TWIN SEEDS

WORK PACKAGE 4

Recent and emerging trends of GVCs and MNEs: impacts on the environment

Acknowledgements

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Glossary

Backshoring - the strategy of transferring business operations that were previously offshored to a foreign location back to the country from which they were initially relocated.

Carbon emissions – carbon dioxide emissions, CO_2, the most abundant greenhouse gas responsible for global warming.

Carbon Footprint (CF) – total carbon emissions released worldwide through global value chains due to the activities of a particular individual, organization, or community. For a country, it is the total emissions released to meet the final demand of the economy.

Friendshoring (allyshoring) - the strategy of transferring business operations or sourcing from countries regarded as political and economic allies.

Global value chain (GVC) - production structures resulting from geographically dispersed stages of production, following locational advantages tied to a particular destination.

Greensourcing (or rightsourcing) – GVC reconfiguration following low-carbon criteria, so the lowest carbon suppliers are chosen.

Multinational enterprise (MNE) - a company producing goods or delivering services in more than one country.

Nearshoring - the strategy of transferring business operations to a nearby country, especially in preference to a more distant one.

Offshoring - the strategy of transferring business operations, such as production, from the home economy to a foreign host economy.

Producer Footprint (PF) - direct and indirect carbon emissions generated globally to make production possible of those finished products. For a country, it accounts for total emissions generated worldwide to satisfy its requirements for intermediate inputs incorporated into the final goods and services produced by the country.

Reoffshoring - the strategy of transferring business operations, such as production, away from the host economy towards another economy in a previous period and being relocated again towards a third economy in a later period.

Reshoring - the strategy of transferring business operations that were previously offshored to a foreign location back to the country or region from which they were initially relocated.

Resilience - the capability to bounce back from a shock, leading to a rebound or a return of the system to the pre-shock path; the ability of the system to absorb the shock or a process of positive adaptation.

Resource shuffling - the foreign supplier exports low-carbon materials to the home market and sends higher-carbon ones to his own country's market or to third countries.

Source shifting – change of supplier.

Take-back system – System implemented within or among firms to achieve the re-use of end-of-life products.

Executive summary

The WP1 report on "Trends and drivers of global value chains in the pre-pandemic wave of globalisation" has outlined new empirical findings on EU's performance and specialisation in GVCs, the effects of changing trade, investment and industrial policies on the development of GVCs and MNEs, as well as the implications of technological innovations on the structure of production and knowledge creation in GVCs. The COVID-19 pandemic highlighted the fragility of global production networks, resulting in severe supply security issues and the supply shortage of intermediate and final products. Then, the WP2 reports on "Emerging trends of Global Value Chains and Multinational Enterprises in the pandemic time" focused on how the pandemic induced changes in GVCs and production networks and assessed how sustainable the strategies adopted by MNEs were for their future operations. Key factors considered were the role of reshoring practices in enhancing the resilience of GVCs, as well as companies' digital shift to Industry 4.0. technological paradigm.

The present WP4 report builds on the previous WP1 and WP2 analysis of the impacts of technological, geo-economic, and geo-political changes on GVCs and production networks, now focusing on the effects of the resulting GVC reconfiguration on the environment. By doing so, it complements with sustainability issues the analyses of WPs 3 and 5, mainly concerned with social costs of GVCs restructuring (the first one) and with economic growth and inequalities (the second). Environmental impacts occur at different levels, and the research developed assesses the impact of reshoring strategies (that is, transferring business operations that were previously offshored to a foreign location back to the country from which they were initially relocated, known as backshoring, or to near countries, as in the case of nearshoring and rightsourcing or greensourcing, where the GVC reconfiguration follow low-carbon criteria) on the EU carbon emissions, the synergies between the goal of resilience through trade policy and the fight against climate change, the complex nexus at a firm level between the development of circular business models and take-back programs and GVCs, the role played by MNEs, including the potential of their technology transfers in the host countries, and the mitigation potential of a GVC reconfiguration following low-carbon criteria. To do so, we apply quantitative and qualitative analyses, including several environmental extended multiregional input-output models and case studies at the firm level.

The key messages of the report can be summarised as:

- Since the beginning of the 2008 global crisis, global trade entered a deglobalisation phase with GVC reconfiguration processes tending to shorten and regionalise them. These GVC restructuring phenomena have been accelerated recently by sudden shocks highlighting the GVC vulnerability and countries' exposure, forcing governments and firms to look for ways to increase resilience and sustainability and giving room to reshoring processes. The environmental effects behind such restructuring play an essential role in pursuing the goals of resilience and sustainability, which need to be assessed because they can foster or counteract the fight against climate change.

- Past GVC reconfiguration and trade-relocation patterns (geographical changes of suppliers) have contributed to the increase in emissions in the EU from 1995 to 2018, even in the context of general reductions in emissions shown in the post-crisis period. These shifts contributed to 23.4% of the carbon footprint growth in the pre-crisis period (1995-2008) and counteracts a higher reduction of around 6% by increasing emissions in the second. In both periods, indirect emissions were the leading component in the absolute growth in the EU's carbon footprint, which points to the relevance of intermediate steps in GVC when considering environmental impacts, which are also the ones that experience the most geographical relocation.
- We found synergies between the GVC resilience goal and the commitment to fight climate change. Scenarios of reshoring strategies for five selected strategic products (iron and steel, electrical motors and batteries, chips and circuits, antibiotics, and vaccines) generate reductions in the EU carbon footprint (CF). Considering that imports relocated are below 1% of total EU imports, the most significant reductions in emissions are achieved by reconfiguring the iron and steel supply chains (4.0% reduction in the contribution of the basic metals industry to the EU's carbon footprint and 9.0% when considering just the imported counterpart). The impact of reshoring on territorial emission increases are minimal for the EU and member states, though higher in Eastern EU countries.
- The joint analysis of changes in trade volume and the EU's CF of reshoring scenarios highlights that a slight shift in imported production can lead to a more significant reduction in the EU's CF when applied to the aforementioned strategic products. In basic metals, emission reductions are slightly more substantial in the backshoring scenario than in the nearshoring one. However, in the cases of chips and circuits, and electric motors and batteries, nearshoring strategies lead to more significant emission savings than backshoring.
- From the firm perspective, companies face growing demands from policymakers and civil society to counteract environmental pressures. This implies reducing their carbon emissions and decoupling value creation from consumption of natural resources, integrating circular economy (CE) practices. The firms' CE implementation must be analysed considering the effects of firms' circular strategies on GVC structure and

sustainability and, conversely, whether and how shifts in global and regional production networks may provide new opportunities for circular business models and environmental upgrading.

- Case studies show that achieving scale and volume is a major barrier for CE practices and take-back systems. Focusing on the construction and textile industries in France and the EU, CE policies can reshape GVCs by promoting circular business models. Future policies, like eco-design standards and harmonising EU recycling criteria, are crucial for circularity, as confirmed by Danish firms' take-back systems. Regulations need to shift from treating end-of-life products as waste, to enable value extraction, while also making landfilling more expensive.
- Multinational corporations' (MNEs) influence along GVCs is central to trade restructuring. The pursuit of resilience through EU-MNEs-led reshoring of strategic products to EU peripheral countries can generate synergies with the fight against climate change and convergence of these countries. The estimated impacts of reshoring strategies on EU carbon emissions show that relocating low-emission strategical sectors like computer, electronic, optical, and electrical equipment within the region results in a slight emissions increase in the EU. Environmental technology transfers within these sectors generate minor reductions, while the relocation of energy-intensive industries like basic metals leads to higher emissions reductions, thanks to the EU's cleaner environmental performance compared to former exporter countries.
- Scenarios of backshoring for the EU-owned MNEs producing abroad for three sectors (computer, electronic, and optical equipment; electrical equipment; and basic metals) point that the more significant improvement of the EU carbon emissions would come when technology transfers directed to decarbonising electricity are included.
- Exploring in depth the manufacturing MNEs' location and technology transfer decisions through case studies, we found that environmental issues still constitute a significant element in understanding the firm sustainability concept. All expected environmental changes are measured at the corporate, not subsidiary, level. However, foreign subsidiaries adopt solutions individually, in agreement with the headquarters but not unified across subsidiaries. MNEs have a "pool of best practices" that can be benchmarked across the organisation; although subsidiaries are not forced to adopt these solutions as long as they achieve Key Performance Indicators (KPIs).
- Unlike in the past, contemporary decisions on Foreign Direct Investment (FDI) location and hence the perception of host country attractiveness depends on the ability of the host country to ensure compliance with home-country regulations, e.g. achieving climate neutrality, but only if the other criteria for investment (economic, market, etc.)

are met; so environmental factors are still secondary to the cost or market-access. However, upholding the existing subsidiaries depends on the ability to adjust operations in line with SDGs. Additionally, when perceiving the host country-level policies as criteria for FDI attractiveness, MNEs are more interested in looking at stability.

- Current governments' policies driving GVCs restructuring are primarily motivated by the pursuit of resilience. However, GVC reconfiguration driven by shifting to low-carbon sources (greensourcing or rightsourcing), not by the search for resilience as in the previous reshoring scenarios of strategic sectors, could result in a reduction in EU carbon emissions ranging between 14 and 25%, depending on the features of the proposed scenarios. Sectors with significant emission reduction potential in a greensourcing simulation include manufacturing, computer, electronic and optical equipment, electrical equipment, transport, machinery, textiles, and food products.
- A greensourcing scenario in which all sectors select suppliers based on low carbon criteria would increase reductions compared to individual sectors doing so. However, resource shuffling has the potential to undermine these positive effects. If the EU's absorption of cleaner production results in other countries shifting to dirtier suppliers, the global impact of greensourcing could be null or even an increase in global emissions of up to 0.5%.
- Policy incentives to increase CE and lower carbon emissions can potentially change GVCs' geography. On the one hand, they could revive some sectors (textiles in France), but they face drawbacks like costs, skill shortages, and the need for economies of scale. Nearshoring can exploit regional capacities and complementarities. On the other, such geographical shifts would imply decoupling from more distant sources and recoupling with closer sources, as analysed at the macro level regarding their impact on carbon emissions. Larger companies and EU-level actors in the textile sector don't see this shift happening industry-wide soon due to the advantages of globalised production.
- Research on carbon emissions and CE business models highlights the need for integrated policies addressing production and consumption through GVCs. These policies should incentivise sustainable practices for domestic companies and MNEs, requiring firms to enhance control and transparency over GVCs, incorporating environmental impacts and favouring low-carbon suppliers. Such policies have the potential to significantly change GVCs, both in terms of their governance, their geography and their environmental impact. Similarly, regulations like the Carbon Border Adjustment Mechanism (CBAM) should consider Scope 3 emissions (indirect emissions), which are a significant part of the products' carbon footprint.
- The environmental dimension should be an integral part of the European Union's trade

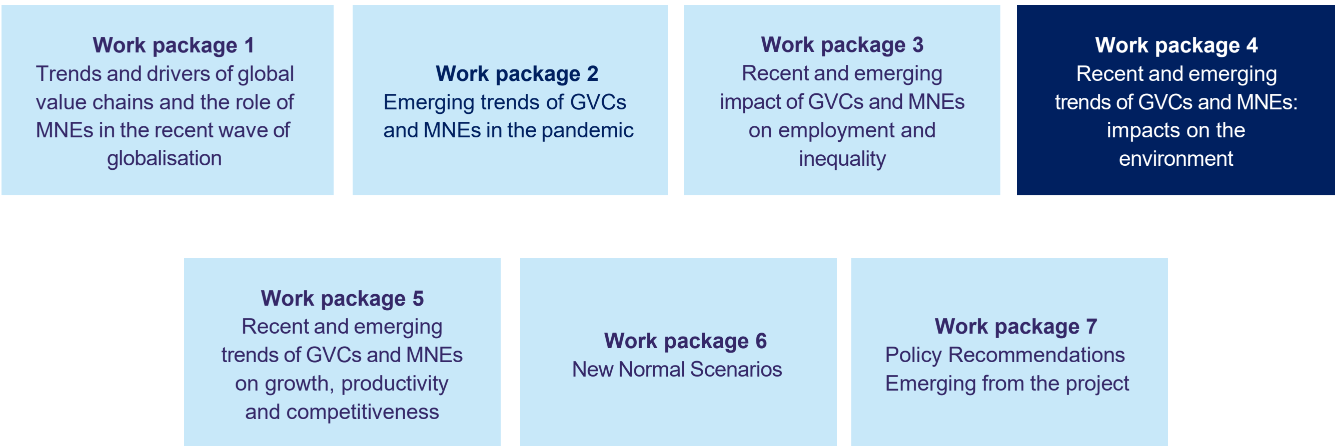
policy. This could include introducing precise emissions and carbon footprint targets into trade agreements and alliances. Such an approach could result in synergies between GVC resilience and member countries' climate goals. Our findings indicate that carbon content may already be playing a central role in new emerging trends in GVCs in that lower emissions are embodied in reshoring and reoffshoring trends than in prior offshoring ones. Policy incentives for the transfer of environmentally friendly technologies when undertaking nearshoring or friendshoring strategies could help in this regard. The intensification of the energy transition across all EU nations is also vital.

- There is a need for public support to enable the transition to circular practices in several areas: for the creation of intermediaries; for a single EU market in used, reconditioned and waste products to secure scale, which also requires harmonised regulation on handling waste at the EU level; for continued openness to the near abroad; for adequate training and re-training; and for investment, especially for research and innovation in recycling technologies. In addition, higher eco-contributions schemes for less sustainable products within Extended Producer Responsibility (EPR) schemes or lower VAT or tariff rates for circular goods could help to improve the economics of these new circular business models.
- Firms need to reduce uncertainty in European and global sustainability reporting standards. An official regulatory framework and bilateral commitments would decrease such uncertainty, and initiatives like the "Sustainable Investment Facilitation Agreement" recently negotiated with Anglola would help in this regard.

1. Introduction

The TWIN SEEDS project aims to provide robust empirical evidence on the significant social, environmental, competitiveness, and growth consequences that have emerged from recent and emergent trends in international trade and global value chains (GVCs) restructuring. Political instability, trade protectionism, and the pandemic have accelerated new trends in international trade and GVCs' reconfiguration that pose challenges to the European Union's (EU) economies and regions with crucial implications on multiple levels. Some of these implications are analysed in the WP3, WP4 and WP5 reports, which have been developed simultaneously. This WP4 report - the fourth in the series of seven research reports (see Figure 1) - is expanding to the environmental sphere the analysis presented in the WP1 and WP2 reports. WP3 research focuses on analysing the impacts on labour markets, including the risks of increasing inequalities in job quality, incomes and wages, as well as potential challenges for education and training. The WP5 focus is on the impact on growth, competitiveness, and income distribution, analysing the extent to which emerging growth opportunities may differ across sectors, regions, and countries. This report results from WP4 research, whose main goal is quantifying and evaluating the environmental impacts of the emergent trends of GVC reconfiguration, looking for their consequences in terms of changes in carbon emissions, circular production, and transfers of sustainable business practices from MNEs.

Figure 1: Summary of the TWIN SEEDS project and its Work Packages



Source: Authors' elaboration.

The report is organized into seven chapters, in which the two main tasks of the work package – the reorganisation of GVCs and environmental impact on the one hand, and the environmental right sourcing strategies and policies, on the other – are analysed. The introduction sets the context, relevance of the research, and main goals. It also has four analytical chapters, a discussion of the results, and, finally, conclusions and policy implications stemming from the research carried out. In Chapter 2, we develop an evolutionary analysis of the main past and current trends in carbon emissions, looking for their drivers and distinguishing between direct, indirect, domestic and imported emissions. We focus on how GVC reconfiguration and trade relocation patterns impact carbon emissions at the global, country, and sector levels, with a particular focus on the European Union (UE). This will serve as the baseline for Chapter 3, where we then examine the impact on carbon emissions of backshoring and nearshoring process of some strategic products for the EU looking for resilience and derisking as a response to GVC ruptures, supply shortages and other challenges derived from the geopolitical context, policy changes or weather events. As firms are the decision agents of relocation strategies, we expand the previous analysis with case studies that look into the firm and its development of a circular business and take-back programs in this context. These case studies focus on several sectors (pharmaceutical, machinery and equipment, retail, textile and construction) and countries (France, Denmark). Additionally, since Multinational Enterprises (MNEs) lead the development of GVCs and their influence in the reshoring processes can be crucial, in Chapter 4, we study their role in the GVC reconfiguration and reshoring and assess the mitigation potential of their low-carbon technology transfers. As a result, Chapter 4 quantifies the potential of backshoring, nearshoring and technology transfers led by MNEs to reduce CO_2 emissions generated in the EU and the function of peripheral EU countries. Besides, we examine through case studies the relevance of environmental aspects in MNEs' location decisions and the organization and most common technology transfers. All these issues refer to Task 4.1, namely devoted to the reorganisation of GVCs and its environmental impact.

While in the previous chapters, the modelling of GVC restructuring through reshoring is based on policy changes and the search for resilience, Chapter 5 considers the environmental aspect (lower carbon emissions) as the main driver for reshoring and GVC reconfiguration. In this chapter, we identify the cleanest production processes already in place and quantify the CO_2 emissions curbing potential of EU trade redirected towards the cleanest providers inside and outside the EU. In this way, environmental right sourcing strategies and policies are analysed in terms of their environmental impacts.

In the remainder of the report, Chapters 6 and 7 summarise the key findings and provide policy implications stemming from the research and findings.

2. The impacts of recent and emerging trends of GVC on the EU carbon footprint

Contextual background and research objectives

Since the beginning of the global crisis of 2008, global trade seems to have slowed down (Gaál et al., 2023), and by the end of 2019, some authors argue that international trade entered a phase of deglobalisation (Antràs, 2020), with the increasing importance of reshoring trends (The Economist, 2020; Gray et al., 2013; Piatanesi & Arauzo-Carod, 2019). These trade-restructuring phenomena have been accelerated recently by geopolitical tensions, the increasing protectionism and nationalism (Javorcik, 2020), the war in Ukraine and the COVID-19 pandemic (Antràs, 2020; Khorana et al., 2022; Yagi & Managi, 2023). Such sudden shocks have highlighted the vulnerability of global value chains (GVC), which has led companies and governments to seek to make the GVC shorter, more domestic, and more diversified through new schemes such as reshoring or reoffshoring, among others. The environmental effects behind such restructuring trends play an essential role in GVC strategies. The increasing importance of environmental policies such as the Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2021a) provides an incentive for shortening GVCs. Therefore, it is necessary to analyse the recent evolution of GVCs and alterations in trade trends from an environmental perspective to shed light on the interaction between resilience to global disruptions and sustainability.

Despite the increasing interest in reshoring, nearshoring, and multi-sourcing trends, the outcomes of reshoring have been studied by only a few papers, are oriented to particular sectors, are conceptual, or focused on the business dimension (Gereffi, 2020; Pedroletti & Ciabuschi, 2023), so there is insufficient research on the effects of reshoring on multiple levels. In particular, broad agreement arises regarding the little empirical work on the environmental implications of these current trends of deglobalisation and reshoring (Fratocchi & Di Stefano, 2019; Fratocchi & Mayer, 2023; Gupta et al., 2021; Orzes & Sarkis, 2019; Stentoft et al., 2016), so their environmental impact analysis is claimed to be a necessary next step (Espinosa-Gracia et al., 2023).

This gap in the reshoring literature is a prominent issue for several reasons. Firstly, the problem of lower efficiency and higher costs linked to reshoring processes fails if the externalities are included in the cost of the offshore locations (Crowe & Rawdanowicz, 2023). Secondly, all these strategies of GVC reconfiguration need to consider sustainability and carbon emissions to be effectively resilient (Gaál et al., 2023). Thirdly, there is an interaction between relocation decisions and environmental impacts: sustainability and carbon emissions can affect firms' decisions to reshore, providing additional arguments for choosing locations (Gaál et al., 2023; Tate, 2014) and, at the same time, sourcing decisions crucially affect environmental sustainability (Wang et al., 2023).

Chapter 2 aims to fill the literature gap by measuring the impact of trade relocation patterns on carbon emissions at the global, country, and sector levels, with a particular focus on the EU. As global production networks and production locations are likely to change in the coming years, our results are a crucial basis for assessing future changes in GVC reconfiguration and their impact on carbon emissions. The momentum of regionalisation of some GVC is strong, especially for industries where resilient supply flows matter as much as cost and efficiency (Pla-Barber et al., 2021), and social and environmental issues are expected to shape strategic decisions by firms increasingly. In addition, analysing the evolution and impacts of trade trends -like offshoring and reshoring- is vital to assess whether countries are likely to benefit or not from potential supply chain reconfiguration.

The main research question we aim to assess is to what extent the recent evolution of trade flows and the GVC supplying the EU are geared towards decreasing carbon emissions, as well as the role played by reshoring strategies so far. Our approach allows the identification of potential threats, mapping local and international players, as well as synergies or trade-offs between resilience and climate change fighting when the carbon emissions impact from these GVC restructurings are considered. In addition, we differentiate between final and intermediate goods in international trade and the role of imports from the perspective of the supplier (seller) and the buyer (receiver, consumer), with a particular focus on the EU.

For this purpose, we set two main objectives: first, we aim to analyse the trends in global emissions by calculating carbon footprints (CF) in the period 1995-2018. In the CF measure, we distinguish domestic emissions embodied in production to supply domestic final demand and exports, as well as the imported carbon emissions required to provide final demand. The imported CF is detailed by country and sector of origin of imports (intermediate and final goods), which allows us to identify those sectors especially relevant either as carbon emissions' suppliers or carbon emissions' consumers in the EU's footprint (i.e., sectoral hotspots). Our second objective is to disentangle the different factors impacting emissions embodied in EU imports, isolating the effect of geographical changes in GVC from other components, and assessing the implications in terms of emissions of trade-restructuring trends such as reshoring, reoffshoring (relocation of production previously offshored towards a third economy in a later period), maintained offshoring, and new offshoring. In this sense, we consider offshoring as the strategy of transferring business operations, such as production, from the home economy to a foreign host economy. Thus, reshoring is defined as the strategy of transferring business operations that were previously offshored to a foreign location back to the country or region from which they were initially relocated.

Methods of analysis and data

To address the key issues raised in this Chapter, we applied a multi-regional input-output (MRIO) model to calculate CFs using data from the Intercountry Input-Output (ICIO) data from 1995 to 2018 (OECD, 2021). We analyse changes in trends, origin and destination countries, and sectors, with a particular focus on embodied emissions into the EU final demand. See more details on the environmental extended multiregional input-output model in Appendix A.

