Environment, Development and Sustainability
https://doi.org/10.1007/s10668-023-03563-9

Is there a pollution haven in European Union global value chain participation?

Hugo Campos-Romero[1] · Paulo Reis Mourao[2] · Óscar Rodil-Marzábal[1]

Received: 19 January 2023 / Accepted: 29 June 2023

Abstract
This paper aims to test the pollution haven hypothesis within the European Union (EU), especially among newcomer countries, through the participation in global value chains (GVCs). The study used a combination of multiregional input–output method and multi-level mixed econometric analysis to investigate the relationship between global value chain trade flows, foreign direct investment flows, energy consumption, and carbon emissions across countries, sectors, and time. The study tested both the "pollution haven" and "pollution halo" hypotheses and found a non-linear relationship between foreign capital flows and carbon emissions, which became less relevant after the economic integration process. The results suggest the existence of a pollution haven in Europe. Although Eastern economies still exhibit problematic issues in relation to pollution control, they have made significant progress in reducing their emissions intensity. The conclusions include some policy recommendations based on the main findings of the research.

Keywords Pollution haven hypothesis · European Union · Global value chains · Pollution halo hypothesis · Environmental regulation · CO_2 emissions

1 Introduction

The impact of international trade on the environment remains a topic of great analytical interest, considering that decades of research have yielded only mixed results. Several issues have been discussed in recent years, including analysis of the relational dynamics

✉ Hugo Campos-Romero
hugo.campos.romero@usc.es

Paulo Reis Mourao
paulom@eeg.uminho.pt

Óscar Rodil-Marzábal
oscar.rodil@usc.es

1 Department of Applied Economics, Faculty of Economics and Business Studies, Universidade de Santiago de Compostela, Campus Norte, Av. Do Burgo das Nacións s/n, 15782 Santiago de Compostela, A Coruña, Spain

2 Department of Economics & NIPE, School of Economics and Management, University of Minho, Braga, Portugal

Published online: 13 July 2023

involving the stringency of environmental regulation, trade performance, the effects of trade liberalization, and free capital mobility from developed economies to other territories. These issues have been analyzed based on several hypotheses, including the pollution haven hypothesis (PHH), Porter's hypothesis, the pollution halo hypothesis (PH), and the environmental Kuznets curve (EKC) (Balsalobre-Lorente et al., 2019; Birdsall & Wheeler, 1993; Copeland & Taylor, 1994, 2004; Porter, 1990; Porter & van der Linde, 1995).

Despite the extensive research on pollution havens in the literature, there has been limited attention given to this issue in the context of the EU, and even less to its connection with global value chains (GVCs). Given the integration of EU countries into the global market, it is essential to investigate whether participation in GVCs is associated with worse environmental conditions and the presence of pollution havens. GVCs arise from international fragmentation of production, whereby a single production chain is broken down into small tasks that are carried out by different suppliers in diverse geographical locations (Arndt & Kierzkowski, 2001; Feenstra, 1998; Gereffi, 2005, 2014; Humphrey & Schmitz, 2001). As a result, two negative environment impacts can be expected. First, intense freight transport flows compared to those resulting from traditional trade. Second, developing countries that typically assume manufacturing tasks when integrating into a GVC also tend to maintain lower environmental standards. Without technology transfer or the inclusion of specific environmental standards in supply contracts, global environmental conditions may worsen (Ge et al., 2020).

The aim of this research is to analyze the presence of a pollution haven effect in the European Union (EU), focusing especially on the influence of Eastern European countries that became newcomers to the EU during the period of analysis. The underlying hypothesis to be tested is whether trade liberalization and the entry of foreign capital displaced the most harmful productive tasks from the more developed countries to the more recently integrated (and less developed) economies. In such a scenario, Eastern Europe would be supplying the most polluting production inputs to the European value chain.

As a relevant contribution to the literature, this paper contributes to the development of the discussion on pollution havens by analyzing the case of the European market from the perspective of GVCs. One of the key findings of this research is the identification of a pollution haven in the EU. This finding is supported by empirical evidence that also reveals that the integration of Eastern European countries into the EU has led to a concentration of polluting activities in these territories, which acted as suppliers of the most harmful production inputs to the European value chain.

