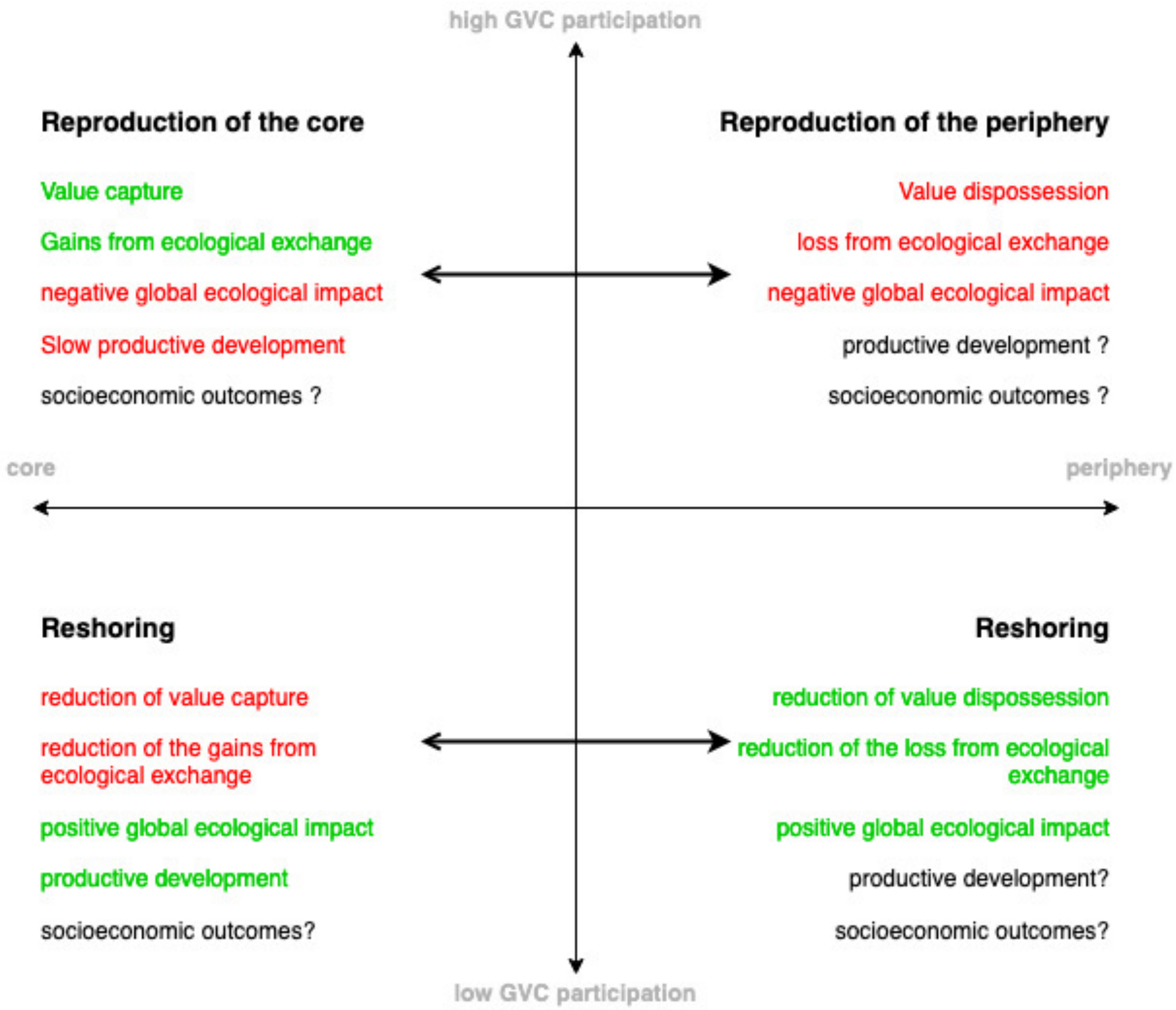
3.5.3 H3. Negative global ecological impacts of GVC participation with some relative gains to the Core at the expense of the Periphery

In terms of ecological impact, we hypothesize that GVC participation always has a negative impact at the global level, largely since processes performed in the Periphery are dirtier than in the Core. First, this is likely because Peripheral infrastructure and manufacturing processes have lower energy and resource efficiency and therefore tend to rely more on fossil fuels (Jiang & Green, 2017). Second, GVC participation also fosters ecologically unequal exchange, implying the displacement of the ecological burden at the expense of the Periphery and to the benefit of the Core. The most polluting and environmentally-intensive production processes are likely to be offshored to the Periphery.

Conversely, a retreat from globalization should be beneficial to the environment as some productive activities are reshored to places with cleaner and less resources intensive productive processes in the Core, which should also reduce the material imbalances of trade vis-à-vis the Periphery.

However, as shown in Figure 2 these relational dynamics could be affected by potential ecological improvement in productive processes in the Core. Provided that their positive global ecological impact is larger than the negative ecological effect of offshoring, we could observe a decrease in overall ecological impact and an increase in Core-Periphery material imbalances, simultaneously.

Figure 2. Ecological and socioeconomic compossibility of development patterns along GVCs



4 Data analytics

The aim of this contribution is to show the diversity of development patterns and ecologically unequal exchange dynamics in relation to participation in GVCs. As cross-national macro regressions risk masking the heterogeneity of relationships among the variables by sub-groups of countries (Rodriguez & Rodrik, 2000), we perform a principal component analysis (PCA) and then a cluster analysis on the results. This methodology is suited to capture the heterogeneity of relationships between economic, social and ecological variables among groups of countries.

4.1 Construction of variables and data sources

Our analysis includes six dimensions at the country level: participation in GVCs, value capture in GVCs, productive development, socio-economic development, domestic ecological impact and the external balance of ecological degradation.

The first two dimensions of participation and value capture in GVCs rely on Carballa-Smichowski et al. (2021). To evaluate productive development, we selected a country's investment rate and capital stock as our variables. For the socio-economic development dimension, four socio-economic variables capture the multi-dimensional nature of 'social upgrading' (Milberg and Winkler, 2013, p. 251): the rate of employment, the Palma ratio of inequality, the median income and labour's share of income. The environmental variables include measures for biodiversity loss, material extraction, local pollutants and CO_2 emissions. These variables account for the main aspects of the ecological footprint of economic activities. We approach countries' ecological footprint in two ways, reflecting our two ecological dimensions. First, we measure environmental impacts domestically, through production-based environmental variables. Second, we include an international environmental balance – a consumption-based perspective – which accounts for the environmental content embodied in net imports (Peters, 2008; Piñero et al., 2019b). As such, we include a total of 8 ecological variables.

We collected data for 133 countries for these 16 variables for the years 1995 and 2015. While some variables (e.g., the employment rate) were retrieved from a single source, others (e.g., GVC participation) were built using multiple sources.

Table 2 lists all variables and the data sources employed to retrieve or build them. The data appendix details how these data were compiled and their limitations.

Table 2. Description of the variables and the data sources

Dimension	Variable	Meaning	Description	Data sources
GVC insertion	GVCpart	GVC participation	GVC trade* as percentage of GDP	Eora26 (trade), World Bank (GDP), UNCTADStat (share of primary products in trade)
	GVCvalcap	GVC value capture	Value captured from GVC trade as a percentage of GVC trade	
Productive development	invrate	Investment rate	Gross fixed investment as percentage of GDP	World Economic Outlook (IMF)
	Kstockpop	Capital stock	Capital stock (constant 2017 USD PPP) per capita	Penn World Tables (capital stock in current USD 2017 PPP), World Bank (population and deflator)
	emprate	Employment rate	Employed population as a share of active population	ILOStat

Socio-economic development	invpalma	Palma ratio	Top 10% share of income as a ratio of bottom 40% share of income	World Inequality Database (WID)
	medinc	Median Income	Median income (household per capita equivalized, 2014 USD PPP)	PovcalNet (World Bank)
	labshare	Labor share	Gross wages as a share of net value added	Eora26
Domestic ecological impact	biodiv_ctrsize	Biodiversity loss	Domestic biodiversity loss normalized by country size. Biodiversity loss is measured as potentially disappeared fraction of species	Bjelle et al. (2021), World Bank (country size)
	domextract_ctrsize	Domestic material extraction	Domestic material extraction normalized by country size	UNEP Global Material Flows Database (materials), World Bank (country size)
	locpollgdp	Local pollutants	Kilograms of domestic local pollutant emissions per 2017$ PPP GDP	Edgar v5 (pollutants), World Bank WDI (GDP)
	co2gdp	CO2 emissions	Kilograms of domestic CO2 emissions per 2017$ PPP GDP	World Bank WDI
External balance of ecological degradation	rawtb_matfoot	Raw materials trade balance	Net embodied imports of materials as % of material footprint	UNEP Global Material Flows Database
	biodiv_importfoot	Biodiversity loss imports	Net embodied imports of biodiversity loss as % of biodiversity footprint	Bjelle et al. (2021)
	locpoll_importfoot	Local pollutant imports	Net embodied imports of local pollutants as % of local pollutant footprint	EDGAR v5, Eora, World Bank
	co2impfoot	CO2 imports	Net embodied imports of CO2 as % of CO2 footprint	Eora

* As defined by Carballa Smichowski, Durand & Knauss (2021).

To build our six dimension-based indexes and proceed to the statistical analysis, we had to normalize our variables. We scaled all variables to centre them around a mean of 0 and normalize them by the standard deviation. However, as our objective was to assess the *evolution* of development patterns and ecological dynamics along with insertion in GVCs, we opted for a hybrid treatment to express these evolutionary dynamics that considers both the differences in initial levels in 1995 and the differences in variation between 1995 and 2015. The reason for this is that the variation rate alone is not sufficient to meaningfully assess the relative shift in countries' positioning given large differences in initial levels. Based on our standardized raw variables, therefore, we composed an index for the six dimensions used in our analysis (see Table 2) by weighing each raw variable within that dimension equally, and for each variable, by weighing the 1995-2015 evolution and the initial 1995 value equally (details are provided in the data appendix).

With the resulting indexes, we ran our PCA for 133 countries for the period from 1995 to 2015. We then used the results to perform a cluster analysis that led to the identification of three groups of countries that represent three GVC-related patterns of development and ecologically unequal exchange (Section 4.3).

4.2 Statistical analysis

The principal component analysis was therefore performed with six index variables for 133 countries. For the two GVC dimensions, GVC participation and GVC value capture, a higher score simply indicates a greater gain in GVC participation / value capture between 1995 and 2015 and/or higher initial levels of GVC participation / value capture within GVCs in 1995. The other four dimensions are comprised of multiple variables weighted equally and the interpretation follows the same logic. A higher productive development index indicates greater gains and/or initial levels in investment rates and/or capital stock. A higher socioeconomic score indicates greater gains (and/or initial levels) toward outcomes associated with social upgrading along the four underlying variables – a more equal society as measured by the labour share of income and the Palma ratio; a better standard of living as measured by a higher median income and employment rate.

The two ecological dimensions should be interpreted as follows. A higher score for domestic ecological impact represents bigger increases in domestic pollution (CO2 and/or other local pollutants), biodiversity loss and/or material extraction (and/or higher initial levels in 1995). A higher score for the net external balance of ecological degradation indicates that the foreign amount of pollution (CO2 and/or other local pollutants), biodiversity loss, and/or material extraction carried out abroad in order to satisfy a country's final demand grew more rapidly than a country's domestic ecological impacts embedded in exports to foreign countries (and/or was already much higher initially in 1995). In other words, it can be seen as a measure of ecologically unequal exchange as it is often measured in the literature.

Before performing our statistical analysis, we check whether our data are suited for factor analysis using the Keyser-Meyer-Ohlin (KMO) and Bartlett tests (see Appendix). We then analyse our dataset made of the six index variables using a principal component analysis and a hierarchical clustering. Performing the PCA before the clustering reduces the number of dimensions to be analysed by getting rid of the noise in our data and keeping only the statistically significant information. It therefore improves the quality and the stability of the clustering, which we perform on the principal components rather than on the raw data (Husson et al., 2010, 2017).[3]

Our analysis indicates that at a 90% confidence level the first two axes are statistically significant and carry real information. These axes present an amount of inertia of 53.71%. This is higher than the reference value of 42.71%, which is the 0.9-quantile of the inertia percentages distribution obtained by simulating 100,000 normally distributed data tables of equivalent size. Since the first two axes carry an inertia just above 50% of the total inertia contained in our dataset, we nonetheless decide to keep the third principal component as well. This allows us to keep 70.9% of the inertia while still removing a substantial amount of the statistical noise contained in the data.[4]

4.3 Results of cluster analysis

Table 3 shows the country composition of each class resulting from the cluster analysis along with the number of countries in each grouping. To understand the specific features of these three country classes, we now turn to their intrinsic characteristics. We proceed by calculating the mean value of the six synthetic indexes used in the PCA for each class and we compare them to the sample mean. The rationale for this method is simple: when the mean of one of the

[3] See the appendix for alternative strategies.