We also identify sectoral hotspots, understanding a hotspot as an industry of above-average relevance either as carbon buyer ("upstream hotspots", which show significant emissions backward linkages) or as carbon suppliers ("downstream hotspots", which present high forward linkages) through international trade. To extend this sectoral assessment, we propose a climate-reshoring combined index, which shows how the imported CF of EU sectors could be affected by disruptions in the five sectors identified as being strategical or at risk of reshoring (Chemical products; Pharmaceutical products; Basic metals; Computers, electronics and optical equipment; and Electrical equipment). See details on the quantification of emission hotspots through GVCs in Appendix B.

In order to assess specific factors triggering changes in the EU's CF, we apply a structural decomposition analysis (Jiang et al., 2021) and follow and extend Gao et al. (2022). We carry out a complete additive decomposition of the difference in the CF between two years to isolate eight elements according to the emissions affected (direct (D) or indirect (I)), the driver (changes in intermediates (INT), final demand (FD) or emission intensities (EM)) and the nature of the change (technical (Tec), geographical (Geo) or concerning the final demand mix (Mix)). Additionally, we rely on the elements related to suppliers' geographical shifts to measure reshoring, offshoring, and reoffshoring trends. We consider offshoring as production being relocated from the home economy to a foreign host economy (Wan et al., 2019), reshoring as output being relocated away from the host economy in a previous period and taken back to that country or region in a later period (De Backer et al., 2016; Ellram et al., 2013), and reoffshoring as production being relocated away from the host economy towards another economy in a previous period and relocated again towards a third economy in a later period (Fratocchi & Di Stefano, 2019). These definitions require an offshoring activity to take place in a previous period (called the benchmark period) before the corresponding reshoring or reoffshoring activity happens in the reporting period. See details of the SDA in Appendix C.

Findings and discussion

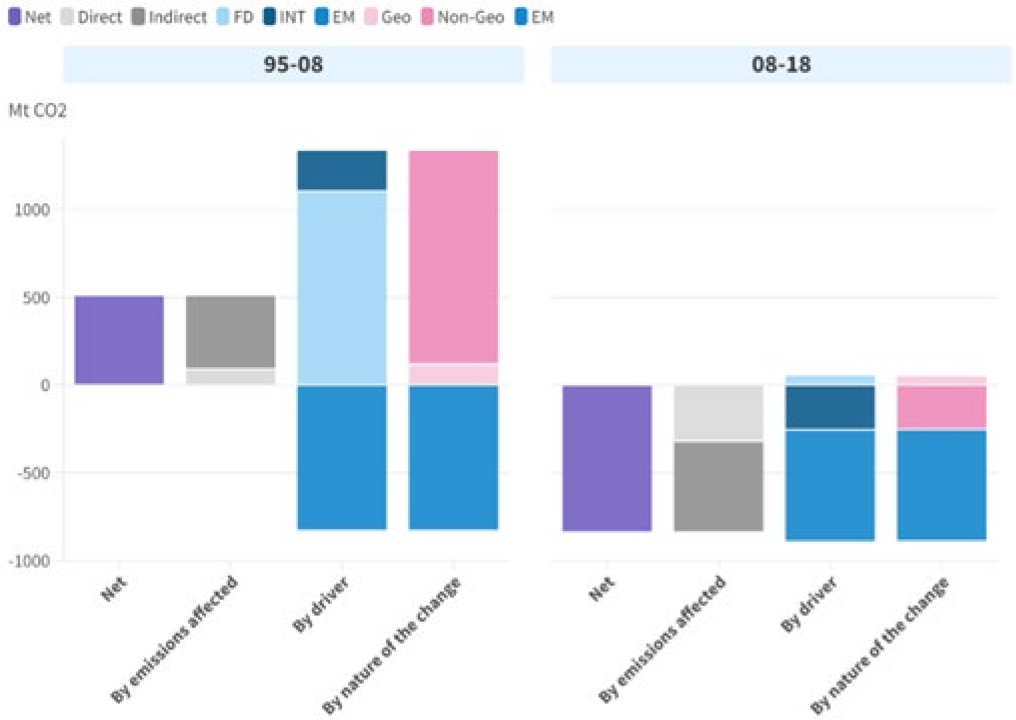
The analysis of the evolution of the main past and current trends in CF and GVC shows different patterns at the global level for seven big regions and China. The differences depend on the development level and the domestic or imported character of the carbon emissions. Domestic emissions slightly declined in the EU and USMCA (United States of America, Mexico and Canada) while they increased in the rest of the regions assessed (BRIIAT, China, East of Asia and Rest of the World), with a more evident growth trend of imported emissions of these regions except for the EU.

The EU CF shows a trend shift between 1995 and 2018. Until 2008, the CF of almost all EU sectors grew, with domestic emissions being substituted by imported ones. From 2008 onwards, the domestic and imported CF of nearly all sectors decreased because of the fall in demand driven by the financial crisis and, above all, due to improvements in carbon intensities. Besides, in the EU, the ratio imported over domestic emissions has reduced its growth trend since the 2008 crisis, in contrast to its high continuous growth before, but become more unstable with ups and downs, particularly pronounced in some strategic industries such as machinery and equipment and vehicles. This higher volatility could result from the vulnerability and lower resilience of the global value chains of these sectors, making them the objective of the EU's Open Strategic Autonomy policy. The increasing relevance of imported emissions points to the relevance of the EU carbon border tax measure to carbon reduction objectives.

Looking deeper inside the EU's imported CF, we find that the most relevant hotspots (strategic sectors that are important both as carbon suppliers and carbon demandants) are energy-related sectors, transport-related sectors, and some manufactures such as chemical products. In order to find how the imported carbon footprint of EU sectors could be affected by disruptions in specific sectors identified as being strategical or at risk of reshoring, we calculate a climate-reshoring risk combined index. We find that the sectors with the highest risk of being affected by climate change implications and shifts in strategic sectors are key manufacturing industries: computer, electronic and optical devices; pharmaceuticals; electrical equipment; motor vehicles, construction and machinery and equipment, among others. Additionally, the risk of services sectors, according to the climate-reshoring index, is relatively low, and only health and wholesale and retail trade are included in the high-risk group.

Figure 2 shows the decomposition of the change in the EU's CF in the pre- and post-crisis periods 1995-2008 and 2008-2018. Not only is the sign of the net change different, but the drivers behind them also show very distinct behaviour. In both periods, indirect emissions are the main component in the absolute footprint's change, which points to the relevance of intermediate steps in GVC when considering environmental impacts (Hertwich & Wood, 2018).

Figure 2: Decomposition of the changes in the EU's carbon footprint by emissions affected (direct/indirect), by driver (changes in intermediates, in final demand or in emission intensities) and by nature of the change (geographical shift of suppliers or other).



Source: Authors' elaboration.

Note to Figure 2: FD stands for final demand, INT stands for intermediate inputs, EM stands for intensity of emissions, Geo stands for change caused by geographical shifts of suppliers and Non-Geo stands for change caused by non-geographical shifts (either technological change of intermediate inputs' structure or change in the final demand mix).

Regarding the drivers involved, in both periods, the contribution of the decline in emission intensities was the most relevant element in reducing the EU's CF, showing the gains in environmental efficiency in most industries. This component was the most significant one in the period 2008-2018, but not in 1995-2008, where the contribution of the drivers that increased emissions was more substantial than the reduction in emission intensities. The increase in the carbon footprint shown in the first period was mainly driven by changes in the final demand, prompting modifications in intermediate input requirements and production. This means that, during economic expansion, the final demand shifted towards products with a more CO_2-intensive value chain (Hoekstra et al., 2016; Jiang et al., 2018). On the contrary, in the second period, the relevance of the final demand was still contributing positively to the CF growth, although minimal. At the same time, the contribution of the changes in the intermediates was more significant to the decline in the EU's CF. This may be related to a contraction of production and consumption in a recessive period and to cleaner value chains.

Looking at the nature of the change, non-geographical changes (i.e. technical change and shifts in the final demand bundle) increased the footprint in the first period, meaning that it was, in total terms, more demanding of carbon-intensive products. However, from 2008 to 2018, they contributed to the decrease in the EU's CF, possibly due to the shift to cleaner, low-carbon technologies. In both periods, the weight of the changes due to geographical shifts of suppliers is lower than its non-geographical counterpart. One of the most striking findings is that, between 1995 and 2018, the geographical changes of international trade had a moderate impact on the EU carbon footprint contributing to its growth, even in the context of general reductions in emissions shown in the second subperiod from 2009 to 2018. Geographical shifts in the EU between 1995-2008 (119 MtCO2) explain 23.4% of the 507 MtCO2 growth in the carbon footprint. In the second period 2008-2018, geographical shifts prevent a higher reduction of the EU CF (that shows a reduction of 835 MtCO2) by implying an increase in emissions of 50 MtCO2. An in-depth analysis of these geographical shifts inside the EU's carbon footprint reveals that their most intense effects occur in indirect emissions driven by alterations in intermediate inputs, which implies that geographical relocation is mainly applied to intermediate stages of production. Regarding the trade patterns behind such shifts, maintained offshoring is the primary trend affecting the EU as a receiver of emissions, but reoffshoring is also relevant in Western EU countries. The relevance of offshoring shifts towards dirtier economies and their persistence throughout the whole period explains its prevalence. At the same time, it highlights the need to include sustainability and emissions objectives when setting trade policy and alliances. In this sense, carbon emissions content might already be playing a central role in the emerging trends in GVCs, because our findings indicate that reshoring and reoffshoring trends in the EU have lower carbon emissions than offshoring ones.

At sector level, the trade-reconfiguration patterns assessed increased emissions in all the European industries. The sector most affected by the relocation of emissions was medium-low R&D manufacturing, followed by resource-intensive activities, mainly due to offshoring practices benefiting the EU in both cases and to the reshoring ones in the case of resource-intensive industries. Looking at intra-EU details, Eastern EU countries experienced the most significant increase in emissions due to offshoring and re-offshoring in mid-low R&D sectors. On the contrary, Southern EU countries reduced their emissions in such sectors, probably because of an intra-EU reoffshoring towards the Eastern countries.

3. Impact of reshoring decisions on the carbon footprint, the take-back programs and circular business models

Contextual background and research objectives

Companies and governments are adopting measures to restructure their supply chains to reduce their vulnerability and the risk of unexpected bottlenecks caused by different kinds of disruptions. In this context, the European Commission has launched a package of industrial policies aiming to increase its autonomy in supplying crucial inputs for strategic industries. In the Open Strategy Autonomy, the EU targeted reshoring and diversifying the supply of strategic inputs towards new suppliers within the EU and nearby. However, the search for more resilient and sustainable GVCs (Gereffi, 2020) is not only about improving, shortening, and diversifying supply chains but also, on the one hand, about incorporating suppliers with low carbon intensities that reduce carbon emissions generated directly and indirectly by companies and consumers residing in the EU. On the other, firms are the decision agents of reshoring, and they are increasingly pressured by governments and citizens to develop circular business models in order to increase recycling and reduce the use of natural resources and waste. Therefore, the resulting GVC reconfiguration has crucial consequences for the environment, particularly for the increase in the circular economy and the fight against climate change. These need to be assessed, which is the purpose of Chapter 3. This goal is addressed from two perspectives with two different methods of analysis regarding the two distinct environmental aspects previously mentioned. At the macro level, in the first line of research of Chapter 3, we use a multiregional input-output model and several scenarios of reshoring to quantify the impacts on the UE’s carbon emissions. As firms are at the centre of reshoring decisions, the previous analysis at the global, country and sector levels is complemented at the micro level, in this chapter's second line of research, where we focus on the firm using qualitative analysis through case studies regarding the implementation of circular business models and the reuse of end-of-life products (take-back programs) and their nexus to GVCs reconfiguration.

The environmental implications of the expected supply chain reconfigurations are so far unknown. Existing literature has focused on the variation of EU’s CO_2 emissions related to the production delocalization or offshoring to extra-EU regions, mainly to Asian countries during the 1990-2010 period (Hoekstra et al., 2016; Jiang et al., 2018; Malik & Lan, 2016). However, the literature have paid scarce attention to the outcome of reshoring processes and even less to the environmental dimension of it (Orzes & Sarkis, 2019; Pedroletti & Ciabuschi, 2023). From the macro perspective, in this Chapter, we estimate the environmental impacts in terms of direct and indirect CO_2 emissions and obtain detailed results on the countries and industries that will be affected at different stages of GVCs. To our knowledge, this is the first study to analyse the effects on CO_2 emissions caused by trade shifts and GVC reconfiguration through backshoring and nearshoring in some products regarded as strategic by the EU. Our analysis aims to contribute to this respect with a macro perspective that complements the more abundant results based on the business dimension and case studies (Sirilertsuwan et al., 2018).

EU companies and countries must be aware of the potential variations in their territorial emissions (direct emissions) and carbon footprint (direct and indirect emissions), under a foreseeable scenario where the production of some key intermediate inputs or final products will be relocated to the EU members and to the near abroad. Assessing the heterogeneous impacts on EU territorial and indirect emissions allows quantifying these new trade trends' net effects on global emissions. Countries and companies need to ensure that their industrial, trade and business strategies are compatible with the commitment to limiting global warming. This issue is highly relevant to both of them. First, regarding countries, because the Nationally Determined Contributions (NDCs) of the signatories to the Paris Agreement are estimated to be insufficient to achieve the goal of limiting the increase in temperature (Höhne et al., 2021; Nieto et al., 2018; Rogelj et al., 2016). The scientific community has insisted on the need for developed countries with high levels of consumption to adopt climate policies aimed at reducing emissions from a consumption-based perspective, including the emission transfers through GVCs (Ivanova et al., 2020; Karstensen et al., 2018; Meng et al., 2018; Wiedmann & Lenzen, 2018). Second, regarding firms, because only 8% of global CO2 emissions of EU companies involved in international trade are released within the EU, while 63% are released in developing non-EU countries (IEA, 2024).

In this line, this Chapter explores the environmental impacts of industrial and trade policies aimed at reshaping the global value chains of strategic products and industries for the European Union. This goal includes the quantification of the impact on carbon emissions of potential reshoring (backshoring and nearshoring) strategies, evaluating whether some are more effective (or less) than others in reducing the EU's total carbon footprint and which sectors, types of emissions (direct or indirect), and countries reduce or increase their emissions after reshoring. Additionally, we assess the trade-offs and synergies between the EU resilience and diversification goals and the carbon mitigation one.

At the same time, from the micro perspective, firms face growing demands from both policymakers and civil society not only to reduce their carbon emissions but also to counteract pressures on the natural environment by decoupling value creation from increased consumption of virgin natural resources and integrating ‘circular’ practices into their business models in order to transition towards a more sustainable economy (The Ellen MacArthur Foundation, 2013; Milios, 2018). Globally, only a small percentage of raw materials used in production and consumption are recycled. More than 90% of what we take from the Earth to fulfil our needs and wants goes to waste, with just 8.6% recycled materials. Therefore, the circular economy features in many governmental and multilateral policies and goals, from the EU Circular Economy Action Plan to the UN Sustainable Development Goals.

Having completed a variety of measures in its first Circular Economy Action Plan (CEAP) between 2015-2019, in 2020, the European Commission adopted a new, more ambitious and far-ranging CEAP (CEC, 2020), which is currently being translated into a variety of policy measures aimed at transitioning towards a more sustainable circular economy. In parallel, several member states of the EU, especially the Netherlands and France, have already started to implement national circular economy (CE) policies with both constraining and incentivizing effects (Mazur-Wierzbicka, 2021). In this context of shifts from voluntary, market-based schemes to 'hard' regulation on CE, firms need to reconsider their product design, production processes, supply chain management, and marketing strategies to minimize environmental impact and to deliver products that are reused or have recycled content, significantly influencing their business model. These changes can affect both the structure of GVCs, and their overall sustainability.

An expanding body of literature has begun to assess the effects of CE regulatory incentives (Fitch-Roy et al., 2021; Giraldo Nohra et al., 2020; Monciardini et al., 2022; Wasserbaur et al., 2022). Much of this work has examined institutional regulation as both a driver and impediment to greater circularity in the global economy. However, this research has primarily focused on the direct links between policy instruments and business practices, without considering international linkages and the changing nature of global value chains (GVCs). Indeed, relatively little is known about either the effects of firms' circular strategies on GVC structure and sustainability (Awan et al., 2022; Hofstetter et al., 2021), or conversely, whether and how shifts in global and regional production networks may provide new opportunities for circular business models and environmental upgrading (Coe & Yeung, 2019; Khattak & Pinto, 2018).

On the one side, France is seen as a 'precursor' in terms of CE policies. It has a strong legal framework through its 2020 law for the circular economy (AGEC law) and over a decade of implementing Extended Producer Responsibility (EPR), which forces lead firms to take responsibility for the end of life of their products. The European Commission is proposing similar policies at the EU level. In this context, it is important to assess the effects of these measures on firms' strategies, in order to evaluate their broader impact on the structure and sustainability of GVCs. Our research provides insights into this changing context through an original qualitative investigation with recent empirical data. By mobilising insights from the French context, we can shed light on the impact of 'hard' regulation on circular strategies and thus inform EU policymaking. Drawing on interviews in two key sectors in France, we explore the extent to which firms are adapting their strategies to CE policies and regulations, and how this affects the structure and sustainability of GVCs.

On the other side, take-back systems, where the manufacturers take back the discarded products, are an operationalization of the circular economy that entails the recycling and reuse of existing materials in products and services rather than exploiting more of the Earth's scarce materials (Geissdoerfer, et al, 2017). The potential and need for more take-back systems are clear. Nevertheless, their potential remains largely unrealized, as product take-back initiatives have proven difficult to implement in practice, in particular, when it comes to organising circularity solutions across borders and across GVCs. Thus take-back systems are gaining popularity, but falling short of action. In this respect, we are trying to understand from a business perspective what are really the challenges in making the take-back system financially viable and feasible in a GVC context (Bockholt et al., 2020).

Methods of analysis and data

To meet our objectives and investigate new firms' strategies regarding reshoring and circular economy impacts, we apply a variety of methodologies, including quantitative and qualitative analysis toolkits.

For the evaluation of the impact on carbon emissions of potential reshoring (backshoring and nearshoring) strategies regarding some strategic products, we use an environmentally extended multi-regional input-output (MRIO) model, using the Inter-Country Input-Output database from the OECD (2021) and international trade data at the product level from EUROSTAT (2023a, 2023b). MRIO models are widely used to estimate the direct and indirect CO_2 emissions incorporated in the production and consumption of countries and industries, as they are the best models to capture inter-industry and inter-country flows of products and CO_2 emission transfers through all the stages of GVCs (Inomata, 2019; Meng et al., 2018). See MRIO details in Appendix A.

We complement the MRIO model with the source shifting technique, which consists of modifying the trade structure of input-output tables in order to simulate reconfigurations in the international trade flows (Cadarso et al., 2021; de Boer et al., 2019; García-Alaminos et al.; Gilles et al., 2021). Thus, we estimate the carbon emission related to the EU's production and consumption in the current trade structure (business-as-usual) and under three GVC reconfiguration hypothetical scenarios for the EU. We simulate backshoring strategies in Scenario 1, nearshoring and friendshoring strategies in Scenario 2, and Scenario 3 is a mix of strategies simulated in previous scenarios.

We apply this procedure for the EU's GVCs related to five strategic products for which the

EU wants to achieve a more diversified and autonomous supply chain, namely: 1) iron and steel, 2) electrical motors and batteries, 3) chips and circuits, 4) antibiotics, and 5) vaccines. These products are selected based on the Pharmaceutical Strategy for Europe, the Green Deal Industrial Plan, the European Chips Act or the Net-Zero Industry Act (European Commission, 2020, 2022, 2023, 2024). Some of these sectors are also found as sectors with a high combined risk of emissions and reshoring in Chapter 2. Since EMRIO data operates with sector-level data, we complement our dataset with product-level international trade data from Eurostat (2023a, 2023b) to quantify the share a specific product represents inside the trade of the corresponding broad sector. These international trade datasets on EU imports at the product level are also used to identify the main non-EU supplying countries for each strategic product. The simulated import relocation amounts to $35.882 billion for strategic products, which is 0.78% of the total EU imports in 2018. See details on methods regarding the source shifting technique in Appendix D.

Additionally, a qualitative methodology building on semi-structured interviews was deployed to carry out the research on firms adapting their strategies to CE policies and regulations and how this affects the structure and sustainability of GVCs. This approach was chosen as it was the most effective means to explore our research question and inform our understanding of the multifaceted nature of firms' adoption of circular strategies in reaction to CE policies.

Two case studies were chosen for empirical analysis regarding the circular economy: the textile and construction industries in France. Both have been ranked as top priorities within the EU circular economy plan and in the context of reaching net-zero carbon emissions by 2050. Yet, they have very different GVC structures with quite varied firm-level linkages. Such variation could be expected to impact the manner in which firms and their GVCs react to policy shifts.

For the construction sector case study, our analysis is based on 44 interviews collected between October 2022 and April 2023 as part of the EU-funded Waste2Build LIFE project1. These interviews were conducted in the Toulouse region and encompassed stakeholders across the construction industry's entire value chain. In order to update the interviews and put them into the wider EU context, we conducted six supplementary interviews in April and May 2024 within the construction industry, including circular intermediaries in the South-West region of France and EU policymakers.

For the textile sector case study, we conducted 26 interviews between January and June 2024, involving representatives from textile firms, circular economy operators and intermediaries, policymakers, and sectoral interest groups. All interviews underwent systematic transcription to facilitate interpretive discourse analysis. Most were in French, although those at EU level were in English. The research team translated those that were in French.

Regarding the take-back systems, based on a comprehensive review of the literature we develop a framework encompassing the elements companies need to consider when developing take-back systems. Then, we apply this framework to 5 companies implementing take-back systems and based on in-depth qualitative data from the companies we further detail the challenges companies are facing when setting up a feasible and viable take-back system. A case study method is suited for addressing 'how' and 'why' type questions when performing an in-depth analysis of a complex phenomenon like take-back systems in its real-life context. Finally, in the discussion section, we provide some reflections on the alignment between the business and societal perspectives on take-back systems. See details on methods in Appendix E.