Another relevant contribution of this research is the identification of a limit to the technical progress in terms of environmental efficiency in the EU. The findings shed light on the controversial results found in the literature, particularly regarding the verification of the Pollution Haven Hypothesis (PHH) both in general and specifically at the European level. These results suggest that additional investments aimed at improving environmental performance may no longer yield significant benefits. Additionally, this study offers a novel insight that participation in GVCs, especially simple value chain flows, is linked with worse environmental conditions. Ultimately, these contributions provide a comprehensive understanding of the complex relationship between trade liberalization, GVCs participation, and environmental sustainability in the EU.

To determine the presence of a pollution haven in the EU, a mixed multilevel estimation is carried out using information collected from two sources: Eora and Eurostat, for the EU28 countries during the period 1995–2015. The data were collected across country, sectoral, and temporal dimensions, which informed the selection of the estimation method indicated, assuming that sectors are nested within countries. Input–output methodology was also used to determine GVC trade-related flows. An additional contribution of this work lies in the three-dimensional analysis within a global value chain approach, which enables the simultaneous contrast of multiple effects.

This paper is structured as follows. Following this introduction, Sect. 2 reviews the main research contributions on the link between trade and the environment, with special attention to PHH. Section 3 describes the input–output methodology and the estimation method used for this research. Section 4 presents the main results and discussion. Finally, Sect. 5 provides the conclusions and suggestions for future research.

2 Literature review

The relationship between environmental impacts and trade liberalization is still a topic of interest in the academic literature. One of the pioneering studies in this area was conducted by Copeland and Taylor (1994), which investigated the environmental effects of trade liberalization. Their study found that increased economic activity did not necessarily increase a country's emissions levels. However, the economic growth triggered by trade liberalization can impact the sectoral composition of a country in ways that are influenced by the variation in environmental regulation across territories. This phenomenon has been referred to as the Pollution Haven Hypothesis, which posits that international openness could potentially result in a rise in a territory's emissions. This hypothesis asserts that emission-intensive industries will relocate their production to regions with less stringent environmental regulations in the context of free flows of trade and capital. In general, more developed countries have more stringent environmental regulations than developing or transition economies (Guzel & Okumus, 2020). Accordingly, the PHH argues that environmental performance in developing economies will worsen and they will become net exporters of emission-intensive goods.

In a later work, Copeland and Taylor (2004) drew three conclusions regarding the PHH analysis. Firstly, it is important to note that a direct causal relationship between increased economic activity and higher levels of emissions cannot be unequivocally established. This is because economic growth is often accompanied by policy initiatives to mitigate the adverse environmental impacts. Secondly, in contrast to their earlier work, the authors now acknowledge that environmental policies can influence global trade and investment patterns. And thirdly, while the authors do identify a Pollution Haven "effect", the centrality of environmental regulation in determining this outcome remains unclear. It should be borne in mind that environmental policy is not the only factor that has an effect on external competitiveness, so more variables that can explain this effect should be considered. The presence of PHH continues to be a matter of debate. In fact, since some studies have found contrary effects, alternative theories have been developed to explain the relationship between investment flows, regulation, and environmental impacts. Among these alternatives, the Porter and Pollution Halo hypotheses stand out. On one hand, the Porter's Hypothesis states that there is no trade-off between economic growth and environmental protection, but that the most emission-intensive industries can even benefit from the implementation of environmental regulation (Porter, 1990; Porter & van der Linde, 1995). The basic argument is that such regulation induces innovations that improve environmental performance as well as productivity and competitiveness (Leeuwen & Mohnen, 2017). Thus, PHH and Porter's are opposing hypotheses in terms of sectoral impacts, changes resulting from trade liberalization and international differences in environmental regulation (Gill et al., 2018).