[4] All the analyses were performed using the packages FactomineR, FactoInvestigate and missMDA for R (Husson et al., 2020; Husson & Thuleau, 2020; Josse & Husson, 2016).

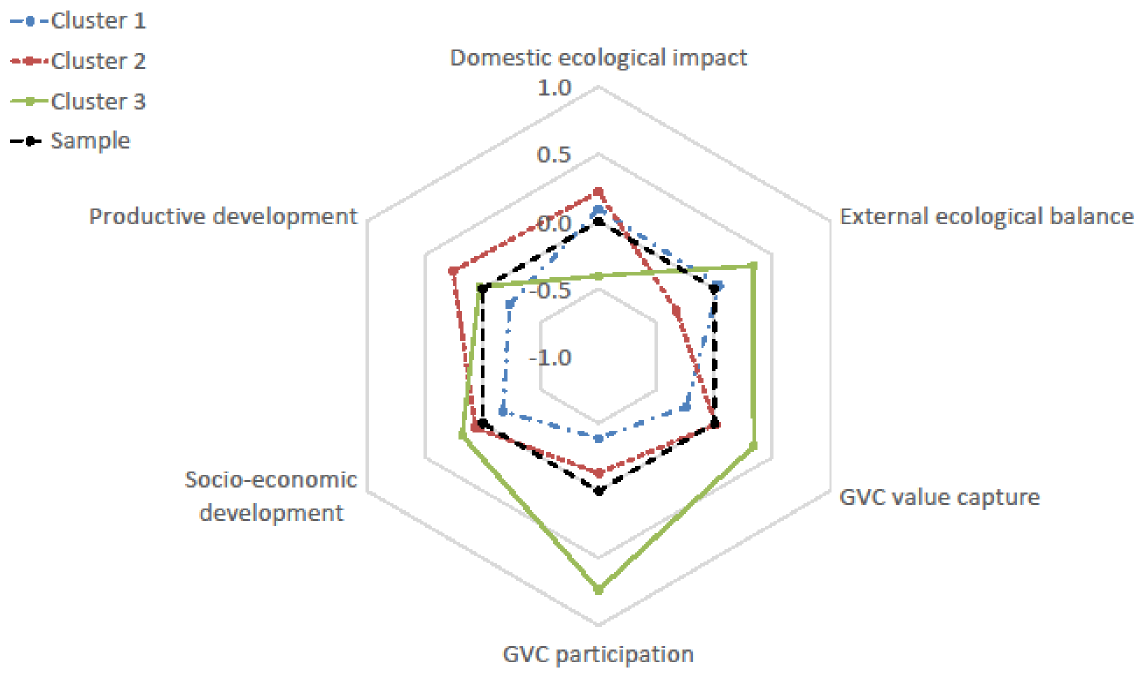
indexes for a class is significantly higher/lower than the mean of all countries in the sample, we can say that a high/low value of that index is characteristic of the class, relative to the whole sample. Given that the raw variables were standardized in order to build the indexes, the mean of the sample is equal to 0 for each index.

Figure 3 shows the result of these calculations in a radial graph. At the end of the section, Figure 4 provides a 3D representation of the cluster groupings that allows for a direct appreciation of countries' positions along the three retained axes of the PCA. Table 4 and 5 summarize the median initial 1995 values and the median 1995-2015 variation rates for all underlying raw variables by cluster and for the sample as a whole. Table 6 reports the absolute amount of domestic based environmental impact by cluster, for 1995 and in terms of evolution for the period of study. Drawing on this set of results, this section describes the characteristics of each cluster relative to the whole sample.

Table 3. Country composition of the classes

Country	Cluster 1	Cluster 2	Cluster 3
Composition	Albania, Argentina, Armenia, Azerbaijan, Burundi, Bangladesh, Belize, Bolivia, Botswana, Central African Republic, Chile, Congo - Kinshasa, Colombia, Costa Rica, Cyprus, Dominican Republic, Egypt, Ghana, Gambia, Greece, Guatemala, Honduras, Jamaica, Kenya, Cambodia, Lebanon, Morocco, Mexico, Mali, Mozambique, Mauritius, Malawi, Namibia, Nigeria, Nicaragua, Nepal, Pakistan, Peru, Philippines, Paraguay, Russia, Rwanda, Sierra Leone, Eswatini, Chad, Togo, Tajikistan, Tunisia, Turkey, Tanzania, Uruguay, South Africa, Zambia	Angola, United Arab Emirates, Australia, Bulgaria, Bahrain, Bahamas, Bosnia & Herzegovina, Brazil, Brunei, Bhutan, China, Côte d'Ivoire, Cameroon, Cape Verde, Algeria, Ecuador, Gabon, Indonesia, India, Iran, Iceland, Kazakhstan, Kuwait, Sri Lanka, Lesotho, Madagascar, Maldives, Mongolia, Mauritania, Malaysia, Niger, Norway, Oman, Panama, Saudi Arabia, Senegal, Singapore, El Salvador, Thailand, Turkmenistan, Uganda, Ukraine, Uzbekistan, Vietnam	Austria, Belgium, Canada, Switzerland, Czechia, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Georgia, Croatia, Hungary, Ireland, Israel, Italy, Jordan, Japan, Kyrgyzstan, South Korea, Lithuania, Luxembourg, Latvia, North Macedonia, Malta, Netherlands, New Zealand, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden, United States
Total	53	44	36

Figure 3. Mean value of each variable by class and for the sample as a whole



4.3.1 Cluster 1

Relative to the rest of the sample, cluster 1 is characterized by a low GVC participation and value capture. These countries are less integrated in GVCs than other countries, and their participation even declines in absolute terms over the course of the time period (Table 5). They exhibit low productive development, poor socio-economic outcomes and high domestic ecological degradation. The external ecological balance of cluster 1 is not significantly different from the sample average.

The external ecological balance is at first glance puzzling, as one would expect these countries to exhibit a negative balance - that is, to be net exporters of embedded raw materials, pollution and biodiversity loss. Indeed, the weak integration in GVCs suggests that these countries export raw materials or basic products to pay for their imports of final products. Since the former tend to use ecological resources more intensively than the manufactured goods that represent the bulk of the latter, the cluster should have a negative external ecological balance.

This result requires two important qualifications. First, Table 4 shows that at the initial 1995 level, the two positive variables in the overall ecological balance index are the local pollutant external balance and the CO2 external balance. One way of interpreting this result is that the positive balance could simply stem from a lack of industrial development and a more extensive use of human and animal labour. This would allow for a less intensive use of chemicals and other mechanical processes in their exports than in the products they import. This qualification is particularly more important since (i) the two other dimensions of the external ecological balance have negative initial values (materials balance and biodiversity balance) and (ii) for the four variables (Table 5), the evolution of the balances is negative, indicating an overall degradation between 1995 and 2015 of the overall position. Revealingly, this is the only cluster to experience a negative evolution of its materials external balance, which points to an overall increase in environmental degradation through exports.

The second important qualification is that this cluster exhibits a very high internal diversity in its external ecological balance: the standard deviation is seven times the mean, which is much higher than for clusters 2 and 3 (table 4 in the appendix). This explains the non-significance of the external ecological balance to characterize countries in this cluster: for some countries in this cluster the export sector is not highly industrialized; for others the balance is strongly negative – a feature consistent with an international specialization in raw materials.

Figure 4 helps to further characterize cluster 1. Although all three retained axes of the PCA are statistically significant, axis 1 is the most significant, and cluster 1 countries have mostly negative values on axis 1. This indicates notably low values for GVC participation and value capture, and a high value for domestic ecological impact, which are the three PCA variables most strongly determining this axis (however, other variables are also significant to determine this axis, see details of the PCA results in the appendix). Marginalization from the 'benefits' of participating in global value chains and high domestic ecological degradation are thus the main features of this cluster.

4.3.2 Cluster 2

As can be seen in Figure 3, the dynamics of GVC participation and value capture for cluster 2 are not significantly different than the sample average. Cluster 2 has the best outcome in terms of productive development, along with an improving socio-economic development. In terms of ecological outcomes, however, this class faces the worst dynamics. Countries in cluster 2 have both a high ecological domestic degradation and a degradation of their ecological external balance.

Table 4 and Table 5 help to specify the dynamic at stake. Continuity in GVC integration and value capture can be related to median income growth, reduced inequalities and productive development. Capital stock per capita at the initial 1995 level was larger than in cluster 1 and it continued to expand with high investment levels. However, these positive developments came along with an accelerated degradation of the external ecological balance in three of the four variables underlying this dimension.

Figure 4 shows that cluster 2 is primarily determined by axis 2. Most of the countries in this cluster have positive values on axis 2. This indicates, in particular, high values for productive and socio-economic development and a low value for the external ecological balance.

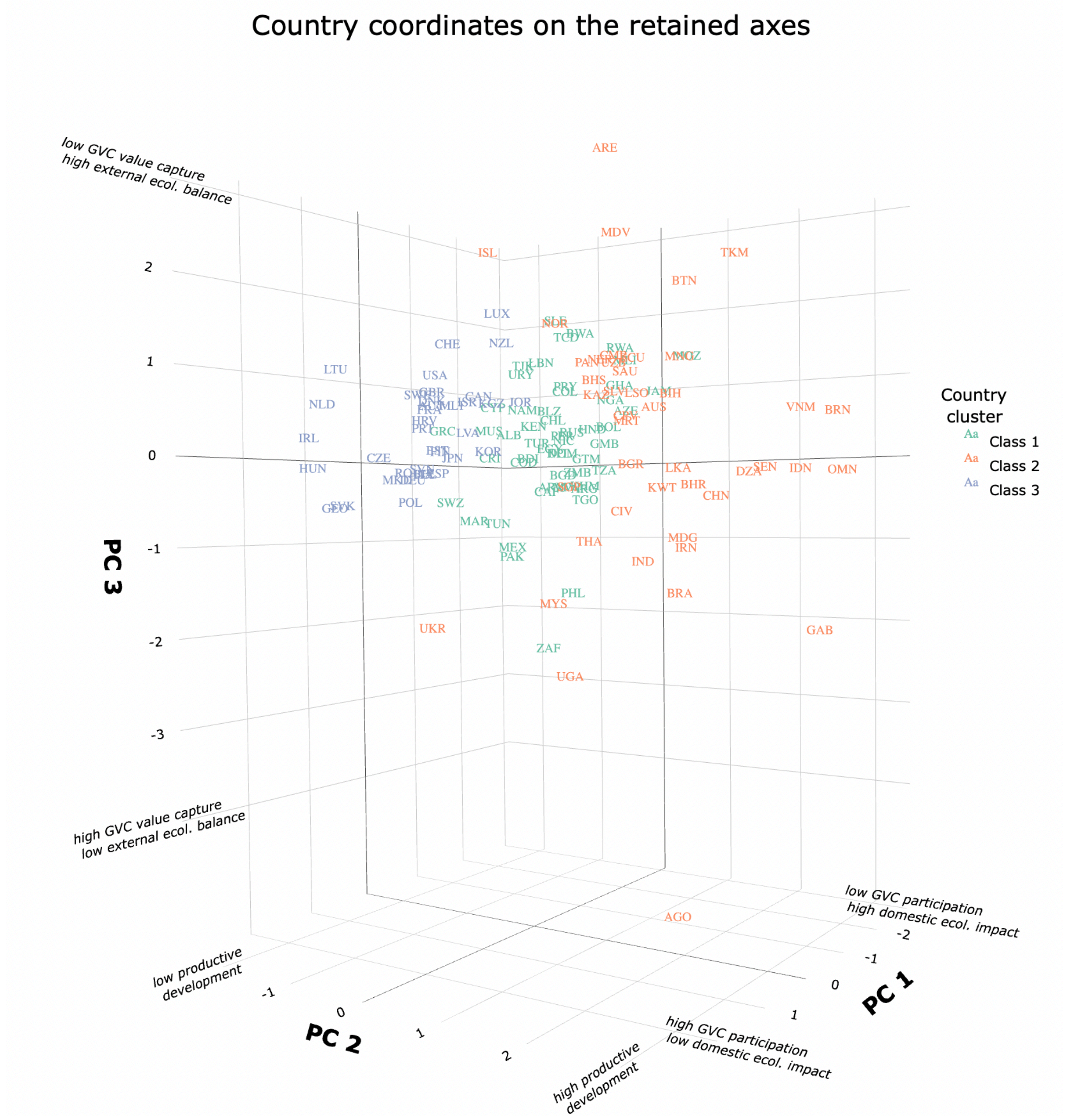
Overall, countries from cluster 2 managed to maintain their GVC integration and value capture, yet at high environmental cost. Cluster 2 appears to have fuelled their productive development and enhanced socio-economic variables in large part by exploiting domestic natural resources. This domestic exploitation was thus linked to their particular articulation within GVCs, as implied by their negative external ecological balance.