Findings and discussion

Macro perspective: Global, country and sector-level impact on carbon emissions

The reshoring strategies of all five selected strategic products generate reductions in the carbon footprint of the EU. The emissions reductions are quite moderate due to the low amount of imports relocated (as pointed out before, 0.78% of total EU imports in 2018). The most significant reductions in emissions are achieved by reconfiguring the iron and steel supply chains, reducing the EU carbon footprint by around 13 megatons of CO_2 ($MtCO_2$). In the second tier, we find the emission reductions related to the relocation of electric motors and batteries and chips and circuits, estimated at around -4 $MtCO_2$. Finally, we found that emission reductions from reconfiguring the supply of antibiotics and vaccines are minimal (less than -1 $MtCO_2$).

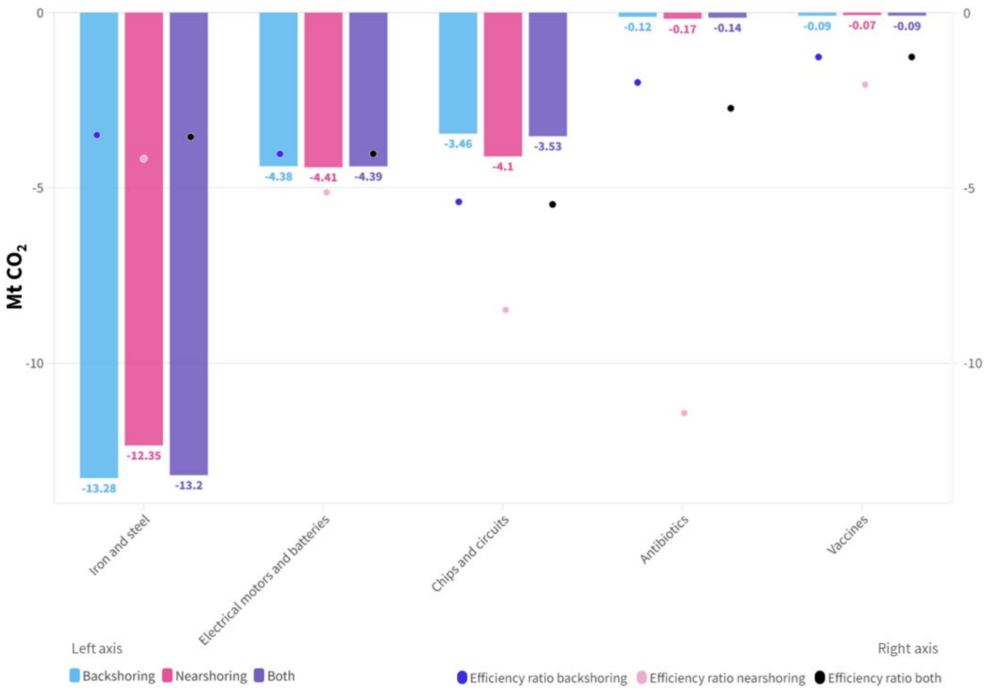
Our findings offer valuable insights into the carbon emissions variations related to new trends of production relocation, i.e. those happening from extra-EU countries to EU's territory, what is known in the literature as reshoring. These findings suggest that reshoring strategies would help EU countries and companies to reduce the whole direct and indirect emissions embodied in their GVCs while mitigating risks to supply chain disruptions and getting closer to the achievement of evidence-based mitigation goals. Finally, we found that, in the search for low-carbon supply chains, the relative efficiency of backshoring compared to nearshoring would depend on the industry undergoing the supply chain reconfiguration.

Considering that we are analysing a particular type of product with substantial strategic value but a relatively small monetary value and emissions content compared to the EU's total imports and emissions, the magnitude of emission reductions is small. Reshoring processes directed to higher carbon emissions content of imports is going to be explored in the Chapter 5. Nevertheless, our results regarding strategic products (summarized in Figure 3) reveal that all the reshoring scenarios proposed for all targeted strategic products reduce the EU carbon footprint, as the total carbon intensity of the EU is lower than that of its former suppliers. At a territorial level, each of these reshoring strategies increases the emissions released in the EU by less than 1% of the EU's current territorial emissions. When looking at the percentage that the emissions decline represents on total carbon footprint, the magnitude of the reduction is modest (around 0.2% in the cases of the sectors with a higher impact). However, when considering the same percentage but referring to the imported part of the footprint, the reduction is more remarkable, especially in the case of iron and steel (1.3%).

However, the EU's carbon footprint savings vary significantly for different products. In the cases of iron and steel, chips and circuits and electrical motors and batteries, a slight shift in imported production can trigger a more significant reduction in the EU's imported carbon emissions. The most significant emissions reduction is achieved for the iron and steel shift in every scenario, accounting for a reduction of 4.0% in the contribution of the basic metals industry to the EU's carbon footprint and 9.0% when considering just the imported counterpart. In the cases of vaccines and antibiotics, the fall in emissions in all the scenarios is much lower than for the other products, which happens because the value of the shifted imports is more minor, their emission intensities are lower, and the emission-intensity differential between foreign importers and EU countries is less relevant than for the other products shifted.

Regarding the effects on different countries, the reshoring and nearshoring processes would diversify suppliers for the analysed strategic products. In terms of the former suppliers, China is the region associated with the largest emission reductions in all three reshoring scenarios, as it is the original supplier of the most targeted products. Additionally, the reshoring strategies simulated led to a reduction of the EU's dependencies (both, in terms of trade and carbon emissions) on Russia and India. In terms of impacts within the EU, in the backshoring scenarios the new suppliers with the most significant increases in their territorial CO_2 emissions are Germany, France and the Netherlands in the case of iron and steel; Poland and Germany in the case of electrical motors and batteries and Germany and the Netherlands for chips and circuits. Close economies, either in terms of geography or in terms of shared values (also known as friendshoring), like Turkey, the United States or Switzerland, could also gain production (and hence emissions) from nearshoring schemes.

Figure 3: Change in the EU's carbon footprint (bars, left axis) with respect to BAU and efficiency ratios (points, right axis) for each targeted product by scenario



Source: Authors' elaboration

Note to Figure 3: The emissions efficiency ratio represents the fall in emissions from former suppliers over the increase in emissions from new suppliers. It is always negative, and the greater its absolute value, the more efficient the relocation is.

The joint analysis of changes in trade volume and the EU's carbon footprint of reshoring scenarios highlight that a slight shift in imported production can lead to a more significant reduction in the EU's carbon footprint when applied to some strategic products, such as iron and steel, chips and circuits and electrical motors and batteries. In basic metals, emission reductions are slightly larger in the backshoring scenario than in the nearshoring one. However, we find the opposite for chips and circuits and electric motors and batteries; with nearshoring strategies leading to larger emission savings than backshoring.

Firm perspective: Circular economy and take-back systems

In the construction case study, the French Anti-Waste Law for a Circular Economy, known by its acronym AGEC, has had strong constraining effects on firms' business models, notably by imposing materials sorting on deconstruction sites. However, from its inception, firms expressed concerns over how to comply with new circularity requirements. To tackle these concerns, we find that the emergence of new intermediary actors specialized in the circular economy has facilitated the transition and the establishment of local circular loops. Many actors all along the value chain expressed difficulties integrating circular loops into their project designs, because of a lack of coordination between the supply and demand of products and materials to be reused. To support the development of circularity, an intermediary - SYNETHIC - was created. It associates various economic and institutional actors from the Occitanie region and supports real estate renovation and deconstruction projects aimed at optimizing resource utilization and recovering construction waste. The establishment of this intermediary was vital to enabling change in business practices in the sector:

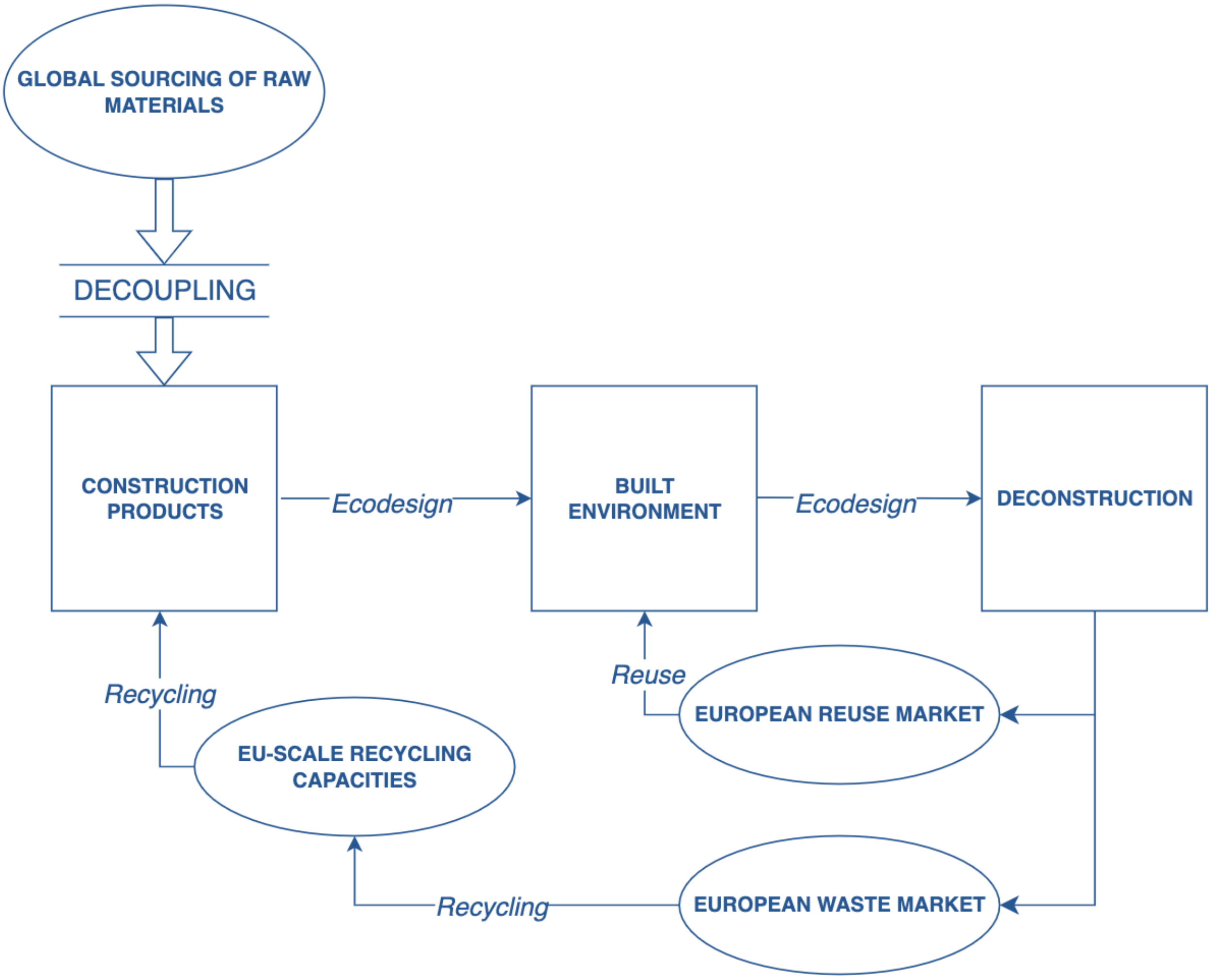
"We realized that in terms of networking, we didn't have enough connections to source sufficient reused materials. Since we met SYNETHIC, they have been making us proposals every week. It really changes the game." (Interview, architecture firm, December 2022)

Another perceived barrier to the development of more circular business models expressed in our interviews in the sector was the lack of appropriate skills. In this case, another intermediary named ENVIROBAT, a professional regional association, has fostered collaboration among professionals by offering training sessions on circularity and developing educational tools for project support.

However, although these new circular intermediaries have stimulated the development of the reuse and recycling model, scaling this trend still largely depends on the adoption of more systematic eco-design criteria at the design phase of projects. Additionally, technical constraints regarding, for example, the modularity of eco-designed buildings, as well as established sourcing habits, still impede the scaling of the model. Consequently, the impact of new circular models on the reconfiguration of the EU-led construction GVC appears minimal for now, although it has favoured local circular loops. EU policymakers nevertheless believe that the upcoming EU legislation in the sector – notably the adoption of green standards for construction products – can accelerate the greening of the construction GVC, as well as enable the industry to scale up, favouring an EU-wide CE through the harmonization of waste markets and related standards (see Figure 4 below).

The wider policy objective is to reduce the EU's reliance on global markets of raw materials, while developing EU-scale circular loops. This implies (i) harmonizing the waste criteria on the EU market to facilitate the circulation of both construction waste and second-hand construction products and (ii) investing in innovation for construction materials recycling and eco-design to enable these new business models.

Figure 4: Decoupling the construction value chain from global sourcing: the potential for European circular loops



Source: Authors' elaboration.

In the textile case study, we found that although French CE policies also had an impact on firms' business models, the effect was more limited. The primary regulatory challenge remains the mass market and the 'fast fashion' sector, which represents (by far) the largest volume of sales and associated pollution. In this 'mass market' segment, traditional lead firms have diverse commitments towards eco-design and circularity, mainly because of GVC constraints regarding the cost-effectiveness of circular strategies. In particular, shorter loops tend to be more labour-intensive, undermining their economic viability:

"The shorter the loop in the value chain [in my circular strategy], the more it costs me" (Interview, French textile lead firm with circular initiatives, April 2024)

Despite these challenges, several lead firms have launched circular innovations focused on intensifying use through the development of the market for second-hand goods and renting. The former may be seen as a marketing tool to attract consumers and compete with emerging online marketplaces, while it does not address the underlying issue of overconsumption. The renting model also increases the intensity of use and may address this latter issue more successfully, by avoiding the purchase of rarely used goods. However, the logistical and practical challenges of rolling out renting of clothing at scale are significant, not least because the process of taking back and reconditioning is labour intensive and currently lacks scale economies. This finding is confirmed by the analysis of take back programmes by Danish firms, explored below.

Traditional textile lead firms have also begun diversifying their product ranges by introducing goods containing recycled fibres, especially polyester. Such fibres can either come from the plastic bottle (PET) recycling industry, or from the recycling of unsold items. The latter is economically feasible thanks to the prohibition of the destruction of unsold goods under French CE law. However, these efforts still appear minimal, as they often involve mixed fibres and cover only a small part of the total range. Many lead firms continue to constantly refresh their range at extremely fast rates, further encouraging overconsumption. NGOs underline that for the negative impact of the sector to be mitigated, there is an urgent need to address this issue.

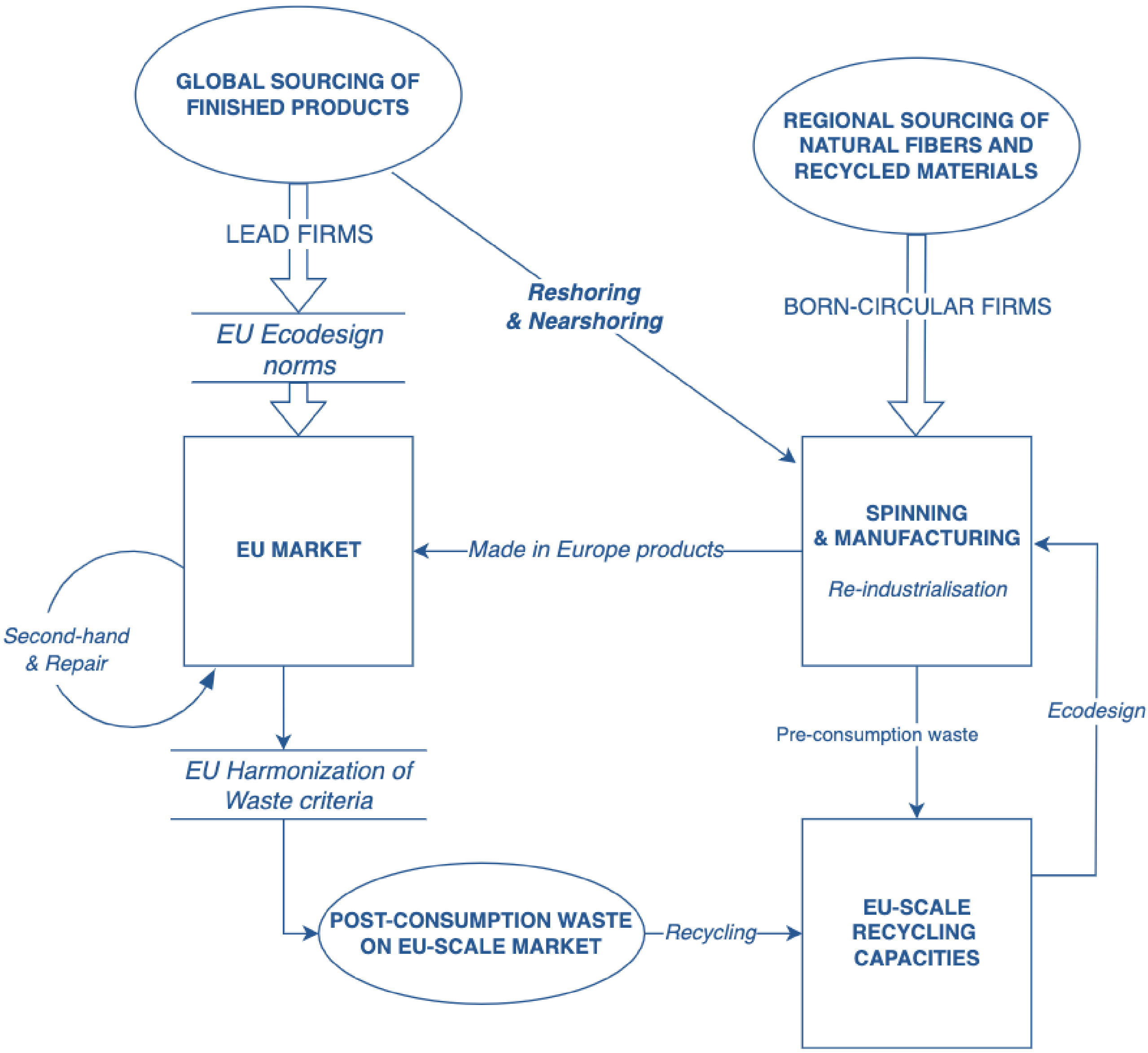
On the other hand, a market for greener products exists and some circular start-ups have emerged to offer sustainable eco-design business models based on local sourcing. However, in our interviews, they expressed concerns that public authorities don't provide enough institutional support to revive regional supply chains, a move which would de facto imply partial decoupling from the EU-led textile GVC. At the same time, they underline the need for public funding to finance ecological experimentation and call for stronger regulation of competition on the EU market through green standards.

Indeed, with minimal eco-design efforts at the mass market level, where firms are not engaging in real changes to their sourcing practices, it seems unlikely that a reconfiguration of global value chains will occur without more stringent regulations. This is precisely why the EU is currently devising several policies that go in this direction. The Regulation on Ecodesign for Sustainable Products (ESPR), which will require importers who place goods on the EU market to respect ecodesign, repairability, and recyclability standards, has already been agreed, although the technical criteria that apply to each sector will be negotiated in the coming decade.

To address issues related to securing access to raw materials and creating incentives to scale the recycling industry, the Waste Shipment Regulation adopted in 2024 will facilitate the internal market for waste and support the development of recycling loops at the EU level. To improve waste management, the creation of an Extended Producer Responsibility (EPR) scheme in the textile sector is also under discussion. Lastly, some consumer-side policies, such as the creation of a Digital Product Passport that would provide information on the environmental impact of textile products, are also in development and should be implemented in 2026-2030. In parallel with these EU market regulations, the French state is also trying to incentivize the reshoring of some parts of the textile GVC through more classic industrial policy measures (Interview, French Ministry of the Economy, May 2024).

The overall goals of policymakers to make the EU-led textile GVC more sustainable are represented in Figure 5 below. This multi-level approach will change the incentive structure and force firms to reassess their design and production processes, but how much this will fundamentally change GVC structures remains an open question. French experience indicates that any such shifts are slow and mass market firms struggle to fundamentally adapt their approaches.

Figure 5: Greening the European textile value chain through regulation and partial decoupling: policymakers' ideal-type scenario.



Source: Authors' elaboration.

The two markets we explore in France, textile and construction, are in a process of slow transition. The development of hard CE regulations such as Ecodesign and EPR will strongly affect the structure and sustainability of EU-led GVCs. European lead firms will have to adapt their sourcing activities (potentially expanding vertical governance of subsidiaries), while the Asian producers currently dominant on the EU market will have to adapt their business models to incorporate circular practices or risk seeing their market access to the EU reduced. Although so far actual shifts in business models are limited, all actors we spoke to expect changes in the near future, although they differ in their views on the extent and speed of change. We highlight some key barriers to the transition in both sectors studied which public policy can address – especially supporting intermediaries, addressing barriers to scale and skill shortages.

In the construction sector, we find that the constraining CE regulation has necessitated the emergence of circularity intermediaries to assist firms (most of whom are SMEs) in the adoption of their business model. CE policies have so far mainly contributed to the development of local circular loops, which are limited in scale. They have thus not (yet) affected the fundamental structure of GVCs.

In the textile sector, even though CE regulations have been less constraining so far, we find that French lead firms are already thinking strategically of adapting their business model towards more circularity. Yet change is limited and barriers remain to scaling up existing circular practices. In the longer term, we expect some partial reconfiguration in order to ensure greater sustainability within the EU-led textile GVC in the coming decade.

Regarding the take-back systems specifically analysed in Danish firms from several sectors, there are two distinctly different retention strategies: the material value strategy and the functional value strategy (Bocken and Ritala, 2022). The goal of the first one is to recover the material without concern for the identity and functionality of the products. The goal of the functional value strategy is contrarily to retain the identity and functionality of used products and their components as much as possible. A material value retention strategy has limited implications on the internal capability, and the viability of take-back lies in the ecosystem development. The ecosystem is often far-reaching as it should secure access to recycling technology and collect products from end-users through different partners. In extreme cases, a manufacturer can outsource most of the take-back system activity, reducing take-back activity to mainly manage contracts and reporting. However, what is often needed is a lead company of the GVC to invest in and orchestrate the formation of the ecosystem. Without the lead company in the GVC committing and investing in it, it will be very difficult to align all partners in the ecosystem to do their utmost best to retain the value of the discarded products.

On the contrary, the higher complexity of a functional value strategy comes from the extensive development of the internal capabilities as well as the ecosystem. Preparing used products to be sold for a second life requires the development of a complete manufacturing set-up that can handle the variation in product versions that will come back. This also implies changes in the support functions like finance and quality, and the ecosystem must be developed to efficiently return products. For the ecosystem to support an efficient functional value capture the partners must return products and information, return only discarded products fit for reuse, and avoid damages in transit from end-user to manufacturer. Essentially, realizing the potential lies in the organization converting in every sense from a "one-way factory to a two-way factory" and re-aligning values in the ecosystem to focus on both financial and resource value.