On the other hand, the Pollution Halo Hypothesis (PH) establishes a negative relationship between FDI inflows and emissions. Like Porter's, it argues that multinationals expand their technologies, which are assumed to be more environmentally efficient, into countries where they conduct FDI operations. This spread of cleaner technologies would make it possible to counteract the scale effect derived from the increasing commercial openness of less environmentally efficient regions, thereby promoting composition and technical effects (Balsalobre-Lorente et al., 2019; Grossman & Krueger, 1995; Hoffmann et al., 2005).

In short, the PHH is confronted with opposing hypotheses and a high degree of uncertainty since numerous studies have found different results in recent decades. Much of the early research found little relationship between the level of stringency of environmental regulation and environmental impacts. For example, Eskeland and Harrison (2003) and Harrison (1994) analyzed manufacturing industries in developing economies and found little evidence to support PHH, noting that pollution abatement cost was not a critical factor in the location decision.

The work of Birdsall and Wheeler (1993) on a set of Latin American countries offers an interesting alternative by suggesting that developing economies increase their emissions faster than developed economies. They argue that trade openness and free movement of capital have not caused PHH effects; rather, the higher emissions of these countries are explained by the higher degree of economic protection offered by their governments. Therefore, the lack of global competitiveness prevents the adoption of cleaner technologies. Bommer (1995) found that relocation occurred for strategic reasons and not due to competitiveness losses resulting from increasing emissions abatement costs. Thus, even if environmental conditions worsen due to production relocation to territories with laxer regulations, the movement of capital would not be motivated by international differences in environmental regulation.

More recent research has rejected PHH or found insufficient evidence to support it. For example, the study on BRICS (Brazil, Russia, India, China, and South Africa) and MINT (Mexico, Indonesia, Nigeria, and Turkey) by Shao et al., (2019) found a long-term negative causal relationship between FDI inflows and environmental impacts. These results point in the opposite direction to PHH, implying that external openness would lead to an improvement in environmental quality in the long run. Similarly, research by Destek and Okumus (2019) rejected the validity of PHH for a set of developing economies, though the study offered complex results. While increased economic activity resulting from trade integration may initially worsen some environmental indicators, in relative terms the use of new, cleaner technologies will partly reduce environmental degradation. However, the absence of stringent environmental regulation means that, in the long term, subsidiaries will not be concerned about environmental quality.

Meanwhile, other papers have found evidence to support PHH. The work of Yang (2001) pointed to an increase in both emissions and the share of carbon-intensive sectors following trade liberalization in Taiwan. Despite a technology effect that reduced emissions, the negative composition and scale effects of new productive specializations outweighed the gains from technology transfer. Azhar and Elliott (2007) also found evidence to support PHH based on a North–South trade analysis. However, the hypothesis only held at certain moments and was not suitable for explaining trade patterns between the two regions continuously over time. The authors also found the difference in environmental regulation and resource endowment (capital and labor) to be significant. López et al. (2013) also verified the existence of a pollution haven in the case of bilateral trade between Spain and China.

According to their results, the trade relations between these countries implied a significant increase with respect to previous emissions. The authors also found evidence of an indirect PHH effect, since most of the emissions from trade between the two countries originated from intermediate production through domestic linkages that arose as a result of increased foreign demand/supply. More recently, Rana and Sharma (2018) found evidence supporting PHH and EKC[1] for the case of India. The authors reported an indirect causality relationship between FDI and GDP growth achieved through trade openness that attracted more environmentally harmful tasks. The work by Balsalobre-Lorente et al. (2019) also provided evidence to corroborate EKC and PHH in MINT countries, in contrast with the results of Shao et al. (2019), who rejected the hypothesis for the same sample of countries.

While most of the research on this hypothesis is conducted on developing countries, much of the recent research focuses on China. Some works verify the hypothesis while others indicate that the results depend on factors such as the environmental regulatory framework. For example, López et al. (2018) stated that even though international trade has succeeded in reducing global emissions, China has become the world's main pollution haven because it has taken over a large part of the most polluting production stages. Shen et al. (2019) also found evidence supporting PHH in Chinese provinces by verifying that several polluting industries moved to other region due to changes in regional regulations on emissions. Meanwhile, other papers have reported opposite results, depending on the indicator chosen as the proxy variable or the economic policy of each province (Wang et al., 2019b; Yang et al., 2018; Zheng & Shi, 2017).