4.3.3 Cluster 3

Figure 3 shows that cluster 3 is characterized by intense participation and value capture in GVCs. Productive development is average (not significant) but socioeconomic development is more favourable than in the rest of the sample. The same goes for ecological degradation, which is relatively more reduced domestically while the countries benefit from a favourable external ecological balance (i.e. they offshore their ecological impact abroad). This position is corroborated by initial values and variation rates exhibited in Table 4 and Table 5. It is also worth noticing that, contrary to other clusters, this cluster experienced a negative evolution of the labour share and a growth in inequality, as indicated by the inverse Palma ratio. As such, the overall high positioning in terms of socioeconomic outcomes reflects a favourable initial position rather than an improvement. Also worth noting, the employment rate of cluster 3 was the lowest in 1995 and grew the most over the period.

Cluster 3 is mostly determined by axis 1. Interestingly, axis 3 is not significant to determine this cluster. This explains what can be, at first sight, puzzling when looking at Figure 4. Indeed, we can see that as far as axis 3 is concerned, countries of the Core seem to be on the low side of GVC participation and value capture. This is not the case, as clearly indicated by axis 1. Almost all of these countries have positive coordinate on this axis, indicating positive values for GVC variables and lower values for domestic ecological impact.

Figure 4. 3D representation of our clusters



Note: Only the variable or two that contribute a majority of information to the axes are listed on the respective axis labels. For PC1, this is GVC participation (29%) and domestic ecological impacts (25%). For PC2, this is productive development (51%); and for PC3, it is GVC value capture (42%) and external ecological balance (38%).

Table 4. Median starting 1995 values for all underlying variables by cluster and for the sample as a whole

	Initial 1995 level			
	Overall	**Cluster 1**	**Cluster 2**	**Cluster 3**
GVC participation	0.18	0.13	0.17	0.33
GVC value capture	0.34	0.22	0.31	0.56
Investment rate	21.98	20.97	25.0	21.88
Capital stock	21467.8	12276.7	18944.7	110413
Employment rate	93.01	93.57	94.3	91.27
Median income	1974.04	1353.99	1648.1	8613.6
Labour share	0.56	0.55	0.56	0.66
Inverse Palma ratio	-5.07	-7.11	-5.94	-2.49
Domestic material extraction per km2	369.55	310.39	315.66	910.06
Domestic local pollution intensity of GDP	0.02	0.03	0.02	0.01
Domestic biodiversity loss per km2	2.5e-08	4.65e-08	1.8e-08	1.31e-08
Domestic CO2 intensity of GDP	0.22	0.17	0.22	0.31
Materials external balance	-0.05	-0.14	-0.29	0.39
Pollution external balance	0.18	0.32	0.04	0.17
Biodiversity external balance	-0.004	-0.008	-0.003	-0.001
CO2 external balance	0.18	0.31	0.04	0.18

Table 5. Median 1995-2015 variation rates for all underlying variables by cluster and for the sample as a whole.

	1995-2015 variation rate (%)			
	Overall	**Cluster 1**	**Cluster 2**	**Cluster 3**
GVC participation	10.76	-4.03	3.27	66.0
GVC value capture	9.5	9.27	15.73	3.38
Investment rate	6.9	16.8	15.35	-0.75
Capital stock	122.9	122.	169.3	78.9
Employment rate	0.31	0.19	0.09	1.07
Median income	58.83	58.8	80.68	42.9
Labor share	0.12	0.66	0.38	-0.36
Inverse Palma ratio	0.79	14.53	5.24	-14.25
Domestic materials extraction per km^2	74.1	84.94	93.04	18.48
Domestic local pollution intensity of GDP	-52.04	-44.24	-46.46	-68.93
Domestic biodiversity loss per km^2	1.94	3.64	4.31	-4.08
Domestic CO2 intensity of GDP	-21.92	-10.3	-2.21	-43.57
Materials external balance	11.91	-28.17	14.74	30.35
Pollution external balance	-0.64	-9.41	-10.29	43.93
Biodiversity external balance	-1.79	-3.64	-3.07	3.95

CO2 external balance	-5.88	-12.08	-16.63	32.12

Table 6. Absolute amount of domestic production-based environmental impact by cluster and for the sample as a whole

		Material extraction (billion tons)	CO2 Emissions (trillion kilograms)	Local pollutants (kilograms)	Biodiversity loss (potentially disappeared fraction of species)	GDP (trillion constant 2017 $USD PPP)
Initial 1995 levels	Sample	46.1	20.7	925377	3.5	54.6
	Cluster 1	8.5	3.2	185725	1.33	8.7
	Cluster 2	22.6	6.5	42444	1.91	13.2
	Cluster 3	15	11.1	315212	0.25	32.7
Percentage change, 1995-2015	Sample	81.29	52.85	6.83	4.04	99.38
	Cluster 1	61.53	37.04	21.38	2.85	110.23
	Cluster 2	143.96	157.03	39.42	6.36	212.9
	Cluster 3	-2.19	-3.5	-45.63	-5.82	50.59

5 Discussion

This section briefly discusses our results. After presenting the three compossible development patterns we identify (Table 7), we elaborate on the implications of this analysis for the ecologically unequal exchange perspective and our understating of the GVC-environment nexus.

5.1 Labelling three compossible development patterns

Cluster 1, which we label ***the curse of GVC marginalization***, is made up of countries that stayed at the margins of global value chains and experienced poor economic and social outcomes and ecological degradation. The explanation of this development pattern relies on the lack of GVC integration, which generates *(i)* less income (directly through GVC value capture, indirectly through less productive investment) to redistribute, *(ii)* a lack of access to more ecologically efficient technologies, which results in more pollution-intensive production processes and/or specialization in more pollution-intensive activities, leading to high local ecological degradation and *(iii)* an external ecological balance that is highly heterogenous.

Cluster 2, which we label ***ecologically perverse upgrading***, exhibits an average integration into GVCs with positive productive and socio-economic outcomes. However, these favourable developments are obtained at the cost of higher-than-average local ecological degradation, which is at least in part the result of a negative external ecological balance. The logic of this development pattern is economic and socio-economic upgrading through integration in GVCs. While it may in the medium term improve incomes broadly for the population, it also implies ongoing local ecological degradation.

Cluster 3, which we label ***reproduction of the Core***, is composed of countries that are benefitting the most from integration into GVCs in terms of value capture and high incomes relative to others, while suffering less from ecological degradation. This is the story of most developed countries and some of their immediate Periphery in eastern Europe. The rationale of this development pattern is that they increased their participation in GVCs while positioning themselves withing high-value, lower ecological impact sectors. Value capture based largely on high-tech production, services (finance, marketing and branding) as well as monopoly control over patents, meant that domestic ecological impacts were kept to a minimum. This sustained an already relatively high standard of living, and provided outsized incomes that enabled greater access to consume ('dirty') foreign products.

However, contrary to cluster 2, these socio-economic benefits rely to a greater extent on an already-existing productive capacity. Moreover, they escape the immediate ecological costs of their consumption by imposing the ecological burden on other Peripheral countries.

5.2 Possible relational dynamics

Although our empirical study does not demonstrate causal effects, it suggests a relational dynamic between the three classes that are broadly aligned with our initial hypotheses.

First, while GVC participation is not associated with productive development in countries pertaining to the *reproduction of the Core* group, the findings are broadly positive in those of the *ecologically perverse upgrading* group that were able to integrate within GVCs. Interestingly, marginalization from GVCs is associated with the lowest levels of productive investment. This corroborates hypothesis 1 concerning a positive link between GVC integration and productive development being limited to Peripheral countries.

Second, we consider the contradictory channels through which GVC participation impacts socio-economic outcomes (hypothesis 2). Our analysis suggests that these are broadly aligned with productive dynamics: for marginalized countries, a lack of integration within GVCs meant poor socio-economic outcomes, while those countries capable of integration saw mostly positive gains. However, in Core countries, the positive positioning reflects mostly an initially favourable situation rather than an improving dynamic.

Third, we posited a negative global ecological impact of GVC participation with some relative gains to the Core at the expense of the Periphery. Hypothesis 3 is therefore partially corroborated but requires further elaboration and some qualification. This is where our study brings some new insights to the ecologically unequal exchange framework and to the understanding of the GVC-environment nexus.

Table 7. The compossibility of three observed development patterns

	Curse of GVC marginalization	**Ecologically perverse upgrading**	**Reproduction of the Core**
GVC participation	Low	Not distinctive	High
GVCs value capture	Low	Not distinctive	High
Productive development	Low	High	Not distinctive
Socio-economic development	Low	Above average	High
Domestic ecological degradation	Above average	High	Low
External balance of ecological degradation	Not distinctive	Negative	Positive

5.3 EUE revisited

According to EUE, ecological imbalances result automatically from exchanges in Core-Periphery trade and the development of modern technologies. The Core specializes in technologically-advanced, high-value-added production, providing it with greater purchasing power over Peripheral resources. While our results confirm a clear asymmetry in ecological degradation between high-income and low-income economies, we also find reasons to nuance the traditional EUE narrative, in particular we distinguish between two types of peripheries.

First, we locate the distribution of environmental benefits and burdens within chains of value production. Countries are differently able to integrate and capture value along production chains. This offers vastly different capacities to either accept or displace environmental impacts. We therefore provide evidence that the distribution of environmental impacts is intimately related to the global division of labor. These two dynamics appear to be interdependent and co-evolving at the world scale, a stylized fact increasingly recognized in the literature on GVCs (Althouse & Svartzman, 2022; Baglioni & Campling, 2017). Global environmental inequalities then arise through the uneven geography of value capture. Ecologically unequal outcomes are thereby shaped by socio-technical relations, institutional regulations and historical power struggles.

Second, we show that Peripheral countries that increase their participation in GVCs tend to do so at a high environmental cost. While this finding is broadly aligned with the EUE literature, we more clearly highlight the mechanisms through which the geographical distribution of global production processes reinforces environmental inequalities. In particular, we show that integrating within GVCs can upgrade productive structures and socio-economic outcomes but does not improve environmental quality for these countries.

Third, we highlight a group of countries that appear to be 'marginalized' from GVC dynamics. These countries are either participating less in trade in general compared to other countries, or are specializing in non-GVC related commodity production. This group of low-income economies also suffers from high levels of ecological degradation. Low domestic environmental safeguards due to a weak environmental regulatory state, use of highly inefficient technology and/or resulting specialization in pollution-intensive activities could explain this outcome at any level of trade.

What is puzzling from the point of view of EUE is that this cluster experiences a neutral external ecological balance, on average. First of all, it is important to stress that this group is far from homogenous along this dimension. Some countries have a strongly negative external ecological balance due to their reliance on exports of raw materials and agricultural products to generate income and foreign currency, and for such countries there is no puzzle. However, some countries in this cluster exhibit a strongly positive external ecological balance.

For this latter group of countries, further analysis in future research is required. One can nonetheless mention three potential explanations. Specialization in environmentally-intensive low-value exports may be 'balanced' materially by importing greater amounts of higher-value goods if the countries exhibit large current account deficits, funded by external finance and growing indebtedness. This would imply that foreign finance could be, at least in the short-term, a means of displacing environmental impacts by the marginalized countries. Moreover, there may be instances where value-added processes that are further along the chain are more polluting than previous stages. More precisely, these countries may rely on imports for energy and other resource intensive basic materials while their exports of primary products do not incorporate industrial processes that are intensive in resources, but instead rely extensively on labour.

Our study has also attempted to tease out the differences between environmental impacts, GVC participation, and efficiency that cannot be seen from within the EUE framework. Looking back at Table 1, we designated the domestic and global ecological differences for the Core and Periphery based on changes in reshoring, offshoring, and efficiency. All things equal, all cases of what show up as increased EUE from an accounting perspective would not have to designate a situation of an increasing global footprint.

Table 6 shows that, at the global level, the correlation between economic growth and environmental impacts is largely positive for CO2 and materials extraction and moderately positive for biodiversity and other pollutants. At the global level, there are no signs of absolute decoupling for any of the variables relative to GDP. While Core countries do exhibit some signs of absolute decoupling (particularly for CO2 and pollutants) domestically, this must be considered along with the other groups' domestic increases and the net external ecological balances of each cluster. Decoupling in the Core has largely come about by offshoring environmental impacts to the Periphery.

Interestingly, neither the c*urse of marginalization* nor the *ecologically perverse upgrading* groups saw reduced environmental impacts in absolute terms for any of the environmental variables. These findings imply that even if efficiency increases were forthcoming in the non-Core countries, they were overwhelmed by increases in environmentally-intensive production.