From a business complexity perspective, a material value capture strategy is to be preferred given the limited need for organizational capability development. However, this contrasts with a societal perspective where a waste hierarchy places a higher preference on functional value recovery than material value recovery. From a societal perspective, retaining as much functional value as possible is optimal, which speaks to the functional value strategy, but this is also the more complex strategy making it harder to become financially viable. These opposing logics demonstrate the need for policy and financial incentives driving industry development towards resource recovery strategies that retain the functional value, particularly for products with limited retention values like electronic products, food, and textiles.

While it is difficult to set up take-back systems in a domestic context, it becomes even more complicated to set up a take-back system that crosses country barriers. While the linear business model works in an international context, the circular business model runs into several barriers when crossing country barriers. This is due to different natural regulations regarding handling waste, different distribution systems, and, not least, different cultures and perceptions of the value of end-of-life products. These barriers make it very difficult to create global value chains-based circularity. With separate take-back systems in each country, creating the needed scale to form a viable take-back system is challenging.

All companies need partners and a suitable infrastructure to implement take-back systems in order to collect, sort, access and handle end-of-life products, and it takes time to create this kind of ecosystem and align all partners on the goal of retrieving the value of the end-of-life products. This is obviously a challenge when changing the configuration of the global value chain e.g. through reshoring.

4. Mitigation potential of reshoring strategies: the role of MNEs and technology transfers

Contextual background and research objectives

The last decades of intensive globalization have brought on increased international trade and internationalisation of GVCs. A significant phenomenon within this process is foreign direct investments (FDI), where companies establish a cross-border presence in a foreign market. Studies on FDI indicate that investment decisions are driven by different sets of factors that are strongly dependent on the stability of the ecosystem in which the companies function. Increased geopolitical tensions and pressure to achieve green transition point to new antecedents that currently offset the FDI-related choices. A key issue remains how to decide on the investment location, as in many cases, the FDI is driven not only by the desire for market penetration but also by cost and efficiency reasons. In effect, companies face location dilemmas where managers are forced to make decisions based on several interconnected variables. FDIs are said to bring numerous benefits to the host countries, including economic development stimulation (Dobrowolska, Dorożyński, Kuna Marszałek, 2021), boost in international trade (Sahoo and Dash, 2022) development of resources, increase in employment, productivity, etc. Yet, still in 2022, the US and China remained the two top FDI destinations worldwide, whilst emerging and developing markets struggled to attract new greenfield investments. Globally, the FDI momentum slowed in 2022 as flows dropped by 24% compared to the previous year and still remained below the pre-pandemic values (OECD, 2023).

The climate emergency and geopolitical and post-pandemic aspects also reshaped the current global context, which presents an opportunity to reconfigure global production chains. The multinational corporations' influence along GVCs will be vital in addressing the new economic and environmental challenges derived from this reconfiguration. Moreover, international trade has been traditionally considered a channel of technology transfer (Rigo, 2021), with a particular interest in the role of multinational enterprises (MNEs) as disseminators of technology spillovers (Keller, 2010).

In recent decades, this international transfer of know-how led by MNEs from advanced-technology countries has allowed low-wage nations to industrialize more than in any previous period (Baldwin & Lopez-Gonzalez, 2015). In this line, as part of the EU resilience strategy, in Chapter 4, we study hypothetical EU MNEs backshoring processes directed to EU peripheral countries. First, we address the knowledge gap related to quantifying the potential of backshoring and technology transfers led by MNEs to reduce CO_2 emissions generated by EU production. Second, we evaluate the resulting role of peripheral EU countries (with emissions-intensive and fossil fuel-dependent energy mixes) in these reconfiguration processes. Third, we go deeper into MNEs' location and low carbon transfer decisions through qualitative analysis from case studies of EU MNEs with subsidiaries in one of those peripheral countries, Poland.

The pursuit of resilience through reshoring strategic products will boost the growth and creation of subsidiaries of EU MNEs that hold know-how in strategic industries across EU countries. It is crucial for the EU that the ends and means of these companies contribute to meeting the climate change mitigation objectives set by the European Commission's agendas (European Commission, 2021, 2022, 2023; European Commission et al., 2021). Since the environmental impacts of MNEs exceed their parent countries' borders, we highlight these firms' potential to transfer low-carbon technologies from developed EU parent countries to peripheral EU host countries. Then, this study provides novel and relevant findings on the risks and opportunities that the EU will face concerning the environmental impacts of the MNEs-led dynamics described above.

In the foreseeable transformation of GVCs into regional value chains, comparative advantages will continue to drive international trade and foreign investment. Then, EU countries with low labour costs will be attractive locations for backshoring production from far locations (e.g. Asian countries, Russia, etc.) to EU territory. In this context, one of the leading research questions of Chapter 4 is: What are the potential impacts on carbon emissions of reshoring trends and technology transfers driven by EU Multinational enterprises (MNEs) operating abroad fostering new hosting peripheral EU countries? The analysis carried out allows us to understand to what extent the reconfiguration of the production of EU-owned MNEs will impact the EU's carbon footprint performance while seeking intra-EU environmental and economic convergence.

Additionally, through case studies, we complement the previous quantitative analysis by providing qualitative insights into the impact of technology transfers from MNEs to their subsidiaries or domestic firms in the host country and discussing the impact of environmental factors on FDI location choices.

Recently, the increasing number of policy acts (e.g. CBAM, CSRD and CSDDD) pressures companies to consider environmental issues while conducting business across different countries. In the literature, it is presumed that the company’s headquarters would engage in transferring technologies to its subsidiaries (Li et al., 2009). The technologies might be of different nature, including those aiming to achieve environmental goals (Steenbergen & Saurav, 2023). Yet, at the same time research suggests that not all MNEs are willing to engage in technology transfers, as these are associated with significant cost (Jensen & Scheraga, 1998). Hence, we formulated the following research question to be addressed from case studies: What environment-related technology transfers are most common between MNEs and their subsidiaries in manufacturing industries? How are they organized?

Literature also points to numerous factors impacting the FDI location choices (Chowdhury et al., 2023), including market size and its growth rate, labour costs and quality, taxation, political and geopolitical risks, corruption level and many others. Presuming that the technology transfers are taking place and that European companies are forced to comply with an increasing number of environmental policies, we then turn to investigate whether the advancement achieved by those transfers increases the attractiveness perception of a given location. Conversely, the pollution haven hypothesis (PHH) argues that in manufacturing industries of high pollution, operations are transferred from countries with relatively strict environmental regulations to countries with less stringent regulations (Hille, 2018). This is due to the environmental standards that force companies to invest in new equipment, stricter landfill protocols, impose limitations on specific materials and byproducts, and cause increased production costs linked to alternative waste management solutions. Hence, we investigate through case studies whether the PHH remains valid or whether the environment-related technology transfers increased the FDI location attractiveness and whether environmental factors are important antecedents for FDI location choices for MNEs. Both, the qualitative and quantitative assessments allow us to evaluate how EU MNEs can be relevant in leading a greener transition.

Methods of analysis and data

The core model of the quantitative part of the research in this chapter is an environmentally extended multiregional input-output model (MRIO) with firm ownership heterogeneity and applying the Producer Footprint (PF) accounting. We use the AMNE database the OECD provides, which offers multiregional input-output tables that distinguish foreign-owned and domestic-owned companies in every sector and country. This data and model are suitable for tracking the virtual transfers of CO_2 emissions along GVCs and estimating the carbon footprint of production (producer carbon footprint), which accounts for all the emissions occurring along the global production chain until the last production phase of the good or service (López, Cadarso, Zafrilla, & Arce, 2019; Ortiz, Cadarso, López, & Jiang, 2022). See Appendix A for details on the MRIO model and Appendix F for details on implementing the model with the AMNE database.

We conduct a scenario analysis to evaluate the variations of the resulting EU's environmental performance in four scenarios that simulate backshoring and low-carbon technology transfers (environmental technology transfers, ETT) led by MNEs to foreign-owned enterprises (FMNEs) and to domestic-owned enterprises (DOEs) and take peripheral EU countries as the primary receivers of the relocation of production and technology transfers. The scenarios proposal also includes the simulation of the electricity decarbonization process of the new hosting countries to assess the policy actions on emissions hotspots. The scenarios are built applying the source-shifting technique, which is commonly used in the literature for the study of reconfigurations of international trade flows and GVCs (de Boer, Rodrigues, & Tukker, 2019; Giammetti, 2020; Gilles, Ortiz, Cadarso, Monsalve, & Jiang, 2021). Table 1 summarizes the scenarios' features.

Table 1: Description of scenarios of backshoring and low-carbon environmental technology transfers by EU-MNEs, including sectors and types of firms affected.

Scenarios' details			Changes in emission coefficients from ETT	
	Label	Description	Sectors affected	Firms affected
Pure back-shoring	*1*	Pure backshoring towards peripherical EU countries	None	None
Backshoring + environmental technology transfer (ETT)	*2.1*	Backshoring + ETT in targeted sectoral production by foreign MNEs operating in the country	Targeted strategic industry	FMNEs
	2.2	Backshoring + ETT in country-wide targeted sectoral production	Targeted strategic industry	FMNEs + DOEs
	2.3.	Backshoring + ETT in country-wide targeted sectoral production and country-wide electricity sector	Targeted strategic industry Electricity generation	FMNEs + DOEs FMNEs + DOEs

Source: Authors' elaboration.
Note to Table 1. DOEs: domestic-owned enterprises. FMNEs: foreign-owned enterprises.

The new hosting countries within the EU where the MNEs' production is being backshored have been chosen according to labour cost criteria. This production scheme reconfiguration promotes the convergence of EU countries with specific comparative advantages in labour terms, incentivizing the decision to relocate from the side of EU MNEs. In this way, we have selected the top 13 EU countries with the lowest hourly labour cost in 2022, according to Eurostat (2024). The European periphery is characterized by the heavy presence of foreign capital within their structures of production (del Río Casasola & Paz, 2023; Seers & Vaitsos, 1980), which makes these regions suitable to receive FMNEs production without a substantial alteration of their dynamics. According to Grodzicki and Geodecki (2016), Central and Eastern European countries pose some features that make them suitable for manufacturing technologically advanced intermediate goods for the core European countries: low labour costs, a relatively high level of technological specialization, and strong integration into European production and transport networks. Southern Europe can benefit from foreign direct investment and ETT since it has suffered the weakening of its competitiveness and connectedness to global networks in the last few years.

Since the study was also meant to exemplify technology transfer practices, we used qualitative methods in the form of case study analysis that captured in-depth remarks on the researched phenomenon. The study was designed to answer the two research questions above, but we used a grounded theory approach to allow the respondents to conceptualize their reflection on the topic. Grounded theory is specifically helpful for emerging or under-researched issues, where it is insufficient to base the conclusions on only aggregated data. We have collected the data through interviews and internal company documents. Since the focus of the study was on technology transfer and FDI, we have restricted the interviewee selection to manufacturing industries only. The companies that participated in the study had operations located in Poland (subsidiary) and headquarters located in another European country. The interviews were held between December 2023 and June 2024; the documents analysed reflected the reporting period of 2020-2024.

During the analysis stage, we iterated the data until theoretical saturation was reached. The cases had exploratory character aiming to understand two issues: (1) how the companies approached the strategic technology transfers within their corporate group and (2) whether the environmental ecosystem created, e.g. by those technology transfers, could increase the positive perception of FDI attractiveness of a host location. We used open, semi-structured interviews (in English and Polish), observations, note-taking and document analysis as data collection methods. The interviews were accompanied by an interview guide based on Agee's (2009) recommendations. The interview protocol was supplemented with a support document detailing the aim and meaning of specific questions and listing some additional sub-questions that, if need be, could be used in company-specific cases to expand certain elements. As the interviewing team included several researchers, we composed memos during and after each interview to explore the data from different perspectives. Our qualitative research did not have pre-defined hypotheses or answers to avoid bias. The interviews were transcribed and analysed using the MAXQDA software. While coding, we applied an inductive approach since it enabled us to adopt more empirical grounding. We subsequently performed open, axial and selective coding to recognize themes and categories.

Findings and discussion

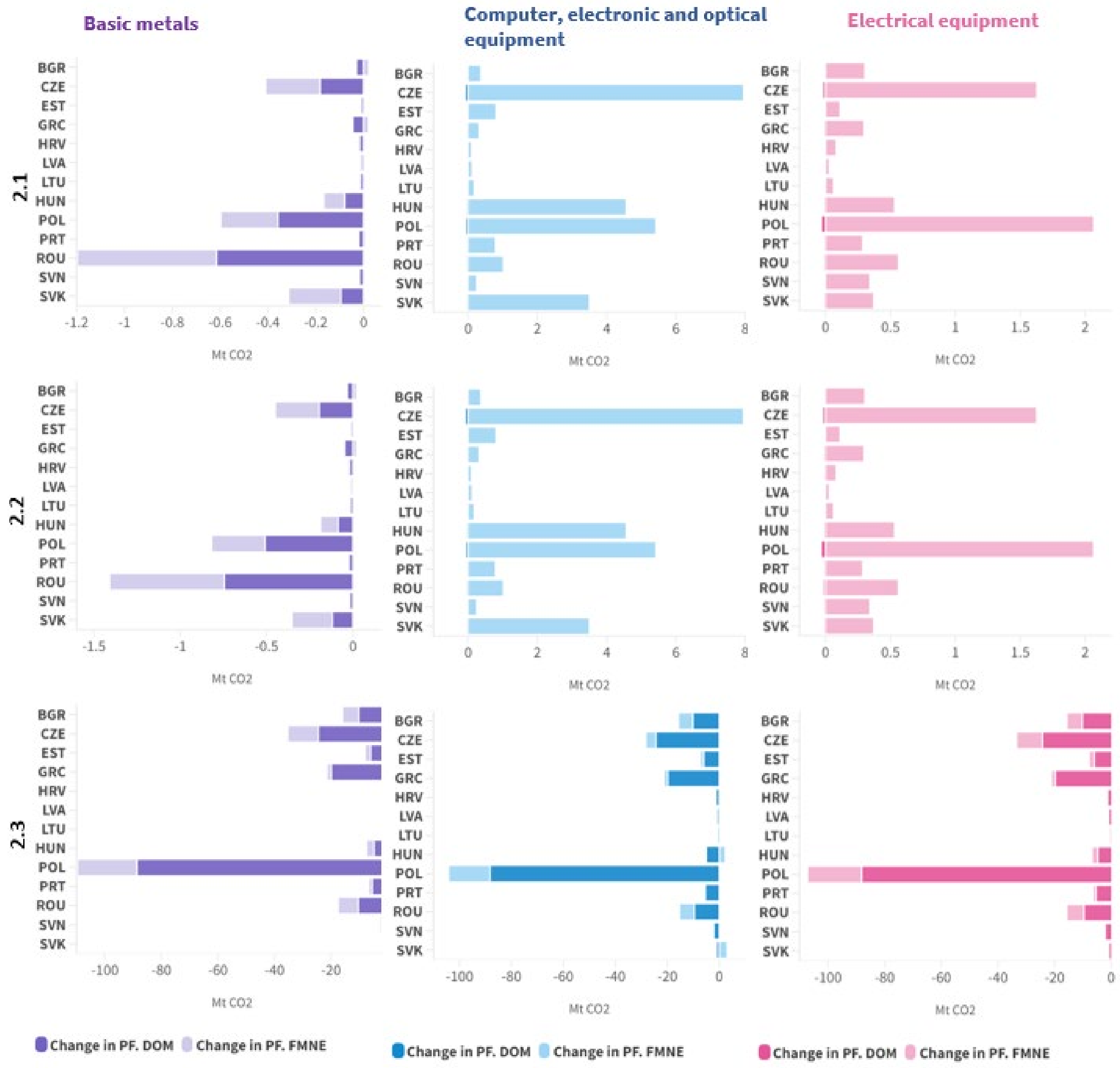
The results of the quantitative analysis of reshoring scenarios for EU MNEs revealed that domestic electricity generation acts as a critical hotspot to be assessed in technology transfer schemes when trying to reduce the EU's producer footprint, regardless of the targeted industry.

Additionally, impacts on carbon emissions show different behaviours depending on the sector analyzed. For the case of the relocation of sectors with relatively low emissions intensity, such as computer, electronic, and optical equipment, and electrical equipment, the emissions increase within the EU borders is relatively low. Additionally, the ETT of coefficients of the same sector generates small emissions reductions given the similarities between the emissions intensities of parent and subsidiaries’ host countries. However, the production relocation of energy-intensive industries, such as basic metals, provides different results. The cleaner environmental performance of the EU compared to the former exporter countries' pollution intensity is translated into an emissions reduction if the EU supplies that amount of production. For the three sectors mentioned (computer, electronic, and optical equipment, electrical equipment, and basic metals), the more significant improvement of the EU environmental performance would come when the decarbonization of the electricity sector of new hosting countries is simulated, accounting for remarkable emissions reductions and lower energy prices, which promotes the economic attractiveness of those new EU-producing countries.

Figure 6 shows emissions changes for the technology transfer scenarios under the producer footprint criterion, which accounts for all the emissions required to generate all the production of a sector (including production exported and emissions embodied in inputs) by country, sector selected, and differentiating between MNEs and DOEs. On the one hand, for the cases of computer, electronic and optical equipment, and electrical equipment, the PF, after the backshoring scenario, shows an emissions increase, concentrated mainly in MNEs without impacts on DOEs, located in countries such as the Czech Republic, Poland, and Hungary. On the other hand, basic metals present a remarkable PF reduction shared between MNEs and DOEs concentrated in countries such as Romania, Poland and the Czech Republic. The results for the electronic sectors are expected as the EU is assuming new production within the EU borders, so emissions increases are expected in footprint terms compared to the BAU scenario. The results for basic metals are also interesting; even considering the increase in production of several basic metal sectors in several countries, the EU would still reduce emissions compared to the BAU scenario, because of the dirtier environmental performance of the former suppliers of basic metals beyond the EU borders.

Scenario 2.3 of Table 1 results show the importance of guiding the technology transfers to those hotspot sectors to reduce emissions within the EU. Emission reduction after the decarbonisation scenario is relevant for most countries, with outstanding results in Poland's case. For all the sectors, emissions reduction in Poland is very large, and more significant reductions are generated in the case of DOEs. DOEs appear to be relevant engines for emissions reduction because of the indirect linkages in energy terms among sectors and firms. The case of Poland as a host country is further explored through this chapter's case studies.

Figure 6: Producer footprint emissions changes by new host, type of firm, scenario, and targeted sector (MtCO2)



Source: Authors' elaboration based on Eurostat.

Micro perspective: Technology transfers and FDI location choices

From the qualitative analysis at the firm level, the grounded research approach allowed us to understand that companies have shifted from viewing environmental issues as a separate notion to understanding them as a coherent part of their sustainability strategy. Whenever possible, companies design their KPIs in such a way that their actions enable them to achieve environmental, economic and social goals simultaneously. In manufacturing MNEs, environmental issues still constitute a significant element in understanding the sustainability concept, but they are treated as a coherent part of the sustainability strategy; all and any expected impact relates to interconnected changes where environmental, social and economic dimensions are treated as equally important. As a rule of thumb, the headquarters are responsible for delineating the main SDG-related aims and pointing out which actions will be addressed by the corporate groups. In all our cases, the KPIs are set for the entire corporate group on the corporate and not subsidiary levels. This means that strategic units enjoy the "substitution effect"; if a certain subsidiary is not able to achieve the desired level of improvement, this can be compensated by the additional effort of another subsidiary as long as the corporate-level KPIs are met. Upholding the existing subsidiaries is, in many cases (but not all of them), dependent on the ability to adjust operations in line with SDGs.

The solutions to meet the environment-related KPIs remain the responsibility of the individual subsidiary. MNEs have a "pool of best practices" that can be benchmarked across organizations. However, subsidiaries are not forced to adopt these solutions as long as they achieve KPIs. Headquarters organise and supervise a way in which companies can adopt solutions already enforced in other subsidiaries. Depending on the company, the practices in this aspect vary, starting from an online platform where applied technologies and organisational innovations are listed, up to organized networked in-company visits and joint programmes designed to share the know-how. However, all interviewees reported that they can make use of the technology transfer, although they are not forced to do so, if their specific circumstances enable them to adopt individual, designed "from-the-scratch" solutions. However, in all the cases, the technology transfer was taking place along the whole network, i.e. between headquarters and subsidiaries and between subsidiaries themselves. The transfers were not "top-down", meaning that they did not originate from headquarters as a superior entity.

The type of technology transfers differed depending on the specificity of the manufacturing process, though most of the cases reported to prioritise energy transition technology transfers aimed at achieving net-zero emission (SDG7), such as the ones addressed in the quantitative part of this chapter, and waste management (SDG12). Likewise, some of the interviewed companies worked on improving water usage management (SDG12). However, the scale of these technology transfers was relatively lower than the ones mentioned above.

Regarding FDI location choices, all our cases reported that the environmental factors were not among the key FDI decision antecedents in the past. The new subsidiaries were either launched to gain access to new markets or to increase cost-effectiveness. Companies report that, while making the FDI location choices, they are still led mainly by the cost and market determinants. However, the investment is made only if the host country is able to ensure compliance with the sustainability-related KPIs expected by the headquarters. This is due to the new policy regulations, either enforced or expected (e.g. CSRD & CSDDD). Companies headquartered in Germany and France are at the forefront of taking action on sustainability. The changes are for now restricted to European locations but have become a factor in undertaking new non-European investments. At present, in the case of two companies, relocation of certain activities is considered if given subsidiaries cannot meet the environment-related expectations.

However, the interviewees have not given an unambiguous answer to whether technology transfers observed among the MNEs are altering the perception of FDI attractiveness of a location. They did acknowledge that the technology transfers were needed and had a general positive impact on the host country. Yet, while considering their own foreign investments, they were more concerned with the headquarters' environmental expectations and host country stability. They considered both the European regulations that are becoming more demanding and the host country's expectations. The interviewees reported that they mostly considered how often the host country changed its environmental regulations, how quickly the changes were enforced (incremental vs radical approach) and whether the changes were drastic. A dominant concern for companies is the interoperability of European and global sustainability reporting standards. In case of a conflict, companies are expected to refer to the requirements of European Sustainability Reporting Standards (ESRS) and International Sustainability Standards Board (ISSB) standards separately, which may increase the uncertainty over the expected results and associated costs.