Regarding the relationship between PHH and GVCs, it is worth noting that there is a limited number of studies available. Despite the unique characteristics of GVCs, which involve a high degree of geographical fragmentation and intensive use of transport, there is a lack of research on this topic. Zhang et al. (2017) addressed this issue by utilizing the input–output (IO) analysis framework to examine the effects of different trade patterns on PHH. The authors found that international trade generally resulted in a reduction in global emissions, although the specific results varied depending on the trade patterns in each case. However, subsequent research by Duan et al. (2021), which also employed input–output methods, suggested that high-income countries tend to shift the most environmentally damaging stages of the value chain to developing countries. Based on their findings, the authors concluded that global emissions chains (and pollution havens) do indeed exist.

As commented before and shown in Singhania and Saini (2021), while most of the existing literature has focused on developing countries, particularly China, and to some extent the USA and Japan, relatively little attention has been paid to the case of the EU. The study by Martínez-Zarzoso et al. (2017) is one of the few to analyze this issue. Their results partially supported PHH in the trade of emission-intensive goods but found stronger evidence for Porter's hypothesis related to trade in "clean" goods. The research of Tsagkari et al. (2018) on Poland showed an increase in both exports and imports –measured in terms of CO_2– resulting from trade liberalization and European integration. However, Ho and Iyke (2019) reported that in the long run, EKC predictions were upheld for Central and Eastern European countries. This implies that the greater economic development derived from the integration processes is positive.

While looking for environmental imbalances in the European Union from an international trade approach is a relatively under-researched issue, some additional contributions

[1] The EKC hypothesis states that a country's emissions will increase up to a certain level of per capita income, above which further economic development will lead to better environmental performance.

have been published recently by Christoforidis and Katrakilidis (2021), Duarte and Serrano (2021) and Balsalobre-Lorente et al. (2022). The first paper focuses on the impact of FDI flows during 1995–2014 in Eastern European countries and found a non-linear relationship between these investments and environmental degradation (inverted U-shaped curve). The second paper highlights the reduction in emissions intensity and emissions embodied in exports of Eastern European countries following economic integration. This is due to both technological improvement processes and a gradual shift away from coal and other highly polluting fossil fuels. However, since 2012 this trend seems to have been reversed. The third paper analyzed the PHH in Portugal, Ireland, Italy, Greece, and Spain. The authors found evidence of PHH in these countries, consistent with previous studies, but with a new focus on the impact of renewable energy. The study highlights the potential of renewable energy to offset carbon emissions.

In summary, the literature highlights a dual gap in the analysis of the PHH. Firstly, there is a need for an approach that considers the impact of GVCs on the increasing fragmentation of productive processes. This fragmentation can potentially lead to the division of tasks based on pollution levels, giving rise to the concept of pollution havens. Research, such as the study conducted by Duan et al. (2021), highlights the significance of considering this specific form of foreign trade. They emphasize that analyzing foreign trade in gross terms can potentially lead to errors when examining the hypothesis.

Also, there is a lack of studies exploring this hypothesis in the European context, possibly due to the stricter environmental regulations, the consideration of a pollution haven effect originating within the EU is not currently explored. However, an examination of the recent trends in emissions volume from the producer's perspective and the evolution of emissions intensity reveals a diminishing trend in environmental efficiency gains (Sustainable Development Solutions Network & Institute for European Environmental Policy, 2021). These findings underscore the significance of the topic being studied and highlight the need for further investigation.