It is also worth noting that the *ecologically perverse upgrading* group has the sharpest increases across all four production-based environmental variables compared to the *curse of marginalization* group. This suggests that a large share of the Core's domestic decreases in environmental impacts is achieved through EUE, rather than via efficiency gains. Nevertheless, it should be pointed out that even this group of Peripheral countries strongly involved in GVCs has managed to relatively decouple for two of the four variables (local pollutants and biodiversity losses). It is therefore possible that some efficiency gains and/or legal restrictions (e.g., environmental regulations to limit certain types of pollution, the development of protected conservation areas) could have offset some of the environmental pressures.

Overall, the study suggests that while some increases in efficiency may be playing a role in bringing about environmental improvements, the Periphery's increasing integration within GVCs is a major factor in driving increased local and global environmental burdens. While this conclusion resonates with those in the EUE framework, we nonetheless provide additional explanations of the mechanisms driving environmental asymmetries that remain hidden within the EUE literature.

5.4 The trade-environment nexus revisited

Our analysis offers fresh insights concerning the general mechanisms at stake in the ecological impacts of participation in global trade (Figure 1). Depending on the clusters considered, the dynamics are not the same, which allows for a new representation of the channels linking trade and ecological outcomes (**Erreur ! Source du renvoi introuvable.**).

Countries with limited GVC participation, belonging to the group we label *curse of GVC marginalization,* do not suffer from a large "uneven distribution of ecological burden" effect, nor do they benefit from the positive ecological impacts of GVC participation in terms of more ecologically-efficient processes and higher standards. As a result, the main driver through which trade impacts the environment is through the growth channel - entropy dynamics are then the primary driver of domestic ecological degradation.

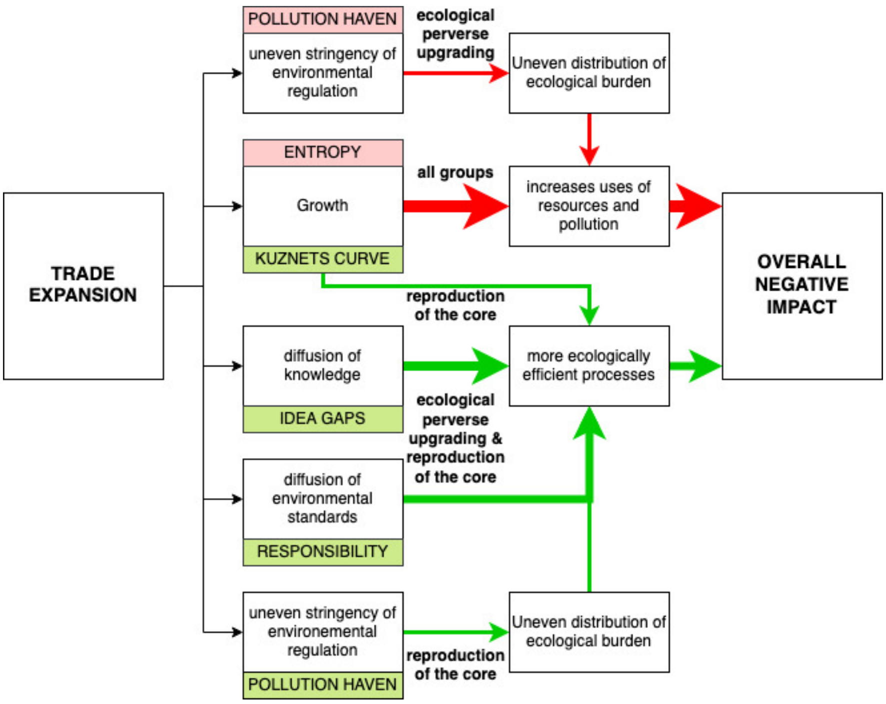
Countries pertaining to the *ecologically perverse upgrading* group do suffer both form high levels of domestic ecological degradation and a negative ecological external balance in a context of greater involvement in GVCs than the former group. This outcome is very informative, since it shows that the negative ecological impacts of trade occur through the entropy channel and the pollution haven mechanism. These dynamics seem to prevail for cluster 2's Peripheral countries, undermining the potential benefits of improved environmental standards and more environmentally-efficient technologies.

Finally, countries pertaining to the *reproduction of the Core* group exhibit much better ecological outcomes than other groups, both in terms of domestic impact and the ecological external balance. For these countries, concentration in low-impact services and end-of-chain production alongside the diffusion of more ecologically-efficient processes and higher environmental standards can play a role to domestically counter-balance the negative entropy effect of growth. However, enhanced efficiencies rely mostly on the pollution haven channel.

The green side of the pollution haven channel did not appear in Figure 1, since it was not explicitly mentioned by the OECD. It needs nonetheless to be considered in order to stress that there is a zero-sum game dimension in the ecological impact of trade.

Overall, considering that the entropy channel plays a role for all groups while the net positive impact is limited to the *reproduction of the Core* group, this framework suggest that the overall ecological impact of trade is negative.

Figure 5. Channels driving the overall global negative ecological impact of trade expansion (Authors' elaboration)



6 Conclusion

This article has provided a theoretical and empirical investigation into the uneven environmental transformations associated with different modes of insertion within global trade. We analyzed compossible development patterns within GVCs for 133 countries between 1995 and 2015, using data covering six key dimensions: GVC participation, GVC value capture, productive development, socio-economic development, domestic environmental impact and international environmental balance. Our results confirm that GVCs are a major driver of unequal socio-ecological developments. While integration within GVCs may enhance socio-economic indicators for some countries there is a general trend towards increasing polarization and ecologically unequal exchange. In other words, while in socio-economic terms GVC participation is a positive-sum game but asymmetrical (some countries benefit more than others), in ecological terms we do find some zero-sum game dynamics.

The clustering analysis allowed us to identify three distinct development patterns associated with integration within GVCs*: the curse of GVC marginalization, ecologically perverse upgrading and a reproduction of the Core*. Countries succumbing to the *curse of GVC marginalization* demonstrated decreases or minor increases in GVC participation and value capture, low productive development, poor socioeconomic outcomes and high domestic ecological degradation. This class of countries was thereby isolated from the potential socio-economic benefits of GVC integration, yet also exhibited relatively high levels of domestic ecological burden.

Those countries whose development is best described through *ecologically perverse upgrading* were most capable of increasing their productive capacity and capturing socio-economic benefits associated with their GVC participation. However, this development pattern was linked to a major increase in domestic ecological degradation and a decline in its external environmental balance. This implies that improvements in social and economic outcomes were driven in large part by exploiting domestic natural resources for export to the rest of the world.

The *reproduction of the Core* dynamic refers primarily to high-income countries whose dominant position in GVCs is demonstrated by increases in levels of GVC participation and value capture. Moreover, this group is characterized by strong levels of socio-economic development, relatively low domestic degradation, and a high external ecological balance. The Core's position within production networks appears to allow them to sustain high levels of profitability and low levels of productive development while offshoring ecological impacts abroad.

Overall, our results imply a difficult road ahead for achieving more ecologically balanced patterns of socio-economic development. On the one hand, high levels of participation in global production networks may bring social benefits, yet are associated with a concomitant increase in environmental exploitation, whether domestic (the Periphery) or abroad (the Core). On the other hand, those countries not integrating into GVCs remain vulnerable to domestic ecological degradation and low levels of socio-economic development.

7 References

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., & Svartzman, R. (2022). Bringing Subordinated Financialisation Down to Earth: The Political Ecology of Finance-Dominated Capitalism. *Cambridge Journal of Economics*, *forthcoming*, 32.

Amin, S. (1977). *Imperialism and Unequal Development*. Monthly Review Press.

Andersson, J. O., & Lindroth, M. (2001). Ecologically unsustainable trade. *Ecological Economics*, *37*(1), 113–122. https://doi.org/10.1016/S0921-8009(00)00272-X

Baglioni, E., & Campling, L. (2017). Natural resource industries as global value chains: Frontiers, fetishism, labour and the state. *Environment and Planning A: Economy and Space*, *49*(11), 2437–2456.

Bair, J., Mahutga, M., Werner, M., & Campling, L. (2021). Capitalist crisis in the "age of global value chains." *Environment and Planning A: Economy and Space*, 0308518X211006718.

Bair, J., & Palpacuer, F. (2015). CSR beyond the corporation: Contested governance in global value chains. *Global Networks*, *15*(s1), S1–S19. https://doi.org/10.1111/glob.12085

Baldwin, R. E. (2016). *The great convergence: Information technology and the new globalization*. The Belknap Press of Harvard University Press.

Barmes, D., & Livingstone, Z. (2021). *The green central banking scorecard. How green are G20 central banks and financial supervisors*. Positive Money. https://positivemoney.org/green-central-banking-scorecard/

Bettelheim, C. (1972a). Preface to the French edition. In *Unequal Exchange: A study on the imperialism of trade*. Monthly Review Press.

Bettelheim, C. (1972b). Theoretical Comments. In *Unequal Exchange: A study on the imperialism of trade*. Monthly Review Press.

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

Brandi, C. A. (2017). Sustainability standards and sustainable development synergies and trade-offs of transnational governance. *Sustainable Development*, *25*(1), 25–34.

Bunker, S. G. (1985). *Underdeveloping the Amazon: Extraction, unequal exchange, and the failure of the modern state*. University of Chicago Press.

Bunker, S. G., & Ciccantell, P. S. (2005). *Globalization and the Race for Resources*. Johns Hopkins University Press.

Cahen-Fourot, L. (2020). Contemporary capitalisms and their social relation to the environment. *Ecological Economics*, *172*, 106634. https://doi.org/10.1016/j.ecolecon.2020.106634

Cahen-Fourot, L., & Durand, C. (2016). La transformation de la relation sociale à l'énergie du fordisme au capitalisme néolibéral. Une exploration empirique et macro-économique comparée dans les pays riches (1950-2010). *Revue de La Régulation. Capitalisme, Institutions, Pouvoirs*, *20*.

Carballa Smichowski, B., Durand, C., & Knauss, S. (2021). Participation in global value chains and varieties of development patterns. *Cambridge Journal of Economics*, *45*(2), 271–294. https://doi.org/10.1093/cje/beaa046

Chamayou, G. (2021). *The ungovernable society: A genealogy of authoritarian liberalism* (A. Brown, Trans.). Polity Press.
Clark, B., & Foster, J. B. (2009). Ecological Imperialism and the Global Metabolic Rift: Unequal Exchange and the Guano/Nitrates Trade. *International Journal of Comparative Sociology*, *50*(3–4), 311–334. https://doi.org/10.1177/0020715209105144
Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics*, *48*(1), 71–81. https://doi.org/10.1016/j.ecolecon.2003.09.007
Copeland, B. R., & Taylor, M. S. (1994). North-South trade and the environment. *The Quarterly Journal of Economics*, *109*(3), 755–787.
Costantini, V., Crespi, F., Marin, G., & Paglialunga, E. (2017). Eco-innovation, sustainable supply chains and environmental performance in European industries. *Journal of Cleaner Production*, *155*, 141–154.
Dafermos, Y., Gabor, D., Nikolaidi, M., Pawloff, A., & van Lerven, F. (2020). *Decarbonising is easy: Beyond market neutrality in the ECB's corporate QE*.
de Bakker, F. G., Rasche, A., & Ponte, S. (2019). Multi-stakeholder initiatives on sustainability: A cross-disciplinary review and research agenda for business ethics. *Business Ethics Quarterly*, *29*(3), 343–383.
De Marchi, V., & Di Maria, E. (2019). Environmental upgrading and suppliers' agency in the leather global value chain. *Sustainability*, *11*(23), 6530.
De Marchi, V., Di Maria, E., & Ponte, S. (2013). The greening of global value chains: Insights from the furniture industry. *Competition & Change*, *17*(4), 299–318.
Dietz, T., & Grabs, J. (2021). Additionality and Implementation Gaps in Voluntary Sustainability Standards. *New Political Economy*, 1–22. https://doi.org/10.1080/13563467.2021.1881473
Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, *49*(4), 431–455.
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
Douglas, S., & Nishioka, S. (2012). International differences in emissions intensity and emissions content of global trade. *Journal of Development Economics*, *99*(2), 415–427.
Duan, Y., Ji, T., & Yu, T. (2021). Reassessing pollution haven effect in global value chains. *Journal of Cleaner Production*, *284*, 124705. https://doi.org/10.1016/j.jclepro.2020.124705
Duan, Y., & Jiang, X. (2021). Pollution haven or pollution halo? A Re-evaluation on the role of multinational enterprises in global CO2 emissions. *Energy Economics*, *97*, 105181.
Ederington, J., Levinson, A., & Minier, J. (2005). Footloose and pollution-free. *Review of Economics and Statistics*, *87*(1), 92–99.
Elkington, J. (1994). Towards the sustainable corporation: Win-win-win business strategies for sustainable development. *California Management Review*, *36*(2), 90–100.
Emmanuel, A. (1972). *Unequal Exchange: A study on the imperialism of trade*. Monthly Review Press.
Foster, J. B., & Holleman, H. (2014). The theory of unequal ecological exchange: A Marx-Odum dialectic. *The Journal of Peasant Studies*, *41*(2), 199–233. https://doi.org/10.1080/03066150.2014.889687
Fransen, L. (2015). The politics of meta-governance in transnational private sustainability governance. *Policy Sciences*, *48*(3), 293–317.
Frey, R. S. (2019). *Ecologically unequal exchange: Environmental injustice in comparative and historical perspective*. Springer International Publishing.