At the same time, however, they reported that if they did invest, they rarely worked in partnership with local actors, including any R&D centers, universities, technology parks or other companies. Their initiatives were restricted to corporate groups, which signals that, in fact, they do not intend to benefit from the technology transfers already experienced by the host country.

5. Towards environmental greensourcing strategies

Contextual background and research objectives

Implementing the proper environmental policy measures will be vital in slowing down the severe climate change problem we are facing. Current governments' policies driving GVCs' restructuring are primarily motivated by the pursuit of resilience and the avoidance of chain disruptions with unintended impacts on global emissions. However, a green target seeking to decarbonise GVCs would also achieve synergies with other desirable political and growth objectives. GVC reconfiguration through low-carbon source shifting could be a feasible alternative, as the shift to cleaner providers will lead to a reduction in the carbon emissions embodied in GVCs and in the carbon footprint. We believe that favouring providers with cleaner processes should be a priority policy for the EU, as it will encourage the necessary reduction in emissions.

There is a growing interest in the potential of new production technologies as a valuable means of controlling CO_2 emissions. However, technologies are slow to develop and spread. For this reason, this Chapter 5 is devoted to evaluating the mitigation potential of new trends and reorganisation of GVCs following environmental goals. To do so, first, we identify the cleanest production processes already in place that will have the most significant impact on reducing emissions. Second, we propose quantifying the CO_2 emissions curbing potential of trade redirected towards clean providers.

This chapter identifies the potential of supplier switching by restructuring GVCs to reduce emissions. By analysing the emissions generated by all suppliers of goods and services to the EU in their country-sector mix, new pathways can be designed to meet EU production and consumption requirements in the cleanest possible way in terms of carbon emissions. This would lead to the EU achieving clean production and consumption targets with currently available technologies without technological breakthroughs. The study will also identify the sectors with more significant reduction potential, which should be prioritised for policy implementation, transforming a theoretical exercise into a practical guide for policymakers.

Our primary research question is the extent to which supplier switching is a valuable strategy for reducing the EU's carbon footprint. Supplier switching does not require significant investments or the development of new, more sustainable technologies so its implementation can be achieved relatively quickly and at a relatively low cost. Keeping this in mind, the empirical application raises the question of whether this switching strategy would make significant progress in our quest for a carbon-neutral EU. On the one hand, various scenarios were designed to replace actual EU input purchase trends with feasible, cleaner alternatives to calculate the potential reduction in emissions. Calculating emissions in scenarios with different assumptions will facilitate the creation of a comparative range of results.

On the other hand, the shift in suppliers that would result from the EU blocking the purchase of goods and services with a dirtier production process would modify the whole structure of GVCs. There is a real danger of resource shuffling. This would affect both the 'dirty' countries that used to sell to Europe and the third countries that used to buy from the 'clean' countries. Given that the production capacity of these sources would be absorbed by an EU with more stringent requirements on its purchases, third countries will find that they need to shift their sourcing to dirtier suppliers. This would stimulate not just a regional, but a global restructuring of the GVCs, the effects of which should be measured worldwide.

Methods of analysis and data

Chapter 5 proposes to calculate the potential for emissions mitigation by redirecting EU global supply chains towards cleaner producers. This is achieved through green or right-sourcing strategies scenarios implemented using the source-shifting technique in an MRIO model. We will develop a novel three-step shifting process: First, we calculate the emissions intensity for each "vertically integrated sector", that is, the total emission intensity of the sector, including emissions embodied in all the inputs required, directly and indirectly, per unit of the sector final product. This allows us to create a 'dirtiness' index, which identifies those countries contributing the most to the global carbon footprint per sector - the 'dirty' countries by sector. Conversely, it identifies countries that could be considered the cleanest alternatives. Secondly, we proceed to shift all "dirty" imports towards targeted countries with cleaner sectors, according to several distinctive scenarios. Finally, we calculate the total emissions reductions of those scenarios to determine the potential improvements of a green sourcing strategy. The scenarios are designed by considering different combinations of four parameters. These parameters reflect different trade policy choices or methodological aspects, such as: i) the location of the clean countries that will be the EU's new suppliers, ii) the decision to maintain or increase production capacity in clean locations, iii) the search for EU trade balance or for global trade balance (requiring global demand to remain stable), or iv) the introduction of changes for sectors individually or all simultaneously. See details on the methods in Appendix G.

Findings and discussion

The implementation of the scenarios of GVC reconfiguration driven by lower carbon content points to a reduction in EU carbon emissions that range between 14 and 25%, depending on the specificities of the proposed scenarios. This means a valuable boost to emission reduction targets and a reinforcement of the role of the EU as a leading region in facing climate change. Our results consider a wide set of 16 scenarios, which differ in parameters that imply different choices regarding the implementation of a hypothetical EU policy of switching trade to clean suppliers.

First, we discuss the environmental impact results common to a hypothetical policy requiring sector-specific switching, which comprises 8 of our scenarios. Sectors with the most significant potential for emission reductions, that keep this character independently of other features of the model, include manufacturing (other than those specifically mentioned), computer, electronic and optical equipment, electrical equipment, transport sectors, machinery, textiles and even food products, all with reductions that range from 10 to 30 $MtCO_2$ as a mean in these scenarios. The scenarios' range allows us to compare the results when clean providers are located within the EU with the options of shifting to any provider from the cleanest per sector globally with little differences in the reductions. This comparison shows the dominance of European manufacturing sectors in the green cleaning rankings, as the improvement in performance when suppliers are global as opposed to European is marginal.

A hypothetical policy in which all sectors would select their suppliers on the basis of an environmental criterion of carbon emission reduction would increase the potential reduction for individual sectors.

Cross-sectoral relationships would reinforce the abatement potential compared to a situation of isolated sectors pursuing emission reductions, leading to sectors with high cross-sectoral dependence to improve their emission reductions. This would lead to a total reduction of the EU carbon footprint between 345 and 545 $MtCO_2$. All the relevant sectors in the case where only individual sectors embrace the clean provider switching policy are still among the ones with the highest reductions, a relevant achievement considering that manufacturing, electrical equipment, and computers are considered strategic sectors for the EU in terms of resilience improvements along GVCs (Eurofound, 2019). Also, construction, chemicals, coke and refined petroleum and metal products, together with the services sectors accommodation and food services and health, reduced their emission of over 10 $MtCO_2$ each as a result of joint environmental efforts due to their high dependence on industrial and energy sectors.

When we analyse the change in the geographical distribution of the EU carbon footprint in clean GVCs, we find that emissions increase within the EU-27 borders is significantly smaller than Non-EU-27 emissions reduction given the cleaner production structures of new producer countries. We comment in more detail by focusing on the industrial sectors with a higher potential to reduce emissions that can also apply a shifting strategy more efficiently.

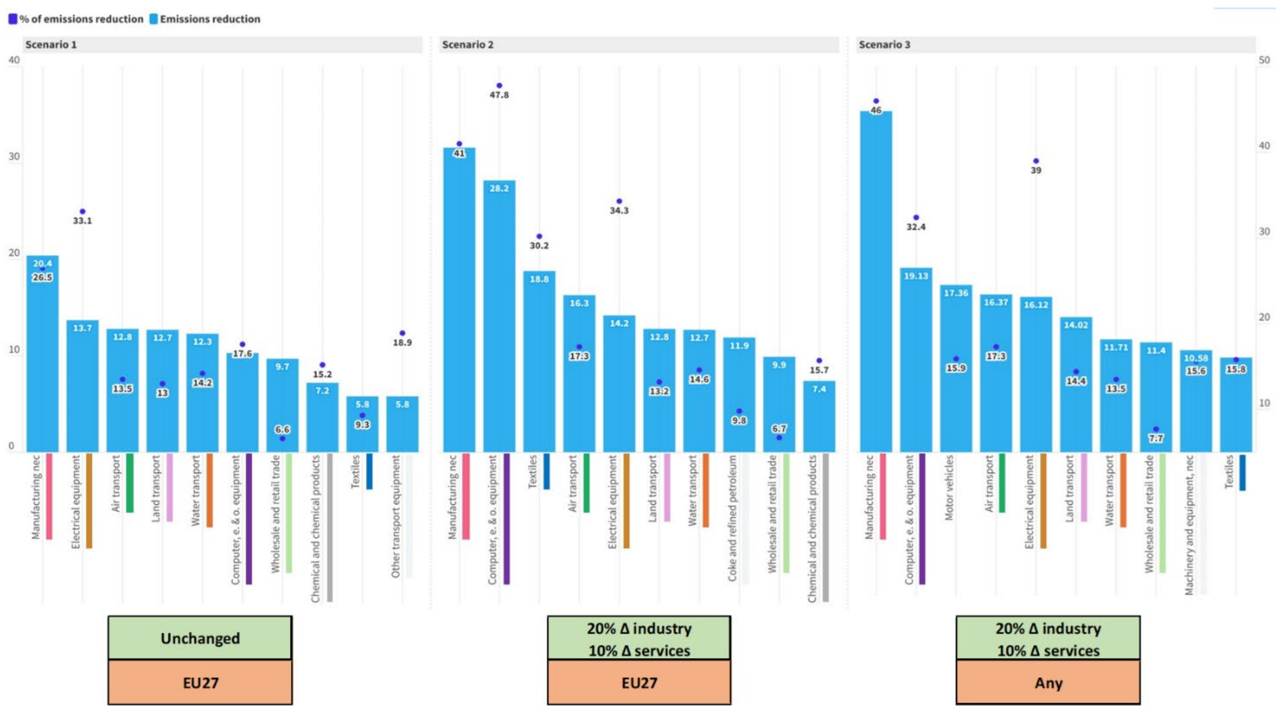
For the strategic sectors of computer, electronic and optical equipment, electrical equipment, and manufacturing nec.; repair and installation of machinery and equipment, the more significant emissions increases are located in those countries with higher production capacity per sector, with Germany always appearing as assuming a relevant part of the new production flows. In indirect terms, the emissions reductions observed for China for all the cases, and some other countries such as India or Hong Kong for specific industries, allow us to identify the emissions hotspots in searching for a more resilient and clean EU global production chain reorganisation.

In our broad spectrum of scenarios, the reduction of EU carbon emissions between 1/7th and 1/4th is a valuable achievement within the context of the Green Climate Pact. However, the problem generated by carbon emissions is global, and the proposed EU shifting to cleaner providers would restructure production chains globally, affecting other regions' carbon footprint. Those regions are forced to source from dirty intermediate and final inputs as the EU absorbs the world's clean production. Therefore, the EU's carbon footprint is only one part of the story, and changes in the global carbon footprint also need to be measured. We find that this EU effort would have a null global impact or even, in the worst scenario, a negative one of 0.5%. Given these results, we conclude that greensourcing is a nearly zero-sum game, where EU emissions reductions are offset by increases in other GVCs, resulting in stagnation of global emissions reduction efforts. Shifting policies need to be reinforced by accompanying measures to achieve results at a global level; international agreements, technological improvements or demand downsizing should also be boosted.

This chapter analyses the potential of redirecting EU imports of intermediate or final goods to cleaner production countries/sectors. This strategy is examined for total EU procurement for all origins and sectors. The proposed analysis has previously been carried out in the literature, albeit with a more limited scope, for one country/region or focusing on one sector (Meno et al., 2022; Giles et al., 2021), and for the whole of the EU considering only one scenario (de Boer et al., 2019) with results in line with those obtained in our case. None of the existing literature models considered that by restructuring the EU’s GVCs, the changes have a broader effect, with countries that were previously customers of clean producers being left without suppliers, and dirty suppliers have no outlet for their products. We have quantified the effect of not controlling for these flows and found that it leads to a reduction in global GDP of between 0.8% and 2.1%, explaining an essential part of the emissions reduction found by previous literature. Our results show that when third-country import and export flows are not affected, and the model requires global GDP to hold constant, a source-shifting policy is not effective, as it reduces emissions in local but not in global terms.

Results for three of the proposed scenarios where modifications apply at individual sector suppliers are shown in Figure 7, without an increase in productive capacity and only EU providers (scenario 1) and with an increase in capacity (scenarios 2 for EU providers and 3 for any clean provider). We have identified 10 key sectors, accounting for around 80% of total emissions reduction. For the three scenarios, results are consistent as at least 8 out of 10 sectors with higher potentials, among which stand out transportation industries, computer, electronic, and optical equipment, manufacturing, electrical equipment, and computers, industries that, in addition, are called strategic sectors for the EU.

Figure 7: Emissions reduction by top 10 industries, individual sectors, % right axis, volume left axis



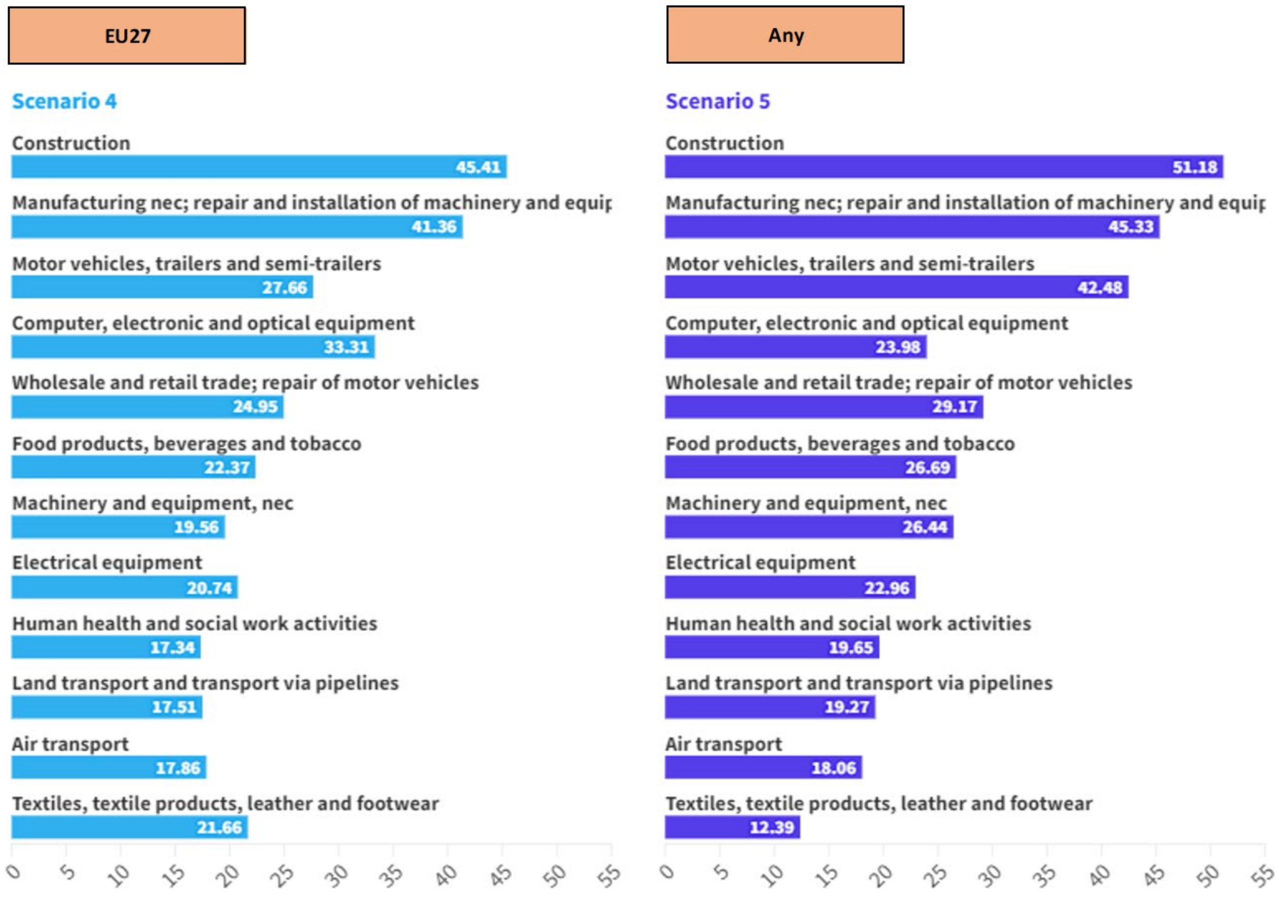
Source: Authors' elaboration.

When changes in GVC are introduced to all sectors, intersectoral interdependencies will reinforce decarbonisation efforts, improving emissions reduction in volume of around 75% as a mean, although sectoral differences depend on the scenario specificities. In these scenarios EU carbon footprint is reduced from 22.1% to 25%, representing a significant step towards the EU's reduction commitments. However, in global terms, this has a slight impact on reducing emissions and may even increase (from -3.44% to 0.53%).

The EU27 emissions reduction and the global emissions reduction are masking a partial restructuring of the GVCs that leaves previous customers in clean countries without suppliers. We propose scenarios where this global GDP reduction is controlled, by assuming that the countries to which the EU stops importing react by adapting their trade structure, stop buying from the EU and redirect their sales to other countries. This is a more realistic situation regarding trade that ensures policy and would explain why there is no reduction in global emissions derived from EU source shifting, but rather the opposite, generating a marginal increase in emissions.

By sectors (Figure 8), we identify again 10 key sectors, which represent from 55.5% to 56.7% of total emissions reductions, highlighting construction, manufacturing nec.; repair and installation of machinery and equipment, motor vehicles, trailers and semi-trailers sector and computer, electronic and optical equipment. These are industries where emissions are very relevant throughout the value chain that are being produced in more polluting countries, so a reshoring strategy improves the EU's carbon footprint. We find that the reduction in emissions is more significant when we consider all the most efficient countries worldwide as potential suppliers to the EU, scenario 4 with a total reduction of 495.4 $MtCO_2$, and not only when considering EU countries as exclusive suppliers, scenario 5, with a total reduction of 545.3 $MtCO_2$.

Figure 8: Emissions reduction by top 10 industries, individual sectors, % right axis, volume left axis



Source: Authors' elaboration.

6. Summary of key findings

The key findings of this report can be summarised as follows:

- The analysis of the evolution of the main past and current trends in carbon emissions (distinguishing between direct, indirect, domestic and imported emissions) indicates the increasing relevance of imported carbon emissions and of indirect emissions which underlines the relevance of intermediate steps in GVC when considering environmental impacts in the changes of the EU's CF.
- Trade-relocation patterns (geographical changes of suppliers) contributed to the increase in carbon emissions in the EU from 1995 to 2018, even in the context of general reductions in emissions shown in the later subperiod from 2009 to 2018. This seems to happen mainly because of offshoring production (maintained and new) towards dirtier economies, despite significant offshoring and re-offshoring towards the EU in 2008-2018.
- In terms of emissions, maintained offshoring is the primary trend in every EU subregion, with reoffshoring also relevant in Western EU countries. Carbon content may already be playing a central role in the emerging trends in GVCs, as our findings indicate that reshoring and reoffshoring trends in the EU have lower carbon emissions than offshoring ones.
- Reshoring five selected strategic products (iron and steel, electrical motors and batteries, chips and circuits, antibiotics, and vaccines) would generate reductions in the CF of the EU. The most significant reductions in emissions would be achieved by reconfiguring the iron and steel supply chains.
- Territorial emission increases generated by the reshoring strategies of all the previous selected products would represent a very low percentage of the territorial emissions of the whole EU and each member state, although Eastern EU countries tend to show the highest increases in relative terms.
- In basic metals, emission reductions are slightly more significant in the backshoring scenario than in the nearshoring one. However, we find the opposite for chips and circuits, and electric motors and batteries, with nearshoring strategies leading to larger emission savings than backshoring.
- Textile and construction sectors in France, already affected by CE regulation, are in a process of slow transition. The development of hard CE regulations has the potential to strongly affect the structure and sustainability of EU-led GVCs, forcing both European lead firms and Asia producers to adapt their sourcing activities and to

incorporate circular practices. Although so far actual shifts in business models are limited, all actors we spoke to expect changes in the near future, although they differ in their views on the extent and speed of change.

- Key barriers to the transition in both sectors studied which public policy can address are: supporting intermediaries, addressing barriers to scale, levelling the playing field and improving skills.
- In the construction sector, the constraining CE regulation has necessitated the emergence of circularity intermediaries and mainly contributed to the development of local circular loops, which are limited in scale. They have thus not (yet) affected the fundamental structure of GVCs.
- In the textile sector, CE regulations have been less constraining so far, although French lead firms are already thinking strategically of adapting their business model towards more circularity. Yet change remains limited and barriers remain to scaling up existing circular practices.
- In Denmark, the case studies agree that the fundamental challenge for all companies on take-back systems is developing the necessary scale and volume.
- The big barrier for take-back systems is the lack of harmonisation of waste regulation, which varies a lot from country to country. Existing regulation treats end-of-life products as waste, rather than value that can be extracted. Therefore, moving end-of-life products across borders is very difficult, making it even more challenging to get scale and volume in the take-back systems. In addition, in most countries, it is not expensive enough to use landfills and dispose of end-of-life products as waste.
- The EU carbon emissions impacts of reshoring strategies of European MNEs vary depending on the sector analyzed. For the case of the relocation of sectors with relatively low emissions intensity, such as computer, electronic, and optical equipment, and electrical equipment, the emissions increase within the EU borders is relatively low, and the ETT of coefficients of the same sector generate small emissions reductions The production relocation of energy-intensive industries, such as basic metals, provides a higher emissions reduction, due to the cleaner environmental performance of the EU compared to the former exporter countries' pollution intensity.
- A more significant improvement of the EU carbon emissions’ performance linked to the backshoring of the EU-owned MNEs’ production abroad in computer, electronic, and optical equipment, electrical equipment and basic metals sectors would come from the decarbonisation of the electricity sector of the new host countries.
- In manufacturing MNEs, environmental issues still constitute a significant element in

understanding the sustainability concept, but they are treated as a coherent part of the sustainability strategy.