It is worth noting at this point that sometimes the PHH is rejected even though the group of developing economies analyzed shows increasing and even relatively higher emissions than developed countries. The acceptance criterion is based on whether the international difference in environmental regulations is found to be the main reason for production relocation. Under a less stringent perspective, PHH can hold if industrial emissions from production and FDI oriented toward relatively pollution-intensive tasks increase following a process of trade liberalization in developing economies. It is not reasonable to consider international differences in environmental regulation as the main reason for relocating; rather, in line with Copeland and Taylor (2004), they should be considered as another factor in the location decision.

To conclude this review, it is necessary to briefly mention the variables usually selected to verify these hypotheses. Although the PHH states an inverse relationship between environmental degradation and the stringency of legislation, it is difficult to develop a proxy variable for the rigidity of environmental legislation, especially in comparative terms. Therefore, in practice researchers use a variety of explanatory variables including foreign direct investment, energy consumption, and, depending on the specific research objective, variables related to foreign trade, institutional quality, or the use of renewable energies. Table 1 provides a summary of the main variables used in some of the research cited before.

To summarize, this section has presented the main hypotheses in the debate on international trade and the environment. These include PHH (offshoring of the most polluting processes), Porter's hypothesis (emissions reduction through innovations encouraged by environmental regulations) and the PH (expansion of high technology through multinational trade networks). The literature review has provided an overview of the main research conducted on developing countries, as well as the studies examining the relationship between participation in GVCs and the presence of pollution havens. Furthermore, the review has included a discussion of the extent to which this hypothesis holds for European countries based on the limited literature available on this region.

3 Materials, methods, and calculation

The research has various innovative aspects as it examines both PHH and PH simultaneously in the, filling a gap in the limited literature on these hypotheses in the EU. Moreover, the analysis is designed to consider country, temporal, and sectoral dimensions concurrently, enabling the verification of whether the integration of Eastern European countries into the EU has transformed the trade and investment structure and, in turn, environmental effects in Europe. Particular attention is given to Eastern European economies due to their relatively higher environmental impact.

Over the years, various research groups have developed projects aimed at providing IO information of international scope. The IO method developed by Leontief (1937, 1951) has been expanded to the multi-regional level, allowing global intersectoral analysis and value-added trade analysis. Although multi-regional IO (MRIO) databases are relatively new, Leontief and Strout introduced the method in 1963 and applied it to United States interregional trade. Their methods are still being applied and are particularly useful for analyzing GVCs. This can be seen in the work of Borin et al. (2021), Kersan-Škabić (2019), Wang et al., 2019a) and many others.

The data required to perform this research was obtained from several databases. For trade related information and environmental data (CO_2 emissions and energy consumption), the MRIO Eora database was selected. Although other MRIO databases are frequently used in the literature, Eora allows for an extended temporal analysis and offers a significant volume of additional information in satellite accounts (Casella et al., 2019; Lenzen et al., 2012, 2013). In this research, the period 1990–2015 has been selected for the EU28. Information on FDI stocks at the sectoral level was elaborated on data available from Eurostat.[2] The IO analysis methodology and the econometric model are presented below.

Koopman et al. (2014) have made a significant contribution to the field of value-added trade analysis. Their work decomposes a country's gross exports into various value-added components based on where each flow is ultimately absorbed. The process by which these value-added flows are obtained is described as follows:

For a set of c countries and n sectors, $T_{cn\times cn}$ is defined as the intermediate transaction matrix, $F_{cn\times c}$ as the final demand matrix and $X_{cn\times 1}$ as the total output vector. From these terms, the following IO identities are defined:

$$X = Ti + Fi; A = T\hat{X}^{-1}; L = (I - A)^{-1} \quad (1)$$

[2] Data can be made available on request to the corresponding author. The data have been obtained from different databases, some of them with restrictions.