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

Gill, F. L., Viswanathan, K. K., & Karim, M. Z. A. (2018). The Critical Review of the Pollution Haven Hypothesis. *International Journal of Energy Economics and Policy*, *8*(1), 167–174.

Givens, J. E., Huang, X., & Jorgenson, A. K. (2019). Ecologically unequal exchange: A theory of global environmental *in* justice. *Sociology Compass*, *13*(5), e12693. https://doi.org/10.1111/soc4.12693

Golgeci, I., Makhmadshoev, D., & Demirbag, M. (2021). Global value chains and the environmental sustainability of emerging market firms: A systematic review of literature and research agenda. *International Business Review*, 101857.

Havice, E., & Campling, L. (2017). Where Chain Governance and Environmental Governance Meet: Interfirm Strategies in the Canned Tuna Global Value Chain. *Economic Geography*, *93*(3), 292–313. https://doi.org/10.1080/00130095.2017.1292848

Hertwich, E. G. (2020). Carbon fueling complex global value chains tripled in the period 1995–2012. *Energy Economics*, *86*, 104651.

Hickel, J., Sullivan, D., & Zoomkawala, H. (2021). Plunder in the Post-Colonial Era: Quantifying Drain from the Global South Through Unequal Exchange, 1960–2018. *New Political Economy*. https://doi.org/10.1080/13563467.2021.1899153

Hoffman, J. (2017). Sustainability and inequality: Confronting the debate. *International Journal of Urban Sustainable Development*, *9*(3), 359–364. https://doi.org/10.1080/19463138.2017.1333004

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. (2003). Cornucopia or zero-sum game? The epistemology of sustainability. *Journal of World-Systems Research*, *9*(2), 205–216.

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. (2014). Ecological economics, marxism, and technological progress: Some explorations of the conceptual foundations of theories of ecologically unequal exchange. *Ecological Economics*, *105*, 11–18.

Hornborg, A. (2016). *Global Magic: Technologies of Appropriation from Ancient Rome to Wall Street*. Palgrave Macmillan.

Husson, F., Josse, J., Le, S., & Mazet, J. (2020). *Package 'FactoMineR'* (2.4) [Computer software].

Husson, F., Josse, J., & Pages, J. (2010). Principal component methods—Hierarchical clustering—Partitional clustering: Why would we need to choose for visualizing data? *Agrocampus Technical Report*, 17.

Husson, F., Lê, S., & Pagès, J. (2017). *Exploratory Multivariate Analysis by Example Using R*. CRC Press.

Husson, F., & Thuleau, S. (2020). *Package 'FactoInvestigate'* (1.7) [Computer software].

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

Jessop, B. (2014). Capitalist diversity and variety: Variegation, the world market, compossibility and ecological dominance. *Capital & Class*, *38*(1), 45–58.

Jiang, X., & Green, C. (2017). The impact on global greenhouse gas emissions of geographic shifts in global supply chains. *Ecological Economics*, *139*, 102–114.

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

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. (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. (2016). Environment, Development, and Ecologically Unequal Exchange. *Sustainability*, *8*(3), 227. https://doi.org/10.3390/su8030227

Josse, J., & Husson, F. (2016). missMDA: A Package for Handling Missing Values in Multivariate Data Analysis. *Journal of Statistical Software*, *70*(1). https://doi.org/10.18637/jss.v070.i01

Kander, A., Jiborn, M., Moran, D. D., & Wiedmann, T. O. (2015). National greenhouse-gas accounting for effective climate policy on international trade. *Nature Climate Change*, *5*(5), 431–435. https://doi.org/10.1038/nclimate2555

Kaplinsky, R. (2000). Globalisation and Unequalisation: What Can Be Learned from Value Chain Analysis? *Journal of Development Studies*, *37*(2), 117–146. https://doi.org/10.1080/713600071

Kaplinsky, R. (2004). *IMMISERISING GROWTH–Note# 2*.

Karp, L. (2011). The Environment and Trade. *Annual Review of Resource Economics*, *3*(1), 397–417. https://doi.org/10.1146/annurev-resource-083110-115949

Kearsley, A., & Riddel, M. (2010). A further inquiry into the Pollution Haven Hypothesis and the Environmental Kuznets Curve. *Ecological Economics*, *69*(4), 905–919. https://doi.org/10.1016/j.ecolecon.2009.11.014

Khan, M. J., Ponte, S., & Lund-Thomsen, P. (2020). The 'factory manager dilemma': Purchasing practices and environmental upgrading in apparel global value chains. *Environment and Planning A: Economy and Space*, *52*(4), 766–789. https://doi.org/10.1177/0308518X19876945

Khattak, A., & Pinto, L. (2018). A Systematic Literature Review of the Environmental Upgrading in Global Value Chains and Future Research Agenda. *Journal of Distribution Science*, *16*(11), 11–19. https://doi.org/10.15722/JDS.16.11.201811.11

Knauss, S. (2019). *Downgrading in Global Value Chains: Theoretical and empirical inquiry into developmental difficulties in the globalization era*.

Lambin, E. F., & Thorlakson, T. (2018). Sustainability standards: Interactions between private actors, civil society, and governments. *Annual Review of Environment and Resources*, *43*, 369–393.

Levy, D. L. (2008). Political contestation in global production networks. *Academy of Management Review*, *33*(4), 943–963.

López, L. A., Arce, G., Kronenberg, T., & Rodrigues, J. F. D. (2018). Trade from resource-rich countries avoids the existence of a global pollution haven hypothesis. *Journal of Cleaner Production*, *175*, 599–611. https://doi.org/10.1016/j.jclepro.2017.12.056

López, L. A., Arce, G., & Zafrilla, J. E. (2013). Parcelling virtual carbon in the pollution haven hypothesis. *Energy Economics*, *39*, 177–186. https://doi.org/10.1016/j.eneco.2013.05.006

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.

McKinney, L. A. (2019). The Entropy Curse. In R. S. Frey, P. K. Gellert, & H. F. Dahms (Eds.), *Ecologically unequal exchange: Environmental injustice in comparative and historical perspective* (pp. 143–166). Springer International Publishing.

Meng, B., Peters, G. P., Wang, Z., & Li, M. (2018). Tracing CO2 Emissions in Global Value Chains. *Energy Economics*, *73*, 24–42.

Milberg, W., & Houston, E. (2005). The high road and the low road to international competitiveness: Extending the neo-Schumpeterian trade model beyond technology. *International Review of Applied Economics*, *19*(2), 137–162. https://doi.org/10.1080/02692170500031646

Millimet, D. L., & Roy, J. (2011). *Three New Empirical Tests of the Pollution Haven Hypothesis When Environmental Regulation is Endogenous* (IZA Discussion Papers No. 5911; p. 45). Institute for the Study of Labor (IZA). http://nbn-resolving.de/urn:nbn:de:101:1-20110927147

Moran, D. D., Lenzen, M., Kanemoto, K., & Geschke, A. (2013). Does ecologically unequal exchange occur? *Ecological Economics*, *89*, 177–186.

Nahman, A., & Antrobus, G. (2005). The Environmental Kuznets Curve: A Literature Survey. *The South African Journal of Economics*, *73*(1), 105–120. https://doi.org/10.1111/j.1813-6982.2005.00008.x

Navarrete, S. D. S., Borini, F. M., & Avrichir, I. (2020). Environmental upgrading and the United Nations Sustainable Development Goals. *Journal of Cleaner Production*, *264*, 121563. https://doi.org/10.1016/j.jclepro.2020.121563

Padilla, E. (2017). What can developing countries gain from a green transformation? In T. Altenburg & C. Assmann (Eds.), *Green Industrial Policy: Concept, Policies, Country Experiences* (pp. 22–37). UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE). https://www.die-gdi.de/uploads/media/GREEN_INDUSTRIAL_POLICY.Endf.pdf#page=17

Peoples, J., & Sugden, R. (2000). 8 Divide and rule by transnational corporations. *The Nature of the Transnational Firm*, 174.

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., Bruckner, M., Wieland, H., Pongrácz, E., & Giljum, S. (2019a). The raw material basis of global value chains: Allocating environmental responsibility based on value generation. *Economic Systems Research*, *31*(2), 206–227.

Piñero, P., Bruckner, M., Wieland, H., Pongrácz, E., & Giljum, S. (2019b). The raw material basis of global value chains: Allocating environmental responsibility based on value generation. *Economic Systems Research*, *31*(2), 206–227. https://doi.org/10.1080/09535314.2018.1536038

Ponte, S. (2019). *Business, power and sustainability in a world of global value chains*. Zed Books Ltd.

Ponte, S. (2020). The hidden costs of environmental upgrading in global value chains. *Review of International Political Economy*, 1–26. https://doi.org/10.1080/09692290.2020.1816199

Porter, M. E., & Kramer, M. R. (2006). The link between competitive advantage and corporate social responsibility. *Harvard Business Review*, *84*(12), 78–92.

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

Raffer, K. (1987). *Unequal Exchange and the Evolution of the World-System: Reconsidering the impact of trade on North-South relations*. Palgrave MacMillan.

Rice, J. (2007). Ecological Unequal Exchange: International Trade and Uneven Utilization of Environmental Space in the World System. *Social Forces*, *85*(3), 1369–1392. JSTOR.

Rivera-Basques, L., Duarte, R., & Sánchez-Chóliz, J. (2021). Unequal ecological exchange in the era of global value chains: The case of Latin America. *Ecological Economics*, *180*, 106881. https://doi.org/10.1016/j.ecolecon.2020.106881

Rodriguez, F., & Rodrik, D. (2000). Trade policy and economic growth: A skeptic's guide to the cross-national evidence. *NBER Macroeconomics Annual*, *15*, 261–325.

Romer, P. (1993). Idea gaps and object gaps in economic development. *Journal of Monetary Economics*, *32*(3), 543–573. https://doi.org/10.1016/0304-3932(93)90029-F

Sarkodie, S. A., & Strezov, V. (2019). A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. *Science of the Total Environment*, *649*, 128–145.

Shandra, J. M., Leckband, C., McKinney, L. A., & London, B. (2009). Ecologically unequal exchange, world polity, and biodiversity loss: A cross-national analysis of threatened mammals. *International Journal of Comparative Sociology*, *50*(3–4), 285–310.

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. JSTOR.

Song, M., & Wang, S. (2017). Participation in global value chain and green technology progress: Evidence from big data of Chinese enterprises. *Environmental Science and Pollution Research*, *24*(2), 1648–1661.

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. *World Development*, *32*(8), 1419–1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Supiot, A. (2016). What international social justice in the twenty-first century. *Labour Law and Social Progress Holding the Line or Shifting the Boundaries*.

Wackernagel, M., Lin, D., Evans, M., Hanscom, L., & Raven, P. (2019). Defying the Footprint Oracle: Implications of Country Resource Trends. *Sustainability*, *11*(7), 2164. https://doi.org/10.3390/su11072164

Wang, Q., & Zhang, F. (2021). The effects of trade openness on decoupling carbon emissions from economic growth–evidence from 182 countries. *Journal of Cleaner Production*, *279*, 123838.

Wang, S., He, Y., & Song, M. (2021). Global value chains, technological progress, and environmental pollution: Inequality towards developing countries. *Journal of Environmental Management*, *277*, 110999. https://doi.org/10.1016/j.jenvman.2020.110999

World Bank. (2020). *World Development Report 2020: Trading for Development in the Age of Global Value Chains*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1457-0

Wright, E. O. (2000). Working-Class Power, Capitalist-Class Interests, and Class Compromise. *American Journal of Sociology*, *105*(4), 957–1002.