- All expected environmental changes are measured at the corporate level, not the subsidiary level. However, foreign subsidiaries adopt solutions individually, in agreement with the headquarters, but not unified across subsidiaries. There are common goals but diversified pathways and a multidirectional exchange of know-how.
- Unlike in the past, contemporary decisions on FDI location and hence the perception of host country attractiveness is dependent on the ability of the host country to ensure compliance with home-country regulations, e.g. achieving climate neutrality, but only if the other criteria for investment (economic, market, etc.) are met; hence environmental factors are still secondary to the cost or market-access.
- When perceiving the host country-level policies as criteria for FDI attractiveness, MNEs are more concerned about stability (frequency of adopted changes, pace of changes, severity of changes) than the policies themselves.
- Scenarios of GVC reconfiguration driven by lower carbon content points to a reduction in EU carbon emissions that range between 14 and 25%, depending on the specificities of the proposed scenarios.
- Sectors with the most significant individual potential for emission reductions include manufacturing, computer, electronic and optical equipment, electrical equipment, transport sectors, machinery, textiles and even food products.
- In scenarios where all sectors select their suppliers based on a low carbon criterion, the potential reduction increases compared to the scenarios where only individual sectors follow this criterion and sectors such as construction, chemicals, coke and refined petroleum and metal products, together with the services sectors accommodation and food services and health, reduced remarkably their emissions.
- EU efforts need to be seen in the global context. If we consider scenarios where the EU absorption of cleaner production from new suppliers forces other countries to source from dirtier EU former suppliers, the EU effort to implement greensourcing would have a null global impact or even, in the worst scenario, a negative one, increasing global emissions by up to 0.5%.

7. Policy implications

The post-pandemic scenario, reshaped by the climate emergency and the current geopolitical context, forces the EU to rethink its responses to these challenges in a holistic way. The design of adequate policies must turn needs into opportunities and create synergies among GVC reconfiguration, the search for resilience and sustainability and the fight against climate change. Our research provides insights helpful for policymakers and business leaders to promote sustainable practices within GVC, thereby reducing their environmental footprint and improving the economic and environmental performance of GVC in which the EU is involved.

The increasing relevance of imported emissions is vital when analysing the evolution of the EU's CF. This fact points to the relevance of the planned CBAM (European Commission, 2021b). In addition, the volatility of the ratio of imported over domestic emissions in some strategic industries, such as machinery and equipment and vehicles, could result from the vulnerability and lower resilience of these sectors' global value chains, reflecting the objective of the EU's Open Strategic Autonomy policy in order to safeguard EU firms' competitiveness and promote the choice of low carbon suppliers. Mining, other manufactures and transport are other sectors with increasing relevance of imported emissions. They would require additional efforts to reduce the emissions embodied in their GVCs, including seeking lower carbon suppliers and encouraging trade alliances with those suppliers.

The reduction in the EU's CF over time results from changes in emissions intensities, intermediate inputs, and the mix of final demand products. This seems to result from both policies and business strategies to increase efficiency and reduce emissions. However, shifts in geographical sourcing patterns increased emissions throughout the period analysed (1995-2018). Although their contribution accounts for a relatively small amount, the transition to a low-carbon economy will require that GVC reconfiguration and geographical changes of suppliers contribute to emissions reductions, not to emissions growth, as has been the case so far. As long as international trade and GVC reconfiguration ignore carbon emissions, international sourcing will contribute to the growth in carbon emissions. However, according to our findings, there are synergies between the resilience and emission reduction goals through GVC reconfiguration that have not yet been exploited. Therefore, it is crucial to continue monitoring the GVC trends and reconfiguration, including their carbon content, which is another element of risk in achieving sustainability and resilience.

Our findings underline the need to include carbon emission goals in trade policy, including in trade agreements and other alliances. Accounting for the environmental dimension is needed if we are to attain synergies between GVC reconfiguration, resilience and climate change targets. Our results indicate that the carbon content may already be playing a central role in the new emerging trends in EU GVCs, in that lower emissions are embodied in reshoring and reoffshoring trends than in the offshoring ones. This is in line with the results of Bonilla et al. (2015) and underline the potential advantages of reshoring for sectors such as electronics and apparel, where the EU and UK have been reducing their productive capacity in recent decades. Strengthening the single market is one of the focuses of the EU New Industrial Strategy, arguing not only for the shortening and diversifying of GVC but also for the use of a reshoring policy to reallocate some sectors to the EU (European Commission, 2021c).

Although reshoring responds to some strategic dependencies, the EU still relies on imported resources and goods. Our calculations allow us to identify the resource-based and medium-low R&D industries as the ones experiencing more acute effects on carbon emissions from variations in the origin of providers through offshoring, reshoring, and reoffshoring. Policy implications are very different for those types, as medium-low R&D industries are increasingly considered in backshoring and reshoring policies.

In this regard, diversification through nearshoring or friendshoring (reoffshoring or new offshoring to close countries in terms of distance or shared values) can offset GVC-linked risks, such as bottlenecks and shortages created by disruptions or political instability as well as climate change risk. If such relocation is directed to less carbon-efficient countries, it should be accompanied by low-carbon technology transfers and/or compromises of suppliers' decarbonisation (Hoekstra et al., 2016). Such technology transfers should become a core part of broader development plans (Puig et al., 2018) and FTAs, through which the EU could spread best practice, benefiting sustainability and the environment. An additional way of positively impacting emissions mitigation through trade is creating and distributing international sustainability standards and responsible sourcing (Scott et al., 2018), where there is a need to move from recommendations to requirements and more binding obligations (Farooki et al., 2021).

Regarding reshoring scenarios of strategic products following the EU new industrial policy and the Open Strategic Autonomy, the EU can take advantage of those reshoring strategies to avoid bottlenecks in our industrial systems and prepare for future geopolitical difficulties, without compromising its climate commitments and the energy transition needed to mitigate climate change. According to our results, pursuing the goals of resilience, autonomy, and diversification of EU GVCs creates synergies with mitigating climate change by reducing CO_2 emissions along EU GVCs. Achieving those synergies confirms the claims for including carbon emissions requirements in selecting suppliers along GVCs and the trade agreements as pointed out above.

It is relevant to note that import substitution by domestic production within the EU would naturally increase the direct emissions released within the European borders and this effect could undermine the achievement of the EU's emission reduction targets. However, the simulated relocation strategies have an insignificant impact on the emission reduction commitments outlined in the European Green Deal (European Commission, 2019) because these commitments aim to cut net greenhouse gas emissions in the EU by at least 55% by 2030, compared to 1990 levels, and the simulated increases fall below 1%.

The effect that trade diversion, via backshoring and nearshoring, has on the EU's carbon footprint can be due to the emissions of the traded product itself or the indirect emissions embedded in the necessary inputs to produce these goods. Thus, in the products of Iron and Steel and Vaccines, the most relevant emissions are those of the sector itself. However, in the rest of the products considered (Electrical motors and batteries, chips and circuits, and antibiotics), the emission savings occur due to the different pollution intensity of sectors such as electricity and basic metals among the countries considered. This difference between direct and indirect emissions is relevant when designing trade policies compatible with mitigation objectives consistent with the Paris Agreement. In this sense, the regulation of the Carbon Border Adjustment Measure (European Commission, 2021a), which so far only includes scope 1 (direct emissions) and 2 (emissions from the electricity used) emissions of products, should consider all upstream Scope 3 emissions (carbon emissions from all the inputs directly and indirectly used) to the extent that these emissions are the most important in most products. Incorporating carbon footprint accounting within the binding emission reduction targets of EU members would stimulate firms, industries and countries to reduce not only their direct emissions but also indirect emissions along their GVCs.

Efforts to reduce the energy transition gaps across EU countries should be intensified in order to avoid the deepening of economic gaps. The consolidation of short, low-carbon value chains will favour European countries with a clean energy mix and penalize the competitiveness of countries lagging behind in the energy transition. If Eastern European countries could compete as low-carbon producers, the reshoring trends would be an opportunity to improve their position in European value chains, up-grading and participating in more sophisticated production stages. Therefore, technology transfer agreements between countries should focus on technologies that reduce emissions in the leading suppliers (Jiang et al., 2022). Similarly, the search for industrial alliances with third countries for the supply of strategic goods fostered by the European Commission (European Commission, 2021b) should consider each potential partner's differential on direct and indirect carbon content.

Regarding the impacts of CE policies on GVCs, our case studies in textiles and construction indicate that CE policies have the potential to reshape GVCs by promoting regulatory frameworks that encourage circular business models. Across the two industries we studied, however, firms have reacted differently to policy incentives for circular practices, depending on the policy design and framing, varied GVC constraints and opportunities, and individual firm characteristics.

The development of circularity in GVCs will depend on future policy developments at the EU level regarding eco-design standards and harmonization of the criteria needed to support the emergence of an EU-level recycling industry. For example, in textiles, the ban on exports of textile waste to non-OECD countries that is being rolled out could have an important impact on access to raw materials.

The research on circular business models and GVCs highlights the need for integrated policy approaches that address both production and consumption policies, ensuring that MNEs are incentivized to adopt sustainable practices across their global operations. Such policies have the potential to significantly change GVCs, both in terms of their governance and their geography. Indeed, while for decades, cost-based incentives often led textile MNEs to outsource most or all production, contemporary policy incentives require them to enhance control and transparency over their upstream and downstream GVCs. This implies strengthening relationships with suppliers and other key business partners. Consequently, providing CE policies are successfully harmonized at the EU level and they support the creation of economies of scale for key building blocks of the circular economy, textile GVCs could become more integrated in the near future, with greater incentives to near or re-shore production. This changing policy context could encourage shifts to hierarchical or relational GVC governance, rather than the more captive systems of the past (Gereffi et al., 2005). Similarly, in the construction sector, the need to secure reliable sources of recycled and recyclable material is encouraging the creation of networks of actors, facilitated by intermediaries. These are creating more relational links across GVCs, replacing the market-based links of the past.

A key question which emerges from CE analysis relates to the impact of these shifts in policy and business models on the geography of production. Several interviewees in the textile sector, especially born circular firms and those that support them, see the shift to CE practices as a lever to support the revival of the sector in France. However, cost factors, lack of workforce skills and the need for economies of scale suggest that the relevant level for the development of an efficient system of reconditioning, reuse and recycling would be at least EU and probably include the near abroad. Indeed, the so-called ‘Pan-Euro-Med’ region has strong historical capacities and complementarities in the sector, which could be leveraged.

In any case, such shifts would imply decoupling at least some production links from more distant sources specialized in the large-scale production of fast fashion using virgin resources, like China, Vietnam and Bangladesh and recoupling with closer sources where the flow of new, used and reconditioned goods and raw materials is facilitated by geographical proximity and common regulatory frameworks. Most larger companies and EU-level actors do not see this happening across the industry, at least, not in the near future, given the scale and cost advantages of globalized production structures.

In the construction sector, where the bulky nature of the goods involved favours production relatively close to consumption, the GVC has long been more regionally focused, although raw materials are often traded globally. The shift to CE is facilitated by regulatory requirements but requires the development of local actors which facilitate the storage, reconditioning and reuse of materials within relatively limited geographical boundaries. In this case, the relevant level of the emerging value chain seems much more likely to be regional or national. At the same time, scale is also a big issue, as access to adequate quality supplies of reconditioned or recycled materials for the industry seems unlikely in the short to medium term, such that these local value chains will certainly continue to coexist with GVCs with a much wider geographical scope.

Expanding the environmental aspects to the CE in several sectors, such as the construction and textile industries, pharmaceutical, mechatronic or retailer industries through case studies in France and Denmark highlights the importance of considering the geographic and economic complexities of GVCs, not only regarding carbon emissions but also in the formulation of CE policies, supporting a balanced approach that harmonizes environmental and economic/geopolitical goals. Indeed, while CE policies have the potential to transform GVCs significantly, their success depends on the coherence and effectiveness of regulatory frameworks, the willingness of firms to embrace circular business models, access to workers with the relevant skills and the development of appropriate technology that enables cost-effective solutions to the remaining practical challenges. All of these factors are very sector-specific, as our in-depth case studies demonstrated. Therefore, moving towards a circular economy will necessitate continued coordination between environmental, industrial, educational, R&D and trade policies. Our findings can support policymakers' work and help them overcome the identified barriers to achieving circular economies at the European level.

Key policy concrete policy proposals for actors at the EU and national level which emerge from our work regarding circular economy and take-back systems are:

- There is a need for public support for intermediaries which provide research, advice and networking services to enable the transition to circular practices. Funding such services through EPR schemes is one pathway that has yielded some positive results in the French construction sector, although in the textile sector the low rates of eco-contributions, which are defined by professionals from within the sector, have created limited incentives. Other financing options should also be explored.

- The circular economy and take-back systems need to scale up in order to increase their economic viability. Support for a single EU market in used, reconditioned and waste products is important to securing scale. Waste regulation should be harmonized at the EU level, and the mindset must change to favour exploiting the value of end-of-life products rather than treating them as waste. This will require more sorting of the end-of-life products in clean fractions. In construction, improved waste management practices in concrete and bricks can lead to significant environmental gains (Caro et al., 2024). In textiles, preparing for re-use is a crucial element in creating loops that can provide significant environmental gains (Solis et al., 2024).
- Extending openness to the near abroad could also support scale economies. The barriers for moving end-of-life products across borders should be adjusted accordingly. In many cases, it would be more efficient to build industry solutions for collecting the end-of-life products instead of each MNC/GVC building their own system for reverse logistics. Such a change will enable lead firms in GVCs to create take-back systems on a viable scale.
- This market harmonization needs to be combined with policy support for investment, especially in technological innovation, as recycling capacities are still low in the EU, especially in textiles (JRC, 2023).
- Born circular firms and circular initiatives within lead firms both struggle to secure profitability. For CE practices to become more mainstream, policymakers need to develop greater incentives, such as higher eco-contributions in EPR schemes for less sustainable products or lower VAT or tariff rates for circular goods. This could help to improve the economics of these new circular business models.
- As we find in the case of construction, regulations are also needed to drive the transition forward. Ecodesign norms on the EU market appear to be a potentially powerful tool.
- Europe lacks skills in many key areas vital to the CE. Adequate training and re-training are vital to securing an EU-based circular industry.

Regarding the role of MNEs, multinational corporations are called to lead the GVC reconfiguration and reshoring processes. The empirical evidence has shown that big companies concentrated in medium and high-technology manufacturing sectors have guided the EU's observed reshoring trends in many European countries. Moreover, the European relocation of the EU MNEs must be guided by the transfer of low-carbon technologies to new hosting countries. Technological innovation and the decarbonization of the production processes are vectors of differentiation that increase the attractiveness of the economies.

The proposed scenarios of backshoring, where the production of EU MNEs operating abroad of strategic sectors of the EU (basic metals, computer, electronic and optical equipment, and electrical equipment) is relocated to new EU hosting countries with comparative advantages in terms of labour costs, does not jeopardize the EU's environmental performance, as the escalation in emissions is relatively insignificant, and the point of departure is an environmentally friendly domestic production. The scenario analysis provides estimations of the possible paths to achieve simultaneous environmental and income convergence. Backshoring trends could be helpful in reversing structural polarization in the EU, but they could lead to a problem of environmental polarization that has been scarcely assessed in the literature. Expanding the role of EU peripherical economies in GVCs may imply the risk of fostering energy-intensive and high-polluting manufacturing stages. Yet, income growth can be decoupled from emissions growth if environmental efficiency is boosted during production relocation. The key to mitigating the environmental impacts associated with such GVC restructuring is promoting both technology transfer between parent and subsidiary and domestic companies and spreading the EU decarbonization to non-EU core countries to achieve cleaner processes and structures.

We also have shaped additional scenarios of environmentally friendly technology transfers among EU headquarters countries and new hosting countries where subsidiaries are located, focusing on changing the emissions coefficients of strategic sectors for domestic and foreign MNEs and also changing the emissions intensities of the electricity sectors searching for the EU decarbonization. Our simulations provide valuable information for understanding the interrelationships between the processes of trade restructuring, foreign investment flows and decarbonization, which serve as a reference for guiding EU initiatives towards realistic climate and economic targets in the medium term. The intensification of the Energy Transition across all EU nations, predicated on the achievement of objectives delineated in ambitious strategies such as REPowerEU or the Green Deal Industrial Plans, could equip Eastern and Southern EU nations with additional justifications in terms of not only economic but also environmental comparative benefits, thereby attracting MNEs capital. Advantages in labour costs, lower-carbon energy compositions, and reduced energy prices could facilitate repositioning the EU MNEs' operations in pivotal sectors. The challenge could become an opportunity for Eastern and Southern economies, enabling them to reduce fossil fuel dependency and strengthen renewable energy targets.

The EU could regulate MNEs' activities, promoting sustainable practices and technology transfers in line with the UNFCCC Technology Mechanism for 2023-2027, in which all participant countries shall promote and cooperate in the development and transfer of technologies that reduce emissions, especially from developed countries to developing ones. New EU MNEs' offshoring practices, mainly within the EU, must ensure energy efficiency and promote cleaner environmental performance, including self-consumption and green energy procurement. In this sense, private investment will be essential to fulfil these goals; the EU must design adequate regulation incentives to accelerate commitment to ambitious plans that will reshape the EU's economic and environmental structure. Some programs launched by the European Commission in recent years are on the right track. For example, the Net-Zero Industry Act stimulates financing for investments in strategic green technologies (renewable energies, carbon capture, hydrogen, etc.) whose industrial interconnections make it possible to reduce the carbon footprint of multiple industrial and service sectors. Another possibility is the upgrading of the use of Important Projects of Common European Interest (IPCEIs) and the InvestEU Programme, which should show a particular focus on those types of investments.

Regarding the MNEs' behaviour and decisions, the companies are considering the environment-, or more widely sustainability-related, issues as part of their FDI locations decisions. For now, the dominant relation in these decisions is the impact of the policy on the FDI location choices, yet in time we may observe a loop where the FDI decisions will impact the existing shape of policies. A dominant concern for companies is the interoperability of European and global sustainability reporting standards. For instance, the Corporate Sustainability Reporting Directive (CSRD) requires companies to report their activities according to specific standards that might not be fully aligned with the International Sustainability Standards Board (ISSB) standards. In May 2024, an Interoperability Guidance was published, yet it is treated as a supportive rather than legally-biding document. In case of a conflict, companies are expected to refer to the requirements in European Sustainability Reporting Standards (ESRS) and ISSB Standards separately, which may increase the uncertainty over the expected results and associated costs.

Moreover, companies are expressing increasing uncertainty over the choice of potential FDI locations. They would welcome initiatives like the "Sustainable Investment Facilitation Agreement" (e.g. signed with Angola in 2023), which signal to European investors the approval and support for bilateral cooperation. Such agreements address aspects of climate change, indicating to the potential investors the EU's willingness to foster and uphold such cooperation. The interviewed companies expressed their concern over the inability to predict how the EU will perceive certain host countries in the future in terms of their sustainability frameworks. Official regulatory frameworks and bilateral commitments would decrease such uncertainty.

GVC development has been led chiefly by cost-based incentives coming from low-wage countries. Policy measures should ensure that GVC reconfiguration follows, not only cost-based incentives but also the uptake of low-carbon technologies, high CE possibilities, high security of supply and so on, to achieve resilience and sustainability.

The search for policies which support the reduction of the environmental impact of production and consumption is a recurring theme of debate. We have analysed the impact of emissions of a hypothetical policy with an EU-driven reconfiguration of value chains where only clean providers are considered to satisfy EU imports. This policy aligns with the Fit for 55 European Climate Law (European Commission, 2020). By meeting the EU's import requirements from clean suppliers, the proposed source-shifting measure would ensure a reduction of the EU carbon footprint. These redesigned GVCs would reduce the EU's carbon footprint by between 14 and 25%, with important contributions from sectors that are both energy and import dependent, such as motor vehicles, computer and electronics, machinery and other manufacturing sectors, together with construction or transport.

Such source-shifting approaches could also contribute to the Green Deal Industry Plan (European Commission, 2023) by making trade work for the green transition, promoting cleaner producers and putting European clean industries in the lead. It could also support the updated New Industrial Strategy, (European Commission, 2023), since when choosing clean providers, European industries are always amongst the first choices. The implementation of green GVC would require non-tariff measures (NTMs) in pursuit of a Net-Zero EU. The final design of any EU policy measures would need to better integrate the complexity of GVCs into decision-making (Curran & Joltreau, 2024).

Although the results of the proposed green sourcing strategy are very relevant in EU terms, any restructuring of GVCs would likely lead to an EU reduction in carbon footprint being offset by an increase in third countries, resulting in a neutral outcome in global terms. The contrasting results, with high domestic reductions in the EU carbon footprint, but a neutral result at the global level, should inform thinking about the importance of leadership at the supra-European level. Specifically, the EU needs to be aware that measures implemented regionally could lead to international shifts in sourcing that offset them. This observation was key to the introduction of the CBAM in the EU, a reaction to the fact that the emissions reduction efforts of the EU were being offset by increasing emissions outside its borders through the relocation of production to non-EU countries. However, similar shifts could undermine the global effectiveness of this novel tool.

This neutral policy result should also serve as an incentive to promote complementary measures to the CBAM and/or secure appropriate policies to avoid such hypothetical resource-shifting. In general, shifting trade policies need to be reinforced by accompanying measures to achieve results at a global level through international agreements, technological improvements or demand reductions.

Other actions are required, especially in terms of technology transfer, to adopt better production processes globally, as has been analysed regarding EU MNEs. Only in this way can we reduce the global impacts of GVCs through a reduction in the embodied emissions of trade (Kander et al., 2015; Steininger et al., 2014). Facilitating the adoption of green technologies, promoting the uptake of green energies, accelerating the substitution of fossil fuels, and introducing technological improvements, especially in the energy sector and high-energy-consuming sectors all over the GVC are relevant and should be promoted through agreements not only for Europe but the whole world.

8. Next steps in the TWIN SEEDS project

The TWIN SEED's investigation of GVCs' impacts does not end here. Other WPs focus on the specific aspects of recent and emerging trends in GVCs and their impact on: employment and inequality (WP3), and growth, productivity and competitiveness (WP5). The reorganization of GVCs that followed the challenges highlighted in WPs 1-2, has involved both the restructuring of activities and the re-allocation of tasks and functions across space, with important implications for jobs, working conditions, and inequalities. WP3 aimed to provide a detailed and comprehensive analysis of the different influences GVCs may exert on regional labour market scenarios and outcomes, such as employment, the composition of the labour force, wages, job quality and working conditions, by using national/regional data at industry- and employee-level at the highest possible level of disaggregation. Finally, we expect that the changing geography of GVCs will lead to delineating winners and losers. Some countries, regions and firms will become key hubs, while others will lose out and become more peripheral. The WP5 analyses examined the effects of these changes on the productivity of GVCs and the competitiveness of MNEs, as well as on firm-level risks and resilience.