Table 1 Summary of papers analyzing the Pollution and Haven hypothesis *Source*: Authors

Authorship	Variables	Sample countries	Period	Method	Verify/reject PHH?
Adeel-Farooq et al. (2021)	Environmental performance, FDI inflows, GDP per capita, urbanization, and energy consumption	76 countries	2002–2012	Panel data (Fixed effects)	Conditional to country case
Albulescu et al. (2019)	CO_2, FDI, GDP per capita, unemployment, energy consumption, population density, human capital, and gross fixed capital formation	14 countries (Latin America)	1980–2010	Fixed and Random effects, First difference analysis, and Panel quantile regression	Reject
Balsalobre-Lorente et al. (2022)	CO_2, economic complexity index, FDI, renewable energy use, and urbanization	Portugal, Ireland, Italy, Greece, and Spain	1990–2019	Dynamic ordinary least square	Verify
Birdsall and Wheeler (1993)	Pollution intensity, income per capita (initial level and growth), and dummy variables for time and trade	25 countries (Latin America)	Selected years (from 1960 to 1980)	Pool regression	Reject
Bulus and Koc (2021)	CO_2, FDI, GDP per capital, Energy use, renewable energy use, government expenditures, exports, and imports	Korea	1970–2018	Autoregressive distributed lag	Verify
Eskeland and Harrison (2003)	Pollution abatement cost, Herfindahl Index, import penetration, regulatory barriers against FDI, labor to capital ratio, market size, wage, time, and sector dummies	Cote d'Ivoire, Venezuela, Morocco, and Mexico	Unbalanced panel (1977 to 1999, varies across countries)	OLS, Fixed and Random effects, GMM	Weak evidence
Guzel and Okumus (2020)	CO_2, GDP per capita, FDI, and energy use	Indonesia, Malaysia, Philippines, Singapore, and Thailand	1981–2014	Panel data estimations	Verify

Table 1 (continued)

Authorship	Variables	Sample countries	Period	Method	Verify/reject PHH?
Hoffmann et al. (2005)	CO_2 and FDI	112 countries	Unbalanced panel (1971 to 1999, varies across countries)	Panel data estimations (Fixed and Random effects)	Conditional to country case
López et al. (2013)	Exports, imports, emissions, and energy consumption	China and Spain	2005 and 2011	Input–Output	Verify
Martínez-Zarzoso et al. (2017)	Dirty exports, clean exports, GDP, total environmental tax revenues, and dummy variable	EU (21 countries)	1999–2013	Gravity model	Weak support
Shahbaz, Balsalobre-Lorente and Sina (2019)	CO_2, GDP per capita, FDI, and biomass consumption	Middle East and North Africa	1990–2015	GMM	Verify
Shao et al. (2019)	CO_2, GDP per capita, energy consumption, trade openness, and urbanization	BRICS and MINT countries	1982–2014	Panel group mean fully modified ordinary least squares	Reject
Shen et al. (2019)	Industrial environmental efficiency, capital, labor, wastewater emission, SO_2 emission, and industrial fume emission	Guangdong Province (China)	2001–2014	Panel ARDL (AutoRegressive Distributed Lag) model	Verify
Singhania and Saini (2021)	CO_2, GPD per capita, energy consumption, trade openness, FDI, financial development, and institutional framework	21 countries	1990–2016	GMM	Verify
Yang et al. (2018)	Mandates, compliance with standards, pollution abatement cost, CO_2 emission intensity, GDP, wages, unemployment, human capital, firm agglomeration, and road intensity	Jiangsu province (China)	2006–2010	Conditional logit model	Conditional to each case analyzed

Table 1 (continued)

Authorship	Variables	Sample countries	Period	Method	Verify/reject PHH?
Zhang et al. (2017)	CO_2, exports, and imports	China, USA, Japan, Germany, Canada, India, UK, Australia, France, Russia, Italy, Taiwan, Korea, and Netherlands	1995–2009	Input–Output	Reject
Zheng and Shi (2017)	Relocation variables, legal instruments, economic policy instruments, public participation (direct and indirect) and regional market size, labor costs, and transport costs	China	2004–2013	Probit model and Bivariate probit model	Verify, but conditional to environmental policies
Zheng and Sheng (2017)	Emissions (from CO_2 and energy consumption), GDP per capita, value-added share by sector, energy intensity, carbon emission from neighborhood regions, and unemployment rate	China (30 province data)	1997–2009	OLS, Fixed and Random effects	Verify