Zhang, D., Wang, H., Löschel, A., & Zhou, P. (2021). The changing role of global value chains in CO2 emission intensity in 2000–2014. *Energy Economics*, *93*, 105053. https://doi.org/10.1016/j.eneco.2020.105053

Zhang, Z., Duan, Y., & Zhang, W. (2019). Economic gains and environmental costs from China's exports: Regional inequality and trade heterogeneity. *Ecological Economics*, *164*, 106340. https://doi.org/10.1016/j.ecolecon.2019.05.020

Zhang, Z., Zhu, K., & Hewings, G. (2017). A Multi-regional Input–output Analysis of the Pollution Haven Hypothesis from the Perspective of Global Production Fragmentation. *Energy Economics*, *64*. https://doi.org/10.1016/j.eneco.2017.03.007

Zhong, Z., Guo, Z., & Zhang, J. (2021). Does the participation in global value chains promote interregional carbon emissions transferring via trade? Evidence from 39 major economies. *Technological Forecasting and Social Change*, *169*, 120806. https://doi.org/10.1016/j.techfore.2021.120806

Appendix

Ecologically unequal exchange and uneven development patterns along global value chains

Jeff Althouse[1], Bruno Carballa Smichowski[1], Louison Cahen-Fourot[2], Cédric Durand[3], Steven Knauss[4]

[1]Centre d'Économie de Paris-Nord, Sorbonne Paris Nord University; [2]Department of Social Sciences and Business, Roskilde University; [3]Department of History, Economics and Society, University of Geneva & Centre d'Économie de Paris-Nord, Sorbonne Paris Nord University; [4]Institute for Ecological Economics, WU Vienna University of Business and Economics

This appendix contains detailed information on the sources and methodology employed to produce each of the variables used in the data analysis (Section 1), methodological choices affecting all the variables (Section 2) and the justification of some methodological choices made during the data analysis process (Section 3). Summary statistics of the variables for all the countries retained in the final sample are presented in

Table 2.

1 Construction of the variables

In this section we provide, for each variable, a description of how it is built, the sources and other relevant variable-specific information regarding the treatment of the variable.

1.1 GVC participation

We calculate GVC participation following Carballa Smichowski et al (2021)'s formula, shown in Equation 1.

Equation 1 : GVC participation

$$\frac{[XDVA * (1 - ppX) + ipM * (1 - ppM)]}{GDP}$$

Where *XDVA* is domestic value added in gross exports, *ppX* is the share of primary products in total exports, *ipM* is gross imports of intermediate products and *ppM* the share of primary products in total imports.

This indicator was chosen over the standard one used by international organizations such as UNCTAD or the OECD, as well as in the macro GVC literature, because we consider it to better capture the particularities of GVC-related trade. The standard indicator calculates GVC participation as the portion of a given product that crosses at least two frontiers (forward and backwards participation) as a share of total exports[1] (Borin and Mancini, 2019; Hummels et al., 2001, p. 76). Carballa Smichowski et al's indicator presents three main differences.

[1] Degain et al (2017) and Wang et al (2017) have nuanced this two-border rule by introducing the concept of "simple global value chain". The latter includes trade that crosses only one border but is produced in at least two countries. "Complex global value chains", in turn, correspond to the standard two-borders rule definition.

First, it does not consider primary products trade as GVC trade. Indeed, primary products are homogeneous in terms of quality of generic character. Therefore, they do not reflect a significant degree of transnational command over production between firms, which is a constituent characteristic of GVC trade. Moreover, given the high volatility of primary products' prices, including them in the sample might generate an inaccurate picture of commodity-exporting countries' involvement and value capture in GVCs. In particular, within the timespan of our study (1995-2015), eliminating primary products offsets the effects of the 2000s commodity boom from the analysis. Our analysis therefore takes into account the ecological impacts[2] of commodities trade by focusing only on those effects embedded in the trade of intermediary and final products within GVC's division of labour.

Second, contrary to the standard GVC participation indicator that is based on the two-borders rule (i.e., GVC trade covers the portion of a given product that crosses at least two frontiers[3]), we include all imports and exports of non-primary products as GVC trade, with the exception of the direct import of a finished product for domestic use. This approach has the advantage of including intermediary inputs imports that are not re-exported on the imports side (backward participation) and all intermediate inputs and final products (as opposed to only re-exported intermediate inputs) on the exports side (forward participation). By lifting the two-borders rule, we are able to capture more trade that translates transnational command over production. For example, contrary to the standard definition of GVC participation, this formula considers that intermediary inputs not re-exported by the importer constitute GVC trade for both the importer and the exporter. This is because a country importing intermediary inputs is linked by command over production links with the exporting country in that it requires to adapt its productive structure to a non-generic productive choice maid by the exporting country. Conversely, given that is unlikely that the exporting country produces all the parts of the exported intermediary input locally, the trade of this intermediary input is to be considered GVC for the exporting country as it is the result of transnational division of labour to produce a non-generic good.

Third, instead of dividing GVC trade by gross exports, we divide it by GDP. This difference responds to the particularities of our research question. We want to assess the environmental and developmental effects of GVCs as a form of division of labour, rather than the share of trade that can be explained by GVCs. Calculating GVC trade relative to the size of a countries' economy gives us a more accurate picture of the relevance of GVCs for a country's economy.

In order to build this indicator, we recurred to three datasets. The first one is EORA26 (Lenzen et al., 2012, 2013), which we use to obtain data on trade. This dataset was chosen over alternative databases, notably OECD'S TIVA since EORA26 has a considerable larger country coverage: 189 countries and a "rest of the world" region. OECD's TIVA 2018 edition includes 64 countries and a "rest of the world" region. Counting with a large panel of countries is critical to our research question, which can only be approached empirically by observing a large number and variety of countries in terms of their insertion in GVCs and ecological characteristics. The latter is particularly important, as a sample with several missing countries could obfuscate ecologically unequal exchange dynamics through which the ecological impact correlate of the value captured by a country through GVC participation is offloaded to another one. The methodology behind the two datasets has been assessed to be solid and their results consistent. Studies comparing traditional GVC indicators values between EORA26 and TiVA have shown strong correlation between the two (Aslam et al., 2017; Casella et al., 2019) . We have calculated our indicators of GVC participation and GVC value capture with both datasets and the consistency between the two for the countries for which they overlap is confirmed.

[2] GVC-related environmental impacts are considered through the variables biodiversity, material extraction, local pollutants" and CO2 emissions, all from both production-based and consumption-based perspectives.
[3] See Hummels et al. (2001, p. 76) for further details

EORA26's dataset contains input-output data aggregated to a common 26-sector classification. For each country, we aggregated all the sectors for each variable. In order to obtain gross intermediate imports (*ipM* in Equation 1) we summed, for each country (row), the columns of the transactions matrix **T**[4] and subtracted the diagonal of the matrix to avoid counting within-country flows. In order to obtain domestic value added in gross exports, we used EORA's 'domestic value added' (DVA) indicator, which is identical to TIVA's XDVA indicator, as explained in Casella et al (2019, p. 122-123).

The shares of intermediary products in gross exports and imports were calculated using UNCTADStat data, which provides information of gross exports broken down by products using the SITC system. We chose this database because SITC is a more precise alternative to other sources that use ISIC classification. Indeed, the latter treats many primary products as processed intermediates (Radetzki, 2008, p. 23). Using the UNCTADStat data, therefore, primary commodities, precious stones and non-monetary gold (SITC 0 + 1 + 2 + 3 + 4 + 68 + 667+ 971) as total volumes in US dollars of exports and imports for each country were made into shares by dividing by total exports and imports in US dollars from the same database.

Finally, we retrieve GDP data for each country from World Bank World Development Indicators' GDP series at constant purchase power parity in 2017 international $ (NY.GDP.MKTP.PP.KD).

Thirty-five countries had missing data for at least one of these intermediary variables for one or both two of the years studied. The resulting number of countries (observations) for which we were able to calculate GVC participation is 153.

1.2 GVC value capture

We calculate GVC value capture following Carballa Smichowski, Durand & Knauss (2020)'s formula, shown in Equation 2 below.

$$\frac{XDVA * (1 - ppX)}{[XDVA * (1 - ppX) + ipM * (1 - ppM)]}$$

Where *XDVA* is domestic value added in gross exports, *ppX* is the share of primary products in total exports, *ipM* is gross imports of intermediate products and *ppM* the share of primary products in total imports.

The indicator represents the value captured by a country when exporting non-primary products (i.e. the total value captured by a country through GVC-related trade, as defined in Equation 1) and the denominator to the total value of GVC-related trade as defined above (the numerator of Equation 1). The choice of this indicator follows from those exposed above to choose the GVC participation indicator. First, it is consistent with the GVC participation indicator given that, as the comparison of Equation 1 and 2 shows, the denominator of the GVC value capture indicator is the numerator of the GVC participation indicator. In other words, GVC-related trade is identical in both indicators. The multiplication of domestic value added in exports (*XDVA*) by the share of non-commodities trade (*1-ppX*) follows the logic explained for GVC participation of not considering commodities trade as GVC trade.

[4] Sometimes referred to as the flows matrix in the input-output literature and denoted as Z

The data sources and the methodology used to calculate domestic value added in exports (*XDVA*), the shares of intermediary products in gross exports and imports (*ppX* and *ppM*, respectively) are identical to those described in the previous subsection.

There was missing data for both 1995 and 2015 for 15 countries. Given that this variable is key to the empirical strategy of this article, we eliminated those countries from the sample.

1.3 Investment rate

The investment rate was taken from the IMF's World Economic Outlook database (April 2021 release). It provides total investment per country-year as a share of GDP. There was missing data for 10 countries in 1995 and for 7 countries in 2015. Missing data were treated using different methods. If data existed for the year in the alternative data source (The World Bank), this data was used as the preferred option. If not, a nearby year from the original source was used with a maximum threshold of +/- 3 years. Finally, if none of these two options were feasible, we statistically imputed the missing data.

We preferred using World Bank's data as the preferred option not only because of the reliability of the source, but also because investment rates are calculated using national accounting variables for which there are standardized calculation procedures. Hence, little variation between sources is to be expected for the investment rate. Table 1 below details which method was used for each of the missing data points.

Table 1: Methods used to treat missing data for the variable "investment rate"

Country code	Country name	Missing in 1995	Treatment of missing data	Year of replacement	Missing in 2015	Treatment of missing data	Year of replacement
BIH	Bosnia and Herzegovina	Yes	Replacement by nearby year	1998	No	-	-
GEO	Georgia	Yes	Replacement by nearby year	1996	No	-	-
LAO	Laos	Yes	Statistical imputation	-	Yes	Alternative data source	-
LBN	Lebanon	Yes	Alternative data source	-	Yes	Alternative data source	-
MKD	TFYR Macedonia	Yes	Alternative data source	-	Yes	Alternative data source	-
PNG	Papua New Guinea	Yes	Alternative data source	-	Yes	Statistical imputation	-
SUR	Suriname	Yes	Statistical imputation		Yes	Statistical imputation	-
TKM	Turkmenistan	Yes	Replacement by nearby year	1996	Yes	Replacement by nearby year	2012
TTO	Trinidad and Tobago	Yes	Statistical imputation		Yes	Statistical imputation	-
VUT	Vanuatu	Yes	Alternative data source	-	No	-	

The limitation of using close years to replace missing observations (e.g., using 1994 data to replace missing data for 1995) and, more broadly, of using starting and endpoints to calculate a variation rate over a 20 years timespan, is that the chosen year might be an outlier. In the case of the investment rate, exceptional circumstances such as wars during the year chosen to replace a missing value may exhibit low values and post-war reconstruction years exhibit high values, hence generating outliers. However, these episodes are unlikely to be numerous in the sample and they are diluted in the aggregate with other variables and countries when building composite indices. Thus, this replacement method does not affect the final results while it assures a wider country coverage and minimizes imputation.

1.4 Capital stock

The data on capital stock is retrieved from the Penn World Tables version 10.0. This data is in current 2017 USD PPP. Given that our analysis spans over 20 years, we converted the data to constant 2017 USD PPP using a GDP implicit deflator equal to the ratio between current 2017 USD GDP and constant 2017 USD GDP PPP for each country. In order to obtain that deflator, we retrieved current USD PPP GDP and constant 2017 USD PPP GDP data from the World Bank for each country. Before computing the above-mentioned ratio, we transformed current year USD GDP data into current 2017 USD GDP using the United States' implicit GDP deflator, also retrieved from the World Bank. Finally, for each of the years under analysis (1995 and 2015), we divided each country's constant 2017 USD PPP by its population that year.

1.5 Employment rate

The employment rate is taken from the International Labor Organization's ILOStat, specifically, their measure *Unemployment rate by sex and age – ILO modeled estimates*. The advantage of the database is that the ILO uses several cross-validation methods to produce maximal comparability across countries for a large country selection. Since we want the employment rate rather than the unemployment rate, we simply subtract ILOStat's unemployment rate figures from 100. Here it should be noted that we consider the employment rate simply as the employed population over active working-age population. We therefore depart from the OECD definition of the employment rate as the ratio of employed labour force to working age population.