In addition, WPs 6 and 7 that follow the present WP4 report (and WP3 and WP5, which are elaborated at the same time in the TWIN SEEDS project) are complementary to the analyses presented here and will build on our findings. The general objective of WP6 will be to identify the likely New Normal scenario for Europe. Such a scenario attempts to reflect the tension between long-term global integration based on value chains, on the one hand, and ongoing longer-term challenges, on the other. The latter are generated by changing geopolitics, new strategic orientations of the main global actors affecting international trade policies, and policies regarding the environment, as well as technological developments and the recent experience of the pandemic. WP7 will draw on the work undertaken in all previous research WPs 1-6 and its key findings in terms of actual and potential shifts in EU GVCs as a result of these pressures. It will draw, in particular, on the scenarios identified in WP6 on the likely New Normal which is emerging post-COVID. The objective will be to build on our findings to propose potential internal and external EU policies to support the emergence of a scenario which balances the need to ensure robust and sustainable supply chains with continued openness and engagement with the EU's key partners in its neighbourhood and beyond. Therefore, future WPs will conclude and explore the consequences of GVCs reconfiguration and the policy implications in vital aspects of contemporary European society in more detail.

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8. Technical appendices

Appendix A: Multiregional input-output (MRIO) analysis for carbon footprints' calculation

The standard multiregional input-output (MRIO) model (Miller & Blair, 2009) includes *R* regions and *S* sectors, each combination with their particular technology, and trade is split into intermediate trade (with specific industry destination) and final trade). The environmental extension of the MRIO model (Atkinson et al., 2011; Davis & Caldeira, 2010) provides the environmental impact of production processes (f), in our case CO_2 emissions, as in expression (A.1):

$$f = e(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}y \qquad \text{(A.1)}$$

Where e is the vector of country-specific e^r emissions per unit of output for each industry in country *r* (direct emission coefficients, calculated by $e^r = f^r(\hat{x}^r)^{-1}$, being f^r total emissions by country *r* and $\hat{x}^r$ the output of the region indicated in the superscript). A is the integrated matrix of technical coefficients, composed by domestic matrices of production coefficients $\mathbf{A^{rr}}$ in the main diagonal (intraregional matrices) and matrices $\mathbf{A^{rs}}$ in the off-diagonal positions reporting the trade between industries from region *r* to region *s*, with both calculated as $\mathbf{A^{rs}} = \mathbf{Z^{rs}}(\hat{x}^r)^{-1}$ for *r*, *s* = 1…*R*, and being Z^{rs} the transactions of intermediate inputs from region *r* to region *s*. $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is the Leontief Inverse. Finally, y is the integrated vector of final demand, comprised of y^{rs} vectors that indicate the trade between industries in region *r* to final consumers in region *s* (final exports of region *r* or final imports of region *s*).

We will work with diagonal matrices (denoted by ^) of final demand and emission coefficients ($\hat{y}$ and $\hat{e}$, respectively). Thus, we will obtain two *R·S* x *R·S* matrices, one for emission multipliers (total emissions intensities), $\mathbf{P} = (P^{rs})$, and one for total emissions, $\mathbf{F} = (F^{rs})$. We also split the final demand between domestic final demand catered by domestic production (y^d) and exports (y^x). The emission multiplier indicates total emissions that occur in country r when attending a unit of final demand from country s, and $\mathbf{F}$ has the equivalent meaning for total emissions. Additionally, the final demand matriz can be rearranged into an alternative form, denoted as $\overline{\hat{\mathbf{y}}}$, which is composed by *R* x *S* diagonal submatrixes $\overline{\hat{\mathbf{y}}}_j^i$, each of which encomprisses the output supplied by region i and demanded by region j. This rearrangement is useful to compute emissions in terms of carbon footprint (CF). This calculation is expressed in equation (A.2):

$$\mathbf{F} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A})^{-1}\hat{\mathbf{y}} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A})^{-1}\left(\widehat{\mathbf{y^d}} + \widehat{\mathbf{y^x}}\right) = \mathbf{P}\left(\widehat{\mathbf{y^d}} + \widehat{\mathbf{y^x}}\right) = \mathbf{P}\,\overline{\hat{\mathbf{y}}}_j^i \qquad \text{(A.2)}$$

An addition of the **F** matrix by rows results in total emissions (domestic) per production country (and sector) ($f^r = \sum_s F^{rs}$). This measure is a country's producer responsibility or production-based accounting emissions (PBA). When applying the final demand in its $\bar{\bar{\boldsymbol{y}}}$, form, the sum of columns in **F** yields' vertical integration by countries' or global emissions linked to one country's final demand ($f^s = \sum_r F^{rs}$). This measure is called consumption-based accounting emissions (CBA), consumer responsibility, carbon footprint or final consumption attribution (Skelton et al., 2011), and it quantifies total direct and indirect emissions linked to the demand for final goods by the country's agents (households' consumption, investment, and public administration consumption). In equation (2), it is possible to distinguish between emissions (domestic and abroad) embodied in domestic final demand and emissions (domestic and abroad) embodied in final imports (or exports). When employing the final demand in its purely diagonal form ($\hat{\boldsymbol{y}}$), the sum of columns in **F** yields' the producer footprint of each sector-country, which allocates the responsibility on the emissions embodied directly and indirectly in a finished good or service on the country that finishes it, regardless where it is consumed.

Appendix B: Hotspots identification through global value chains in an MRIO model

According to Wiebe (2018), emission hotspots are defined as those countries/industries where a large portion of the upstream emissions occur inside a specific value chain. In this work, we are considering a broader concept of hotspot as a country/industry of particular relevance either as carbon demandants (referred to along the text as "upstream hotspots", whose final production embodies significant emissions regardless their origin or, in other words, show significant emissions backward linkages) or as carbon suppliers (denoted here as "downstream hotspots", which directly release significant emissions to be embodied in a specific value chain, presenting high forward linkages) through international trade.

The assessment of key sectors in the input-output framework, as proposed by Hirschman (1958) and Rasmussen (1956), focuses on the degree to which some sectors created a greater-than-average impact on an economy (Hewings et al., 1989), either as diffusers or attractors. For this purpose, Rasmussen (1956) proposed two indexes: the dispersion power and the dispersion sensitivity.

The dispersion power is a normalized measure for the strength of the backward linkages of a sector, allowing the identification of upstream hotspots. Considering that our model has $N=R \times S$ industries, the power of dispersion of a sector k, is computed as the sum of the corresponding column in the Leontief inverse relativized by the average columnwise-addition for the whole of the economy, as shown in Expression (B.1).

$$DP_k = \frac{\sum_{i=1}^{N} L_k^i}{\frac{\sum_{k=1}^{N}\sum_{i=1}^{N} L_k^i}{N}} \quad \text{(B.1)}$$

Dispersion sensitivity is a similar measure of the strength of a sector's forward linkages, which permits the identification of downstream hotspots. The dispersion sensitivity of sector i is computed as the sum of the corresponding row in the Leontief inverse relativized by the average rowwise-addition for the whole economy, as shown in Expression (4).

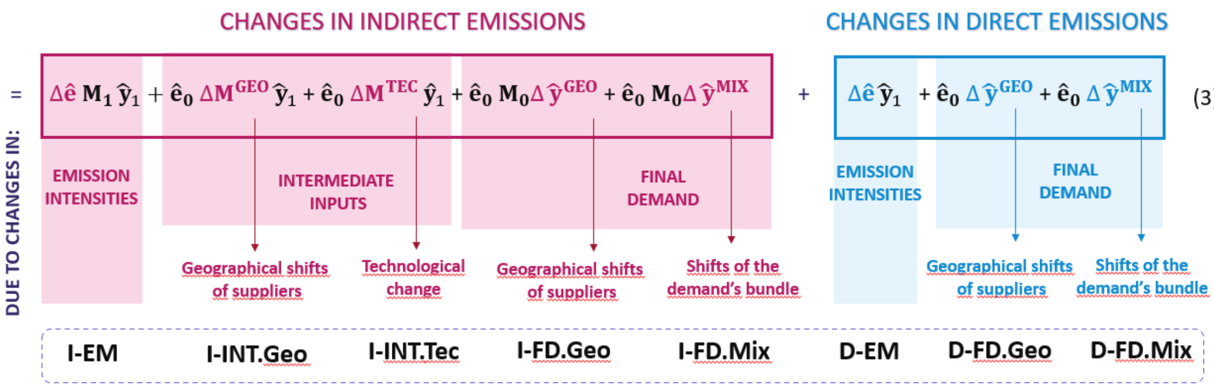
$$DS_i = \frac{\sum_{k=1}^{N} L_k^i}{\frac{\sum_{i=1}^{N}\sum_{k=1}^{N} L_k^i}{N}} \quad \text{(B.2)}$$

A value of the index greater than 1 reveals above-average backward (in the case of DP_k) or forward linkages (in the case of DS_i), while a value lower than 1 implies below-average linkages. In other words, the higher the value of DP_k, the stronger the output stimuli that sector k is transmitting to other sectors in the economy via its intermediate input requirements (Schultz, 1977), and the higher the value of DS_i, the more relevant is sector i as a supplier of intermediates in the economy.

Appendix C: Structural decomposition analysis of the carbon footprint evolution

In Chapter 2, we apply a structural decomposition analysis (SDA) to find the drivers of the evolution of carbon footprint resulting from GVC reconfiguration. Despite we follow the general approach by Gao et al. (2022), we focus on carbon emissions and we extend the analysis carrying out a complete decomposition of the difference in the carbon footprint between two years (denoted as 1 and 0). We isolate eight elements according to the emissions affected (direct (D) or indirect (I)), the driver (changes in intermediates (INT), final demand (FD) or emission intensities (EM)) and the nature of the change (technical (Tec), geographical (Geo) or concerning the final demand mix (Mix)), since each of these elements can involve different GVC and diverse countries and industries (Krenz & Strulik, 2021). Equation (C.1) shows the decomposition proposed, where $\mathbf{M_t} = [(\mathbf{I} - \mathbf{A_t})^{-1} - \mathbf{I}]$, t = 0, 1.

$$\mathbf{F_1} - \mathbf{F_0} = \hat{\mathbf{e}}_1\mathbf{L}_1\hat{\mathbf{y}}_1 - \hat{\mathbf{e}}_0\mathbf{L}_0\hat{\mathbf{y}}_0 = \hat{\mathbf{e}}_1(\mathbf{L_1} - \mathbf{I})\hat{\mathbf{y}}_1 - \hat{\mathbf{e}}_0(\mathbf{L_0} - \mathbf{I})\hat{\mathbf{y}}_0 + \hat{\mathbf{e}}_1\hat{\mathbf{y}}_1 - \hat{\mathbf{e}}_0\hat{\mathbf{y}}_0 = \hat{\mathbf{e}}_1\mathbf{M}_1\hat{\mathbf{y}}_1 - \hat{\mathbf{e}}_0\mathbf{M}_1\hat{\mathbf{y}}_0 + \hat{\mathbf{e}}_1\hat{\mathbf{y}}_1 - \hat{\mathbf{e}}_0\hat{\mathbf{y}}_0 =$$



(C.1)

Structural decompositions are not unique, but taking the average of the two polar decompositions has been proved to provide accurate results (Dietzenbacher & Los, 1998). Expressions (C.2) and (C.3) show the polar decompositions developed. Each element of our decomposition will be the average between the equivalent element in Polar A) and Polar B) decompositions.

$$\boldsymbol{F_1} - \boldsymbol{F_0}|_{polar\ A} = \quad \text{(C.2)}$$

$$= \Delta\hat{\boldsymbol{e}}\,\boldsymbol{M_1}\,\widehat{\boldsymbol{y}}_1 + \hat{\boldsymbol{e}}_0\,\Delta\boldsymbol{M}^{GEO}\,\widehat{\boldsymbol{y}}_1 + \hat{\boldsymbol{e}}_0\,\Delta\boldsymbol{M}^{TEC}\,\widehat{\boldsymbol{y}}_1 + \hat{\boldsymbol{e}}_0\,\boldsymbol{M}_0\Delta\,\widehat{\boldsymbol{y}}^{GEO} + \hat{\boldsymbol{e}}_0\,\boldsymbol{M}_0\Delta\,\widehat{\boldsymbol{y}}^{MIX} + \Delta\hat{\boldsymbol{e}}\,\widehat{\boldsymbol{y}}_1 + \hat{\boldsymbol{e}}_0\,\Delta\,\widehat{\boldsymbol{y}}^{GEO} + \hat{\boldsymbol{e}}_0\,\Delta\,\widehat{\boldsymbol{y}}^{MIX}$$

$$\boldsymbol{F_1} - \boldsymbol{F_0}|_{polar\ B} = \quad \text{(C.3)}$$

$$= \Delta\hat{\boldsymbol{e}}\,\boldsymbol{M_0}\,\widehat{\boldsymbol{y}}_0 + \hat{\boldsymbol{e}}_1\,\Delta\boldsymbol{M}^{GEO}\,\widehat{\boldsymbol{y}}_0 + \hat{\boldsymbol{e}}_1\,\Delta\boldsymbol{M}^{TEC}\,\widehat{\boldsymbol{y}}_0 + \hat{\boldsymbol{e}}_1\,\boldsymbol{M}_1\Delta\,\widehat{\boldsymbol{y}}^{GEO} + \hat{\boldsymbol{e}}_1\,\boldsymbol{M}_1\Delta\,\widehat{\boldsymbol{y}}^{MIX} + \Delta\hat{\boldsymbol{e}}\,\widehat{\boldsymbol{y}}_0 + \hat{\boldsymbol{e}}_1\,\Delta\,\widehat{\boldsymbol{y}}^{GEO} + \hat{\boldsymbol{e}}_1\,\Delta\,\widehat{\boldsymbol{y}}^{MIX}$$

Appendix D: Source shifting method in an MRIO context

In Chapter 3, the basic MRIO model is extended by using the source shifting technique (Cadarso et al., 2021; de Boer et al., 2019; Gilles et al., 2021) to evaluate the net effect that the relocation processes shaped by the EU policy have on global emissions. This method is based on the geographical restructuration of the supplier's network of an economy (in this case, the EU), according to a specific trade reorganisation scheme. Notice that the restructuration can be applied to those suppliers producing intermediate goods or/and final goods. The first case would imply modifying the matrix of technical coefficients ($\boldsymbol{A}$), while the second would mean altering the matrix of final demand ($\hat{\boldsymbol{y}}$). In both cases, the subtraction from old suppliers and the addition to new ones are applied by columns to modify the geographical origin of the purchases but not the composition of input demand.

Thus, expression (D.1) shows the source shifting for the case of intermediate inputs, where the matrix $\boldsymbol{A}$ corresponds to the business-as-usual (BAU) model for a simplified economy with three regions and one industry, while the matrix $\boldsymbol{A}^*$ shows a source shifting model whereby region 1 is replacing a share β of intermediate imports from region 3 by imports from region 2 (with $0 \leq \beta \leq 1$):

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad ; \quad \boldsymbol{A}^* = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} + \beta a_{31} & a_{22} + \beta a_{32} & a_{23} + \beta a_{33} \\ (1-\beta) a_{31} & (1-\beta) a_{32} & (1-\beta) a_{32} \end{bmatrix} \tag{D.1}$$

After that, we apply expression (D.2) to estimate the global CO2 emissions under those scenarios:

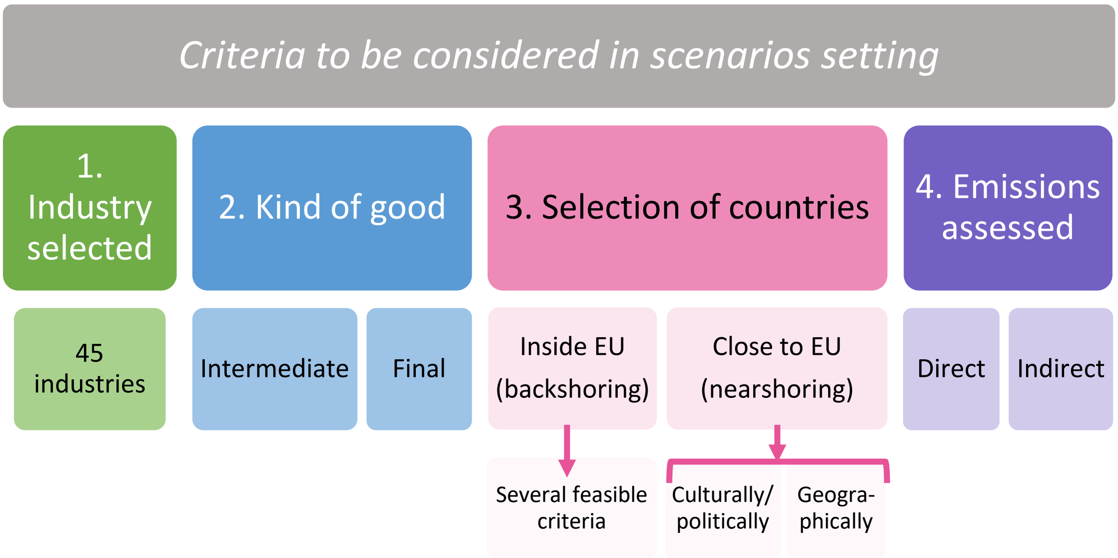
$$\mathbf{F}^* = \hat{\boldsymbol{e}}\,(\mathbf{I} - \mathbf{A}^*)^{-1} \hat{\boldsymbol{y}} \tag{D.2}$$

Differences between the results from the BAU and the source shifting models ($\boldsymbol{F}^{ss} = \boldsymbol{F} - \boldsymbol{F}^*$) capture emission variations due to the reshoring process simulated. Positive signs in the elements of $\boldsymbol{E}^{ss}$ indicate emission increases in respective trade flows, while negative numbers indicate emission reductions. Results captured by $\boldsymbol{F}^{ss}$ allow distinguishing the impacts on direct emissions of the reshored sector (rows sum of the sector) and implications in terms of carbon footprint (CF), that is, direct and indirect emissions released in every country and industry involved in the GVC of the targeted sector (which requires working with the final demand matrix in its diagonalized-by-blocks $\bar{\hat{y}}$ form, as exposed in Appendix A). Since we simulate supply relocation for five specific products, an independent source shifting model is run for each product to isolate the effects on carbon emissions by the respective product relocation.

The underlying assumption of our proposal is that new supplying regions have underutilised production capacity, so the absorption of additional production is met by pushing the use of production infrastructure to full capacity in the short term. This assumption implies that new suppliers do not face production capacity constraints and allows us to isolate the environmental impacts triggered exclusively by the change in suppliers.

Figure D.1 summarises the criteria to be considered for a comprehensive analysis of the carbon impacts of the new reshoring trends, i.e., 1) industries that produce the reshored products, 2) the kind of goods being reshored; 3) the countries to which production is relocated; 4) the scope of the emissions assessed.

Figure D.1 Criteria to set source shifting scenarios



Source: Authors' elaboration.

Considering the criteria mentioned above, we narrow down the general objective of this paper by focusing on the supply chain of five products that the European Commission considers as strategic: antibiotics, vaccines, batteries and electrical motors, iron and steel, and semiconductors. The selection of these products is based on EU reports that support the design and implementation of different industrial policy agendas such as the Pharmaceutical Strategy for Europe, the Green Deal Industrial Plan, the European Chips Act or the Net-Zero Industry Act (European Commission, 2020, 2022, 2023, 2024). Since EMRIO data operates with sector-level data, we complement our dataset with product-level international trade data from Eurostat (2023a, 2023b) to quantify the share a specific product represents inside the trade of the corresponding broad sector. The monetary value of this share will be the production subject to source shifting in the reshoring scenarios. Working with broad sectors that gather a heterogeneous bundle of products is a well-known limitation of input-output models; however, we mitigate such limitation by combining MRIO data with product-level trade data from official sources.

International trade data on EU imports at the product level is also used to identify the main non-EU supplying countries for each strategic product. Given that the EU resilience strategies are focused on diversifying suppliers for products that are currently concentrated by a few supplying countries, we only address the relocation of supplies imported from the top supplying countries of each product, while imports from the rest of the suppliers remain unchanged across scenarios. Table D.1 summarises the information needed to isolate the adequate portion of EU imports related to production subject to relocation in our reshoring scenarios.

Table D.1. Production subjected to reshoring strategies by targeted products and the original supplying country of Chapter 3

Product shifted	BEC classification by end-use	Broad sector [shifted imports]	Suppliers to substitute	Suppliers share on the EU's extra-regional imports by product (%)	EU's broad sector imports to shift (%)
Antibiotics	Intermediate good	Chemicals [672 million $]	Switzerland	39.24%	4.79%
			China	31.85%	1.75%
			United States	14.16%	2.10%
			Singapore	3.90%	2.36%
			Korea	3.76%	1.94%
			India	2.31%	0.85%
				95.22%	
Vaccines	Intermediate and final good	Pharmaceuticals [2,947 million $]	United States	46.23%	8.44%
			Switzerland	35.76%	6.96%
			India	7.47%	18.55%
			South Africa	3.24%	84.97%
				92.70%	
Iron and steel	Intermediate good	Basic metals [10,592 million $]	Russia	10.36%	31.07%
			China	9.80%	37.56%
			Turkey	9.36%	43.41%
			India	8.62%	53.00%
			Korea	8.19%	73.23%
				46.33%	
Chips and circuits	Intermediate good	Computer, electronic and optical equipment [11,002 million $]	China	40.93%	25.30%
			Taiwan	13.14%	59.12%
			Malaysia	12.45%	63.48%
			United States	5.54%	12.43%
			Israel	5.29%	12.43%
				77.34%	
Electric motors and batteries	Intermediate good	Electrical equipment [10,669 million $]	China	65.18%	42.12%
			Korea	6.82%	61.45%
			United States	4.54%	37.35%
			Japan	3.89%	37.27%
			Switzerland	3.05%	37.27%
				83.48%	

Source: Authors' elaboration with data from EUROSTAT (2023a) and EUROSTAT (2023b).

Note to Table D.1: Shifted imports [in square brackets] correspond to the backshoring scenario, in which these quantities reach the highest value.

After defining the products to reshore, their original supplying countries, their monetary value, and whether to modify intermediates of final products, the next step is to determine the destination of the shifted production (Table D.2).

Table D.2. New suppliers by GVC reconfiguration scenarios of Chapter 3.

Scenario	Relocation pattern	New importers	Distribution of the production shifted
1	Backshoring Deviance of production towards domestic market.	EU-27 countries	Each country's participation as a supplier of current intra-EU imports of the product
2	Nearshoring Deviance of production towards close economies.	CLOSE ECONOMIES: Canada, United States, Iceland, Norway, Switzerland, United Kingdom, Turkey, Morocco, Tunisia.	Each country's participation as a supplier of current extra-EU imports of the product
3	Backshoring + Nearshoring Deviance of production towards domestic market and close economies.	EU-27 countries + CLOSE ECONOMIES	Each country's participation as a supplier of current EU imports of the product

Source: Authors' elaboration.

In the backshoring scenario, production initially imported from the countries listed in Table 2 is relocated to EU economies according to their participation as suppliers in intra-EU trade of the products selected (EUROSTAT, 2023a, 2023b). In the nearshoring scenario, the original suppliers are replaced by other non-EU economies close to the EU regarding physical distance, socio-cultural identity, or political perspectives (Peijnenburg & Turunen, 2023). In this case, each new supplier is assigned a share of the shifted production according to its participation in the EU imports of the strategic product from non-EU countries. The third scenario combines the two former ones. All EU members and the so-called "close economies" are assigned a part of the shifted production according to their participation as suppliers of each EU product’s imports (intra-EU and extra-EU).

Appendix E: Take-back systems

Data was collected from 5 companies working with product take-back on different maturity levels. The case companies were selected through purposeful sampling by the researchers. The case companies were selected based on the follow requirements: 1) Experience with developing a take-back system and 2) Operating in a sector where take-back is not common. The interviews were conducted as semi-structured interviews that followed the take-back framework outlined above. Two overall questions framed the conservation: 1) What is the goal of your take-back system and why? Retain material value or functional value? and 2) What have been the challenges in terms of choosing a suitable product, building internal capabilities, and external ecosystem? The table below provides basic data on the primary and secondary data collection.

Table E.1. Basic data on the primary and secondary data collection

	Primary data Interviews	Secondary data Documents
Data items	5 interview transcriptions	ESG report and public communication
Minutes	287 minutes	
Period	August 2023 – October 2023	September - October 2023
Information provided	Details of the company's take-back system or target take-back system	Supplementary information
Data source	The responsible manager interviewed by the first and second author	Company webpage

Source: Authors' elaboration.

The meeting minutes were intelligently transcribed using Microsoft Word and the text files were loaded into NVivo for analysis. The interview data was coded using a combination of deductive and inductive coding to allow for the discovery of novel findings from the empirical data like new categories or elements of the take-back framework. The data was coded and analyzed through three sequences. First sequence: Structural coding labelling text according to framework dimensions, with an embedded inductive coding to allow for empirical informed findings regarding dimensions or elements of a take-back system that was not identified through literature. Second sequence: Axial coding combining similar labels and structuring codes into elements under the same dimension. Third sequence: Selective coding whereby codes were combined according to strategy (material or functional value retention) to create a uniform hierarchical structure aligning with the themes of the study.

Appendix F: Backshoring and environmental technology transfer simulation in an MRIO model with firm ownership heterogeneity

One of the classical limitations in MRIO modelling is the absence of firm heterogeneity (Miller & Blair, 2022). Usually, Input-Output Tables are built for broad sectors across the country, which assumes an average structure inside each industry. However, firm ownership has specific influence in key production features such as production technology (Rigo, 2021), imports and exports structure (H. Ma, Wang, & Zhu, 2015), GVC participation (Fortanier, Miao, Kolk, & Pisani, 2020; Zheng et al., 2022), energy consumption (Herrerias, Cuadros, & Luo, 2016) and carbon emissions (N. Ma et al., 2023; Yan, Wang, Chen, Wang, & Zhao, 2022), among others. Therefore, considering firm ownership is essential to assess the potential of technology transfer to foster peripherical economies and determine the environmental pressures arising from new trade trends.

Our proposal uses the Analytical Activities of Multinational Enterprises (AMNE) database provided by the OECD (Cadestin, De Backer, et al., 2018; OECD, 2020) to overcome this issue. This database offers symmetric MRIO tables in basic prices for 20 years (2000-2019), distinguishing between domestic-owned enterprises (DOEs) and foreign-owned enterprises (FMNEs) operating in 76 countries (plus a "rest of the world" aggregate) and 41 industries. Then, AMNE allows for firm-heterogeneity accounting since it presents a depiction of the activities of multinational enterprises combined with the ICIO tables, distinguishing DOEs and FMNEs operating in each country. FMNEs are defined as those enterprises in which more than 50% of the voting power or the shares are controlled, directly or indirectly, by a foreign company. The AMNE structure is similar to a usual MRIO table, but each input-output trade flow is broken down into DOEs and FMNEs (see Cadestin, De Backer, et al. (2018) for further details). In this way, the table provides a more detailed structure of intermediate and final sales, costs, value-added, and technology for each type of firm. In addition, AMNE provides a bilateral output matrix that splits global gross output by country, industry, and parent country on which the controlling entity is based. In this work, we use the AMNE tables for 2018 because the CO_2 emissions data is available up to this year.

Data required for creating the emissions coefficients, e vector on global CO_2 emissions, are retrieved from the OECD indicators on carbon dioxide emissions embodied in international trade, which offers data on the global CO_2 emissions from fossil fuel combustion for 24 years

(1994-2018) and allocates them to industries following a similar sectoral classification to AMNE tables. To elaborate a carbon emissions diagonalized vector ($\hat{e}$) with firm heterogeneity, we disaggregate the emissions from each industry and country based on the proportions of fossil fuel purchases by FMNEs and DOEs in the same country and industry, taken from the AMNE tables. The whole study will be performed using data from the last year available, 2018.

Regarding the scenario setting, the selection of former host countries for each sector assessed is based on Eurostat data on EU trade (EUROSTAT, 2023a, 2023b). These datasets provide information about the EU imports from each country globally, giving details by broad sector and product. This source lets us determine the main EU importers for each targeted sector in the current international trade structure.

This study implements the backshoring proposal through the source-shifting technique applied to the environmentally-extended MRIO model. This method is intended to simulate the geographical restructuration of the suppliers' structure of a certain economy according to a specific trade reorganization pattern. In this way, we can evaluate the net effect of the geographical MNEs' relocation processes on global emissions.

The source-shifting scheme in Chapter 4 is developed in the following way: first, we eliminate the EU-owned MNEs' production from selected former suppliers in a specific sector. Second, we reassign the detracted production to new supplying countries aligned with the chosen reshoring scheme (in this case, backshoring towards peripherical EU countries). This restructuring can be applied to those suppliers producing intermediate goods or/and final goods. In this case, the shift of production is applied both in intermediate production and in final goods, which implies that the source shifting method requires modifying coefficients in the original coefficient matrix $\mathbf{A}$ and the final demand matrix $\widehat{\mathbf{Y}}$ in Equation (A.2) of the original MRIO model. In both cases, the subtraction from old suppliers and the addition to new ones are applied by columns to modify the geographical origin of the purchases but not the production/demand composition or technology. In this work, this methodology is applied under the assumption that there will be no capacity constraints in the new supplying regions.

In this work, we go one step further by relocating just the production performed by EU-owned FMNEs in former hosts, and relocating it to specific EU countries selected as new hosts according to their current participation in the production of EU-owned FMNEs in the targeted sector. A similar procedure would be applied in the case of changing the country producing final products in the shifted sector, applying the changes in the final demand matrix $\widehat{\mathbf{Y}}$ in a similar way as proposed in the matrix $\mathbf{A}$. The carbon emissions resulting from the change in suppliers proposed is calculated as shown in Equation (F.7], which means implementing the MRIO model in Equation [2] with the modified matrixes $\mathbf{A}^*$ and $\widehat{\mathbf{Y}}^*$.

$$\mathbf{F}^* = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A}^*)^{-1}\widehat{\mathbf{Y}}^* \qquad (F.1)$$

The difference between $\mathbf{F}^*$ (calculated according to Equation (F.1)) and $\mathbf{F}^{\mathbf{BAU}}$ (computed according to Equation (A.2)) quantifies how emissions change due to the relocation process simulated. A positive sign would imply an increase in emissions, and a negative sign would correspond to a reduction in emissions due to the reshoring process.

In addition to the geographical shift of production, our proposal simulates different levels of environmental technology transfer (ETT). This is modelled through changes in emission intensities or emissions coefficients of specific sectors and firm types, as detailed in the "scenarios and hypotheses" section. When the ETT is applied to the sector shifted, the corresponding CO2 coefficient in the new host country (either in FMNEs or at a country-wide level including domestic firms) is substituted by a weighted average of those in the MNEs' home EU-countries, being the weight the participation of such owner countries in the production shifted. The substitution of the CO_2 coefficient takes effect if, and only if, such weighted average coefficient is less polluting than the original coefficient of the new host country.

One step further in applying the ETT scenarios is applying them to the electricity sector. The corresponding emission coefficient of the new host country is substituted by the weighted average coefficient of the top-13 EU-countries with the lowest emission intensity in the electricity generation industry. Again, the substitution is done only if the weighted average improves the CO_2 efficiency in the new host country.

Scenarios and hypotheses

Our proposal is based on a backshoring process in strategic sectors driven by EU-owned MNES, in which production is relocated from former extra-EU host countries to new hosts within the EU. Based on the baseline scenario, we will propose additional scenarios that introduce different variations of ETT.

The targeted strategic sectors are "basic metals", "computer, electronic and optical equipment", and "electrical equipment". Manufacturing sectors present a higher propensity to reshore activity, as evidence shows that firms in these sectors react faster and are more flexible to changing economic conditions. In fact, reshoring activities are mainly concentrated in medium to high-tech industries and larger firms, so MNEs fit these patterns and can restructure their production globally (Dachs, Kinkel, Jäger, & Palčič, 2019; Eurofound, 2019; European Parliament, 2021). Given this evidence, the selection of the three specific manufacturing industries mentioned above is based on particular EU trade strategies and features that made these sectors feasible and interesting to bring back to the EU. Products like batteries and electrical motors (produced by the electrical equipment industry) are considered essential for the decarbonization and the electrification of the economy (European Commission, 2020), which are milestones of the European Green Deal Industrial Plan (European Commission, 2023). Basic metals are critical raw materials in strategic technologies in the energy transition context (European Commission, 2020; McKinsey & Company, 2022), and their production is highly intensive in carbon emissions due to the reliance on coal and natural gas for iron-ore-based production (IEA, 2020). Therefore, relocating this industry within the EU in the context of ETT may contribute significantly to the reduction targets. Finally, semiconductors (including, among others, chips and circuits) are considered critical assets for industrial value chains in digital transformation. As their production is currently highly dependent on a limited number of producers, the computer, electronic, and optical equipment industry is targeted explicitly through the European Chips Act, which intends to boost EU's competitiveness and resilience in such technologies and applications (European Commission, 2022). In addition, the three selected sectors are highly dependent on imported R+D (Guadagno , Landesmann , & Zavarská, 2023), and their value chain presents a high CO2 intensity differential between the top-5 worldwide producers and the top-5 EU producers (García-Alaminos, 2024), which makes them adequate to test the potential effects of a MNE-driven ETT.

Pure backshoring scenario

Starting with the features of the baseline scenario (pure backshoring), the former host countries whose production is backshored towards the EU have been selected as the top-3 exporters supplying the EU for each industry according to international trade data retrieved from EUROSTAT (2023a, 2023b). In this way, for each targeted sector, the production carried on in these countries by FMNEs owned by EU countries is displaced towards new host countries back in the EU. Table F1 details the former host countries and the controlling EU economies.

The new host countries within the EU where the MNEs' production is being backshored have been chosen according to labour cost criteria, obtaining a selection of 13 Central-Eastern and Southern EU countries (Bulgaria, Czechia, Estonia, Greece, Croatia, Latvia, Lithuania, Hungary, Poland, Portugal, Romania, Slovenia and Slovakia1), both considered peripherical EU regions (Gambarotto & Solari, 2015; Pascariu & Frunza, 2011).

[1] Malta and Chipre have been excluded given to their size restrictions, which makes it difficult to host additional production in sectors such as basic metals.

Table F.1. Backshoring data: production relocated by origin country, and main MNEs' controlling EU countries.

Sector shifted	Original producing countries			MNEs' controlling EU-countries	
	Original location to substitute	Shifted imports (million $)	Share of MNEs' output shifted/Total EU output in the sector shifted	Top-3 controlling countries	Participation in total shifted imports
Basic metals	China	9,338.9		Germany	34.36 %
	Russia	2,328.0		France	22.77 %
	India	758.8		Italy	13.07 %
	Total	**12,425.7**	**2.8%**	**Total**	**70.21%**
Computer, electronic, and optical equipment	China	120,856.8		Germany	58.16%
	Taiwan	102,950.0		Italy	20.79%
	Malaysia	7,205.3		Netherlands	9.61%
	Total	**231,012.1**	**67.4%**	**Total**	**88.56%**
Electrical equipment	China	26,056.5		Netherlands	38.09%
	United States	14,017.7		Germany	28.39%
	Korea	2,575.1		France	7.40%
	Total	**42,649.4**	**12.8%**	**Total**	**73.88%**

Source: Authors' elaboration with data from Cadestin, Backer, et al. (2018), EUROSTAT (2023a) and EUROSTAT (2023b).

Once the amount of production to be backshored from former hosts is estimated, the quantity corresponding to each of the 13 new hosts inside the EU is determined according to their current production level (regardless of whether it is sold in the EU markets or abroad, and regardless it is devoted to final or intermediate use). In this way, we follow a specialization criterion that allocates more production to countries where the industry is already more significant. In the case of one of those 13 receiving countries being at the same time a home country owning MNEs in such sector, we exclude this home country from the backshoring process, as the proposal is to foster other economies different from the owner of the MNEs.

Technology transfer scenarios

After the baseline scenario (pure backshoring) is defined, the ETT is introduced along three additional scenarios at different extents. The scenarios implementing an ETT (2.1, 2.2, and 2.3) introduce a change in specific emission coefficients. Scenarios 2.1 and 2.2 assume that this technology transfer exclusively affects the targeted strategic industry (i.e., basic metals; computer, electronic, and optical equipment; or electrical equipment), either in the FMNEs or in the FMNEs and the domestic firms (DOEs). The more striving scenario (2.3) implies the extension of the ETT to the electricity generation sector, as it impacts the indirect carbon emissions in any value chain (Meng, Peters, Wang, & Li, 2018). Therefore, the whole economy would benefit from decarbonizing the electrical generation industry, but such an ambitious strategy would require cooperation between the MNEs leading the process and the public institutions fostering economy-wide decarbonization processes. The need for such public-private partnership efforts to achieve cleaner production in developing countries has been raised by the literature (Kolk, 2015; Saikawa & Urpelainen, 2014), showing that environmental regulations may be a strategy of technology transfer at the same time as technology transfer is a key determinant of environmental regulations.

Appendix G: Greensourcing in an MRIO context

In Chapter 5, we develop a new three-step process for source shifting in the context of an environmentally extended as shown in expression (G.1):

$$\boldsymbol{F} = \hat{e}(\mathbf{I} - \mathbf{A})^{-1}\bar{\hat{y}} \qquad \text{(G.1)}$$

where $\bar{\hat{y}}$ is the final demand matrix, diagonalized by country blocks, and the rest of matrixes follow the deffinitions given in Appendix A. The summatory by columns of $\mathbf{F}^{\mathbf{EU}}$ in the EU matrix positions will be the EU's CF business as usual (EUCFbau); which will be our target to reduce. Additionally, the expression (G.2):

$$\mathbf{P} = \hat{e}(\mathbf{I} - \mathbf{A})^{-1} \qquad \text{(G.2)}$$

provides the emissions multiplier ($\mathbf{P}$), which computes the total impact (direct and indirect) triggered by a unit of final demand for each sector/country of the economy. Adding $\mathbf{P}$ by columns, we will have the emissions intensity of the "vertically integrated sector". Based on this metric, we propose a dirty index for each sector computed as the geometric mean of the intensity emissions of each country (*r*) within the global value chain of the target sector.

$$DI^s = \sqrt[r]{\prod_{i=1}^{r} \mathbf{P}^s} \qquad \text{(G.3)}$$

By comparing the DI with the emissions intensity of each country for the target sector it will be possible to group the countries into the dirtiest ones -when emissions intensity is higher than the DI- and the cleanest ones -when emissions intensity are lower than the DI, and also ranking each group from more polluters and less polluters respectively.

Secondly, we address the restructuring of value chains to ensure that imports from the lowest ones substitute imports from the highest emissions per unit locations. Note that the import substitution or source shifting is only considered for imports outside the EU. The process of source shifting is graphically summarised in Figure G.1 and, succinctly, runs as follows: we blocked the imports and exports of dirty countries; add the first one to the clean countries and the second to the dirty countries. This will "clean" the carbon footprint of the EU by redirecting the exports of the world's cleanest countries towards the EU. It is worth noting that columns r28 to r67 are only rearranged in the set of scenarios where the restructuration of GVCs is relevant for the EUCF.

Figure G.1. Source shifting method applied in greensourcing (Chapter 5)

SHIFTING METHOD		r1 . . . r27 EU				r28 … r67 Clean				r28 … r67 Dirty			
		…	…	*Target*	…	…	…	*Target*	…	…	…	*Target*	…
r1 . . . R27 EUROPEAN UNION	…												
	…												
	Target	FOSTERED								BLOCKED Xs			
	…												
r28 … r67 Clean	…												
	…												
	Target	FOSTERED				DISPLACED				DISPLACED			
	…												
r28 … r67 Dirty	…												
	…												
	Target	BLOCKED Ms				DISPLACED				DISPLACED			
	…												

Source: Authors' elaboration.

Note: Fostered stands for an increase in production; Blocked Ms/Xs stands for those imports/exports that will be blocked by the EU; Displaced stands for the imports of the EU, which will be redirected.

Let's discuss the process in more detail. Our model considers that the sector blockage will trigger a similar response from those classified as dirty countries, freeing productive capacity in the EU sectors that will be used for import substitution. Additionally, we are considering the possibility of an increase in production capacity. Those two elements allow us to compute the domestic coverage ratio for import substitution that quantifies the proportion of the blocked imports that are covered by the blocked exports and increase capacity. The coverage ratio is defined as follows in expression (G.4):

$$cr_i = \frac{c * \sum_i CM}{\sum_i^{j=1 \ldots ue} DM} \qquad \text{(G.4)}$$

where c is the increased production capacity for clean origins, a parameter with different values according to the scenarios (see below); $\sum_i CM$, are the intermediate/final EU exports to dirty countries (blocked in our model) that are transformed to domestic inputs plus imports from clean countries (when these increase their imports), calculated per sector i; and, $\sum_i^{j=1 \ldots ue} DM$, are the intermediate/final dirty imports of EU countries (blocked in our model). The coverage ratios are distinct for intermediate goods and one for final goods.

Depending on the sector, this freed-up EU capacity may be sufficient or insufficient to absorb imports from all countries with dirty production with actual production. If the CR equals or exceeds one, the "dirty" imports are completely obstructed as they can be replaced. If not, they are curtailed according to that ratio. When the CR exceeds one, the EU will replace "dirty" imports, commencing with the cleanest domestic producers and continuing until the total substitution of imports. It should be noted that EU countries will never be obstructed, even if they could have "dirty" production. Conversely, imports to "clean" countries are only augmented when the production capacity of these countries is anticipated to grow. Otherwise, it is not feasible to compel "clean" countries to export to the EU instead of their export destinations. The model encapsulates the impossibility of interfering in other countries' trade policies. The entire process will culminate in a new input-output table derived from intermediate consumption and final demand.

Thirdly, we calculate the total emissions reductions of several scenarios to determine the potential improvements of a potential green sourcing strategy. The scenarios are designed by considering different combinations of four parameters. These parameters reflect different trade policy choices or methodological aspects, such as the location of the clean countries that will be the EU's new suppliers, the decision to maintain or increase production in clean locations, the search for EU trade balance or for global trade balance (requiring global demand to remain stable), or the introduction of changes for individual sectors or all simultaneously.

Among the 16 possible scenarios resulting from the combination of these parameters, seven representative possibilities stand out according to the purposes of this paper and have been selected and summarised in Table G.1. Scenario 1 (Sc1) proposes a simple transfer of international purchases, substituting imports from the dirtiest production process for those with the cleanest one. The remaining scenarios increase production in cleaner countries, following the 20% in industry and 10% in services pattern explained above, compensated by a reduction at the bottom of the class with an expected curbing effect on global emissions. Sc1, together with Sc2 and Sc3, are designed by considering that each sector modifies its structure in isolation, considering no variations in the remaining sectors. This hypothesis helps understand the potentiality of each industry in CF reduction. In Sc4, Sc5, Sc6, and Sc7, changes are introduced jointly; all sectors substitute dirty suppliers by cleaner ones, and this substitution increases production following the 20%-10% pattern. In Sc4 and Sc6, the EU27 substitutes dirty providers only by EU27 producers, while in Sc5 and Sc7, providers could come from any location.

The last column in Table G.1 reflects a methodological issue where our analysis brings the main novelty concerning previous literature, allowing the comparison of results with and without such a modification. Greensourcing aimed at restructuring GVC proposes providers’ substitution, ensuring that the importer is able to acquire required imports from cleaner sources. Consider the case of EU imports, which block imports from dirty country A and substitute them with clean country B’s products; how does this affect country B’s previous importers? Is global trade reduced because previous importers' purchases are not fulfilled?

Table G.1. List of scenarios of greensourcing (Chapter 5)

num.	PRODUCTION CAPACITY	SECTORS AFFECTED	SOURCE SHIFTING TO	REARRANGING MRIO TABLE
1	No increase	One-by-one	Clean EU27	Only shifting countries
2	+20% Industries and +10% Services	One-by-one	Clean EU27	Only shifting countries
3	+20% Industries and +10% Services	One-by-one	All clean countries	Only shifting countries
4	+20% Industries and +10% Services	All sectors	Clean EU27	Only shifting countries
5	+20% Industries and +10% Services	All sectors	All clean countries	All countries
6	+20% Industries and +10% Services	All sectors	Clean EU27	All countries
7	+20% Industries and +10% Services	All sectors	All clean countries	Only shifting countries

Source: Authors' elaboration.

Our scenarios include cases where the methodology follows the pattern of prior works: Sc1, Sc2, Sc3, Sc4, and Sc7, rearranging only the matrix of intermediate and final consumption for actors, EU27. By contrast, Sc5 and Sc6 rearrange the entire global matrix, ensuring that those countries that can no longer buy from clean countries find suppliers for their demand.

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