1.6 Palma ratio

As a measure of inequality, we opted for the Palma ratio as a standard metric. This indicator is defined as the ratio between the income of the 9th decile and that of individuals below the 4th decile in the income distribution.

Its advantage over the Gini index is that it is less sensitive to changes in the middle of the distribution and more responsive to changes between the rich (top 10%) and the poor (bottom 40%). For the same reason, the indicator has the disadvantage of not reflecting changes in income distribution taking place within the 4th and 9th decile. There was also a better country coverage available for the Palma ratio, with the World Inequality Database providing data for 139 out of the 153 countries retained in the final dataset from the Eora26 dataset. That said, we observed a correlation of above 0.6 between our Palma ratio and the Gini index (for 120 countries with available data, the Gini indexes taken from Povcalnet).

Because our other social variables that compose the socio-economic development composite indicator improve as they increase in value between 1995 and 2015, we converted the Palma ratio to its opposite value. That is a Palma ratio of 5 was transformed to - 5 so that the interpretation of an increase or decrease would be the same as with the other socio-economic variables. Therefore, an increase in, say, median income and in the opposite of the Palma indicator both mean an improvement of socio-economic conditions.

1.7 Median income

Median income is a better indicator than the mean to capture the evolution of the average household's income. Most of the data comes from the World Bank's Povcalnet. We accepted surveys done within four years of the target 1995 and 2015 years. We then extrapolated the numbers to the target year assuming an annual rate of change that is 70 percent of the change in consumption expenditures (Kochhar, 2015). Data are taken from the World Bank's *Households and NPISHs Final consumption expenditure per capita growth* variable. Data outside of this range was discarded, except for special cases (three countries with survey years from 5-8 years off). When multiple surveys were available, the closest survey year was taken. When multiple surveys were equidistant from the desired year (e.g., both 1994 and 1996 were available), the latest possible year was taken. When there appeared to be large changes between survey years on both sides of the target year, we interpolated the data to ensure accuracy (e.g., 1992 and 1997).

This procedure gave us data for only 107 countries for 1995 and 119 countries for 2015. To increase our country coverage, we found additional estimates in other datasets, principally Thomas Piketty and Lucas Chancel's "Carbon and Inequality" dataset (they provide average incomes by decile, so we took the median decile) and the Lakner-Milanovic "World Panel Income Distribution" dataset. The same principles were followed for adjusting surrounding years to the target year as with the Povcalnet data. The Carbon inequality dataset added ten countries for 1995 and six for 2015; the World Panel Income dataset added two more for 1995. As the datasets were in different currencies, everything was converted to 2014 USD PPPs using the World Bank's PPP conversion factors and CPI index. Finally, for a few selected additional countries (one country in 1995; three in 2015) we were able to find reliable estimates based on national statistics offices data. Where necessary, this data was converted to household per capita data and to 2014 USD PPPs to be consistent with the other data sources.

1.8 Labor share

As a measure of inequality focused on the division between capital and labor, we also include the labor share of net value-added. The calculation of a comparable labor share for countries with different income levels is not a simple task. If mixed income is available in the national accounts, assumptions have to be made about what proportion to assign as labor income. These assumptions may be more or less accurate depending on whether the non-corporate sector employs capital in a greater or lesser proportion than the corporate sector, which is likely to vary depending on the employment structure and income level of a country (van Treeck, 2020). There is therefore no consensus adjustment to deal with mixed income in the literature. Nonetheless, the Penn World Tables argues for assuming the labor share of mixed income is the same as the labor share of the corporate sector wherever mixed income data is available (Feenstra et al., 2015, p. 24). We follow this principle and use the compensation of employees and mixed income data provided by the Eora26 tables for greater country coverage – the Penn World Tables have missing or unreliable data for 27 countries out of the 153 that the Eora26 provide – and greater consistency with our GVC measurements. In contrast to the PWT, however, we take labor share out of net value-added at factor cost, which follows best practice by removing the consumption of fixed capital from the denominator (Guerriero, 2019). This gives us 153 countries with labor share data for 1995 and 2015. Of these countries, only China required an adjustment since its labor shares were above 1 for both years. We were able to calculate the labor's share of net VA at factor cost for 2015 from the China Statistical Yearbook 2016. For 1995, we used the calculation of Bai and Qian (2010). Since this estimate is at factor cost but of gross value-added, we added 10% to it based on the stable 10% gap between labor share at gross and net value-added in China visible in Qi (2020).

1.9 Biodiversity

Biodiversity loss is a notoriously difficult effect to capture given limited understanding and calculability of how many species exist within a given territory, how many species are lost, and to what extent losses can be attributed to human behavior as opposed to 'natural' losses. Country-level data is also particularly difficult to parse out due to a paucity of data, particularly in low-income countries, and the mobility of non-human animal species. Nevertheless, this variable is particularly important to analyze given increasing recognition that human-induced environmental changes are resulting in accelerated biodiversity losses, causing a sixth-mass extinction (Bradshaw et al., 2021). Some studies have been able to relate biodiversity loss for limited species to socioeconomic factors. Mikkelson et al. (2007) and Holland et al. (2009), for example, find that biodiversity, measured as the number of plant and vertebrate species known to be threatened, increases significantly with greater income inequality across countries. Studies linking income levels, or income inequality, tend to provide only cross-sectional, rather than temporal data, and omit cross-border impacts.

Our analysis uses data from Bjelle et al. (2021), who conduct the most comprehensive analysis of national trends in biodiversity loss. Their study uses a spatially integrated input-output model to link land-use changes to data on biodiversity loss from 1995 to 2015. Moreover, their research determines both domestic biodiversity footprint of production and 'consumed' biodiversity losses, i.e. those losses produced abroad in meeting import demands. The authors find that high-income countries are driving the increase in global biodiversity losses through their capacity to import goods produced abroad. Biodiversity data is expressed in 'potentially disappeared fractions' of species (PDF). This measure accounts for the potential risk of loss of global species equivalents associated with land use patterns in a given year, relative to a hypothetical natural state without any human land use. For more details, see Verones et al. (2019) and Chaudhary et al. (2015).

1.10 Domestic material extraction

In order to account for the ecological impact of GVC participation in terms of extraction of materials, we measure domestic material extraction as a share of a country's size. Domestic material extraction corresponds to biomass, fossil fuels, metal ores and non-metallic minerals extracted by a country within a year, all measured in tons. This data is directly retrieved from UNEP's Global Material Flows database (Schandl et al., 2016).

Given that countries that are richer in natural resources will, *ceteris paribus*, likely extract more tones of materials than other countries, we normalized the data by the country's land area measured in square kilometers. The latter is retrieved from the World Bank. It constitutes a proxy for a variable of countries' endowment in materials. The rationale is that a country's stock of natural resources should be correlated with its material endowments in terms of the four categories mentioned above.

Finally, it should be noted that the use of land size as a normalization variable omits the fact that some of the materials (e.g., fossil fuels) can be located overseas. This could have an impact in the value of the indicator for countries with large and materials-rich overseas territories. Unfortunately, no measure of countries land and sea surface could be found to correct for this.

1.11 Raw materials trade balance

This variable is calculated as the materials embodied in net imports as a percentage of total material consumption (material footprint). It corresponds to the variable *raw trade balance* of the UNEP Global Material Flows Database from which it is extracted.

There was missing data for 13 out of the 186 countries in the database (7% of the total): Comoros, Djibouti, Equatorial Guinea, Grenada, Guinea-Bissau, Kiribati, Marshall Islands, Micronesia, Palau, Solomon Islands, Sudan, Timor Leste, Tonga and Tuvalu. None of them remain in the final dataset.

1.12 Local pollutants

Data on domestic local air pollutants were taken from the European Commission's Emissions Database for Global Atmospheric Research (EDGAR). Aside from CO2 emissions, EDGAR v5 provides data on a range of air pollutants from 1970-2015 for all of the countries in our dataset (European Commission, 2020). The data includes (1) *ozone precursor gases*: Carbon Monoxide (CO), Nitrogen Oxides (NOx), Non-Methane Volatile Organic Compounds

(NMVOC) and Methane (CH_4); (2) *acidifying gases*: Ammonia (NH_3), Nitrogen oxides (NO_x) and Sulfur Dioxide (SO_2); and (3) *primary particulates*: Fine Particulate Matter (PM10) and Carbonaceous speciation, 'Black Carbon' (BC). All data are expressed in gigagrams and can thus be aggregated into a domestic local air pollutant variable for each country. In this way, the load of local pollutants can be understood as a factor linked to a particular level of integration within GVCs.

No data are readily available for consumption-based local pollutants. Therefore, we assume that CO_2 emissions and local air pollutant emissions are correlated and approximate the consumption-based air pollutant emissions as follow. First, we apply the embodied CO_2 in net imports as % of *production*-based CO_2 emissions to domestic local pollutant to get a value for embodied local air pollutant in net imports. Second, we add the value of embodied local pollutant in net imports to domestic local pollutant to get an approximation of consumption-based local pollutant emissions. Third, we normalize embodied local pollutant in net imports by consumption-based local pollutant (the local air pollutant footprint).

1.13 CO2 emissions

Domestic per 2017 PPP GDP CO_2 emissions for both 1995 and 2015 come from World Bank World Development Indicators (EN.ATM.CO2E.PP.GD.KD). CO_2 imports and footprint (consumption-based) data used to compute CO_2 emissions embodied in net imports as a share of total CO_2 consumption come from EORA. For 1995, we use the series from EORA computed using domestic CO_2 data from the Carbon Dioxide Information Analysis Center. For 2015, these series are not available so we use the series from EORA computed using PRIMAPHIST domestic emissions data, itself built upon CDIAC and Edgar data.

2 Final sample

Based on the availability of the GVC variables in the Eora26 tables and UNCTAD-Stat, we have 153 potential countries. However, data are not available across the other 16 variables for all these countries in both 1995 and 2015. To decide how many countries to drop and how much remaining missing data to impute statistically, we decide to draw the line at more than four missing values for a given country. That is, any country with at least 28 out of the 32 data points (16 variables for 1995; 16 variables for 2015) is retained in the dataset.

Any missing values across the remaining data panel are imputed by performing multiple imputations based on principal component analyses. Only median income for 1995 and 2015 still exhibits missing values. We use the missMDA package in R (Josse and Husson, 2016). We generate 1000 imputed datasets to assess the quality of the imputation. Along the way we eliminate a few more countries as their presence substantially decreases the quality of our imputation while they are not key to our investigation: Barbados, Fiji, Vanuatu, Seychelles, Suriname, Trinidad and Tobago, Laos, Papua New Guinea and Haiti. We end up with an imputation of very good quality, as can be seen in Figure 1 illustrating the position of variables, countries and axes across the 1000 imputed datasets.

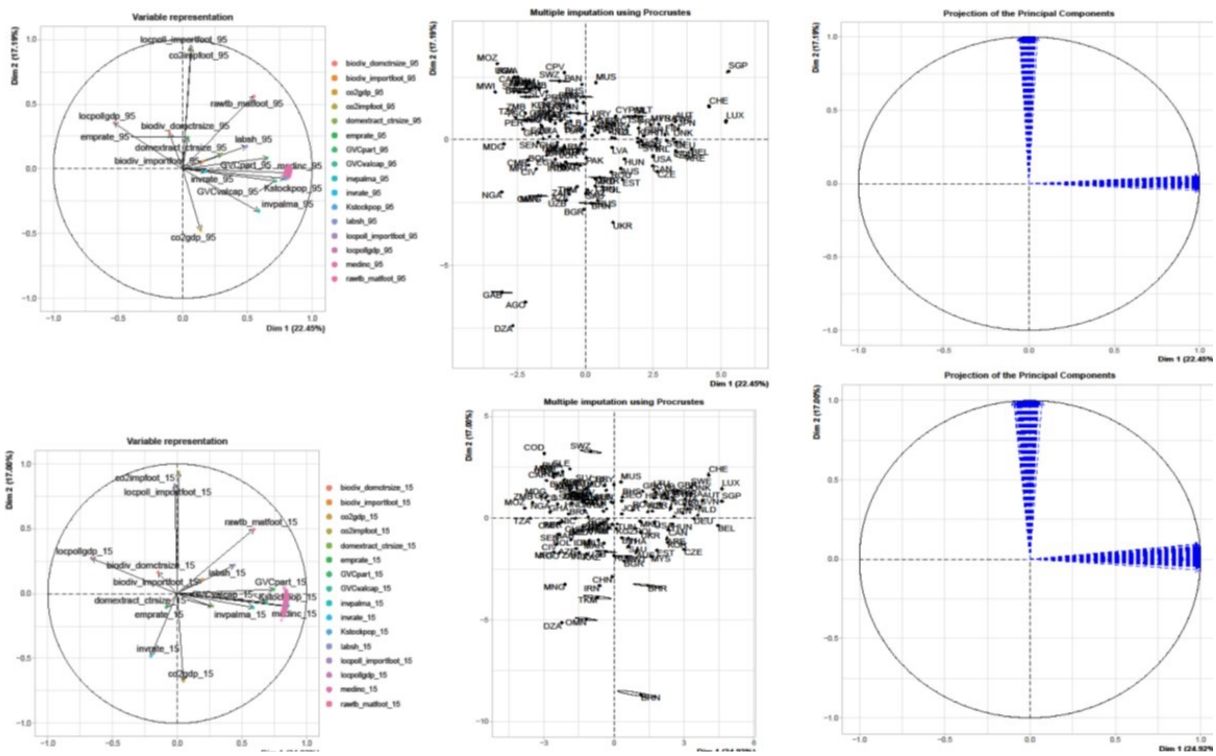


Figure 1. results of the multiple statistical imputation for missing variable. The top figures show results for 1995 and the bottom for 2015. For variables, the color points show variability across the 1000 imputations. For countries, ellipses around country names show the variability. For axes the variability is shown by the arrows. In all six cases, we can see that the imputation is of very good quality with high stability across all imputations.

We obtain a final dataset of 133 countries that is very balanced across income categories: at the beginning point in 1995, 48 countries were considered high income (30) or upper middle income (18) by the World Bank's classifications, 42 countries were considered lower middle income and 43 countries were considered low income. The following table presents summary statistics of all the variables mentioned in Section 1 for the 133 countries retained in the final sample.

Table 2: Summary statistics of the final sample

Variable identifier	Min	Max	Mean	SD
GVCpart_95	.06	1.50	.25	.23
GVCpart_15	.03	1.65	.32	.33
GVCvalcap_95	.01	.75	.35	.20
GVCvalcap_15	.04	.74	.38	.20
invrate_95	3.92	65.02	23.48	9.15
invrate_15	12.10	54.37	24.80	7.66
emprate_95	62.04	99.49	91.61	6.84
emprate_15	72.31	99.61	92.28	5.79
invpalma_95	-24.86	-1.41	-6.12	4.36
invpalma_15	-19.13	-1.68	-5.49	3.23
medinc_95	265.15	27728.52	4386.44	5147.85
medinc_15	-1283.165	23916.57	6440.65	6,147
labshare_95	.05	.97	.57	.14
labshare_15	.06	.97	.57	.14
Kstockpop_95	913.13	552867.6	54518.7	74929.2
Kstockpop_15	1388.18	458803.2	103324.9	105987
biodiv_ctrsize_95	8.2 e -12	6.73 e -07	7.3 e-08	1.2 e-07
biodiv_ctrsize_15	7.38 e-12	6.74 e-07	7.4 e-08	1.2 e-07
domextract_ctrsize_95	14.2	81242.65	1719.45	7515.9
domextract_ctrsize_15	.27	59396.68	2,077.8	6685.4
locpollgdp_95	.004	.27	.03	.04
locpollgdp_15	.001	.11	.02	.02
co2gdp_95	.03	1.99	.31	.32
co2gdp_15	.04	.997	.21	.14
biodiv_importfoot_95	-.36	-3.19 e-07	-.03	.06
biodiv_importfoot_15	-.39	-3.8 e-07	-.03	.06
rawtb_matfoot_95	-3.69	.91	-.17	.7
rawtb_matfoot_15	-2.89	.92	-.17	.76
locpoll_importfoot_95	-2.15	.72	.12	.4
locpoll_importfoot_15	-4.11	.75	.12	.45
co2impfoot_95	-1.9	.83	.13	.37
co2impfoot_15	-1.04	.73	.14	.26

3 Methodological considerations regarding the data analysis

In this section we explicit two methodological choices for the data analysis: the use of factor analysis and the choice of hierarchical clustering over alternatives.

3.1 Pertinence of factor analysis

As mentioned in sub-section 4.2 of the article, before performing our statistical analysis, we check whether our data are suited for factor analysis using the Keyser-Meyer-Ohlin (KMO) and Bartlett tests. The result of these tests is presented in

Table 3 below. An overall value higher than 0.5 for KMO and a statistically significant value for the Bartlett test suggest the use of a factor analysis.

Table 3. Results of the Keyser-Meyer-Ohlin and Bartlett tests of suitability of data for factor analysis.

Test	Value
Overall Keyser-Meyer-Ohlin	0.58
GVC participation KMO	0.62
GVC value capture KMO	0.59
Productive development KMO	0.45
Soceconomic development KMO	0.57
Domestic ecolological impact KMO	0.62
External ecological balance KMO	0.55
Bartlett Chi2	97.71
Bartlett p-value	0.000
Bartlett degrees of freedom	15

3.2 Choice of hierarchical clustering

As described in sub-section 4.2 of the article, we use hierarchical clustering to obtain the clusters. Initially, we opted for a mixed hierarchical-consolidated clustering. In that case, a hierarchical clustering is performed and the gravity centres of the clusters are used to initialize a k-means algorithm. An advantage of proceeding as such is that the k-mean algorithm will further homogenize the clusters. A drawback of this method is that we lose the hierarchical nature of the clustering. In our case, the results given by the two methods are nearly identical and the overall analysis is the same. However, we chose to stick to a purely hierarchical clustering so to be able to sub-cluster from the whole sample if needed to refine the discussion. Indeed, by doing so, we ensure that clusters obtained through selecting a higher number of clusters in a whole sample analysis can be considered as sub-clusters of a lower number of clusters. This would not be the case with a mixed hierarchical-consolidated clustering because the sub-clusters would not exactly match with bigger clusters in terms of country composition. For the sake of potential refinement the discussion, we therefore choose to prioritise the meaningfulness of the analysis rather than the statistical sophistication.

3.3 Clusters

The Table 4 below gives cluster mean, standard deviation and statistical significance for each index variable.

Table 4. Cluster values and statistical significance for each index variable. We consider a variable significant at a 90% confidence (p-values of 0.1 and below).

Cluster	Index variable	Domestic ecological impact	External ecological balance	GVC value capture	GVC participation	Socio-economic development	Productive development
Cluster 1	V-test	2.32	0.81	-4.13	-4.99	-5.51	-6.28
	Mean	0.09	0.04	-0.24	-0.39	-0.17	-0.23
	Standard dev.	0.26	0.29	0.43	0.40	0.25	0.22
	P-value	0.02	0.42	0.00	0.00	0.00	0.00
Cluster 2	V-test	4.76	-5.46	0.20	-1.45	1.74	6.01
	Mean	0.22	-0.33	0.01	-0.13	0.06	0.26
	Standard dev.	0.37	0.60	0.70	0.72	0.29	0.37
	P-value	0.00	0.00	0.84	0.15	0.08	0.00
Cluster 3	V-test	-7.60	4.89	4.34	7.03	4.23	0.56
	Mean	-0.41	0.34	0.34	0.74	0.18	0.03
	Standard dev.	0.14	0.23	0.20	0.58	0.22	0.20
	P-value	0.00	0.00	0.00	0.00	0.00	0.58
Sample	Mean	0.00	0.00	0.00	0.00	0.00	0.00
	Standard dev.	0.37	0.48	0.55	0.73	0.30	0.35

References

Aslam, A., Novta, N., and Rodrigues-Bastos, F. 2017. *Calculating trade in value added*, International Monetary Fund

Bai, C.-E. and Qian, Z. 2010. The factor income distribution in China: 1978–2007, *China Economic Review*, vol. 21, no. 4, 650–70

Bjelle, E. L., Kuipers, K., Verones, F., and Wood, R. 2021. Trends in national biodiversity footprints of land use, *Ecological Economics*, vol. 185, 107059

Borin, A. and Mancini, M. 2019. Measuring what matters in global value chains and value-added trade, *World Bank policy research working paper*, no. 8804, Advance Access published 2019

Bradshaw, C. J. A., Ehrlich, P. R., Beattie, A., Ceballos, G., Crist, E., Diamond, J., Dirzo, R., Ehrlich, A. H., Harte, J., Harte, M. E., Pyke, G., Raven, P. H., Ripple, W. J., Saltré, F., et al. 2021. Underestimating the Challenges of Avoiding a Ghastly Future, *Frontiers in Conservation Science*, vol. 1

Carballa Smichowski, B., Durand, C., and Knauss, S. 2021. Participation in global value chains and varieties of development patterns, *Cambridge Journal of Economics*, vol. 45, no. 2, 271–94

Casella, B., Bolwijn, R., Moran, D., and Kanemoto, K. 2019. Improving the analysis of global value chains: the UNCTAD-Eora Database, *Transnational Corporations*, vol. 26, no. 3

Chaudhary, A., Verones, F., De Baan, L., and Hellweg, S. 2015. Quantifying land use impacts on biodiversity: combining species-area models and vulnerability indicators, *Environ. Sci. Technol.*, vol. 49, 9987–95

Degain, C., Meng, B., and Wang, Z. 2017. Recent trends in global trade and global value chains, pp. 37–68, in *Global Value Chain Development Report 2017*

European Commission. 2020. *Global Air Pollutant Emissions, EDGAR v.5.0*, EC Joint Research Centre, Earth System Science Data, https://edgar.jrc.ec.europa.eu/dataset_ap50 (date last accessed 5 October 2021)

Feenstra, R. C., Inklaar, R., and Timmer, M. P. 2015. Online Appendix: The Next Generation of the Penn World Table, *American Economic Review*, vol. 105, no. 10, 3150–82

Guerriero, M. 2019. The labor share of income around the world: Evidence from a panel dataset, *Asian Development Bank Institute (ADBI) Working Paper Series*, no. 920, Advance Access published 2019

Holland, T. G., Peterson, G. D., and Gonzalez, A. 2009. A Cross-National Analysis of How Economic Inequality Predicts Biodiversity Loss, *Conservation Biology*, vol. 23, no. 5, 1304–13

Hummels, D., Ishii, J., and Yi, K.-M. 2001. The nature and growth of vertical specialization in world trade, *Trade and Wages*, vol. 54, no. 1, 75–96

Josse, J. and Husson, F. 2016. missMDA: A Package for Handling Missing Values in Multivariate Data Analysis, *Journal of Statistical Software*, vol. 70, no. 1

Kochhar, R. 2015. A Global Middle Class is More Promise than Reality -- Appendix: Methodology and Data Sources: Pew Research Center

Lenzen, M., Kanemoto, K., Moran, D., and Geschke, A. 2012. Mapping the Structure of the World Economy, *Environmental Science & Technology*, vol. 46, no. 15, 8374–81

Lenzen, M., Moran, D., Kanemoto, K., and Geschke, A. 2013. Building Eora: A global multi-region input-output database at high country and sector resolution, *Economic Systems Research*, vol. 25, no. 1, 20–49

Mikkelson, G. M., Gonzalez, A., and Peterson, G. D. 2007. Economic Inequality Predicts Biodiversity Loss, *PLOS ONE*, vol. 2, no. 5, e444

Qi, H. 2020. Power relations and the labour share of income in China, *Cambridge Journal of Economics*, vol. 44, no. 3, 607–28

Radetzki, M. 2008. *A Handbook of Primary Commodities in the Global Economy*, Cambridge, Cambridge University Press

Schandl, H., Fischer-Kowalski, M., West, J., Giljum, S., Dittrich, M., Eisenmenger, N., Geschke, A., Lieber, M., Wieland, H., Schaffartzik, A., Krausmann, F., Gierlinger, S., Hosking, K., Lenzen, M., et al. 2016. Global Material Flows and Resource Productivity. An Assessment Study of the UNEP International Resource Panel: United Nations Environment Programme

van Treeck, K. 2020. Measuring the Labor Income Share of Developing Countries: Lessons From Social Accounting Matrices, *The Review of Income and Wealth*, vol. 66, no. 3, 584–612

Verones, F., Huijbregts, M. A., Azevedo, L. B., Chaudhary, A., Cosme, N., De Baan, L., Fantke, P., Hauschild, M., Henderson, A. D., Jolliet, O., Mutel, C. L., Owsianiak, M., Pfister, S., Preiss, P., et al. 2019. LC-IMPACT Version 1.0: A spatially differentiated life cycle impact assessment approach, Advance Access published 2019

Wang, Z., Wei, S. J., Yu, X., and Zhu, K. 2017. Characterizing Global Value Chains: Production Length and Upstreamness, *NBER Working Paper No. 23261*, Advance Access published 2017

WIRTSCHAFTS
UNIVERSITÄT
WIEN VIENNA
UNIVERSITY OF
ECONOMICS
AND BUSINESS

WU Vienna
Institute for Ecological Economics

Welthandelsplatz 2/D5
A-1020 Vienna

+43 (0)1 313 36 4848
ecolecon@wu.ac.at

VIENNA
INSTITUTE FOR
ECOLOGICAL ECONOMICS