Most of the variables are commonly computed in per capita or intensity terms. Intensity is often obtained over GDP

with i as a vector of ones used to perform row or column sums as required .$A_{cn \times cn}$ contains the technical production coefficients matrix, where $\widehat{X}^{-1}_{cn \times cn}$ is a diagonal matrix containing the total output elements on a $n \times n$ diagonal (the elements outside the diagonal are null). The Leontief inverse matrix,$L_{cn \times cn}$, is obtained from A and identifies the direct and indirect effects due to a change of one monetary unit in country-sector pair., with $I_{cn \times cn}$ as the identity matrix. From the technical coefficients' matrix, it is possible to obtain the value-added $v_{1 \times cn}$ coefficients as follows:

$$v = u - iA \tag{2}$$

where $u_{1\times cn}$ is a vector of ones. The GDP of an economy can be obtained as the product of the diagonalized value-added coefficients matrix $\hat{v}_{cn\times cn}$ and the total output matrix.

It is possible to decompose each element of the total output matrix according to where each value-added flow is finally absorbed. In Eq. (3), X^* is a $cn \times c$ total output matrix in which diagonal elements represent national intersectoral exchanges and non-diagonal elements represent sectoral international trade.

$$X^* = LF \tag{3}$$

Therefore, $EXP_{cn\times cn}$ is a matrix of gross exports that represent international trade relations at the sectoral level. To obtain this matrix, X^* is modified by omitting the $n \times n$ diagonal elements. According to Koopman et al. (2014), a country's gross exports can be decomposed into nine value-added flows, three of which are domestic value-added export flows. These three flows are described below, where p, q, and r are three countries and j, k, and m three sectors (with $p \neq q \neq r$, but allowing $j = k = m$). In the following expression, the first subscript and superscript refer to the sector and country of origin, while the second ones correspond to the sector and country of destination, respectively. For a total of s rows and z columns:

$$VAX1^p = \sum_{\substack{z, \\ p \neq q}} \hat{v}_j^p L_{jk}^{pp} F_{jk}^{pq} \tag{4}$$

$$VAX2^p = \sum_{\substack{z, \\ p \neq q}} \hat{v}_j^p L_{jk}^{pq} F_{jk}^{qq} \tag{5}$$

$$VAX3^p = \sum_{\substack{z, \\ p \neq q \neq r}} \hat{v}_j^p L_{jk}^{pq} F_{km}^{qr} \tag{6}$$

The element $VAX1_{jk}^{pq}$ represents the value-added generated by sector j in country p, processed as an intermediate good in the domestic economy and exported to sector k in country q as a final consumption good. This value-added stream is often referred to as traditional trade. The element $VAX2_{jk}^{pq}$ represents the value-added that is generated by sector j of country p and exported as an intermediate consumption good to sector k of country q, where it is processed and finally consumed. This flow represents simple GVCs. Finally, $VAX3_{jk}^{pr}$ represents the value-added that is generated by sector j of country p and exported as an intermediate consumption good to sector k of country q, where it is processed and again exported as a final consumption good to sector m of country r. This flow represents complex GVCs.

The sum of $VAX2$ and $VAX3$ represents a country's total value-added GVC exports. From these indicators it is possible to obtain the basic shares for value-added trade analysis, dividing each of them by the gross exports of each corresponding sector and country. This methodology has been widely used for advanced GVC analysis. It is also the methodological basis of TiVA database (OECD) and the foundation of several studies (Casella et al., 2019; Wang et al., 2017, 2019a, 2021).

In addition, the vertical specialization index (VS index) can be obtained from the following expression:

$$VS_j^p = \hat{v}_j^p L_{jk}^{pq} = (u - \hat{v}_j^p L_{jk}^{pp}) \tag{7}$$

The VS index provides information on the share of foreign value-added that is embodied in domestic gross exports. See Hummels et al. (2001) and Koopman et al. (2014) for a demonstration of the expression.

Regarding the econometric estimation, the following multilevel model is proposed:

$$\begin{aligned} CO_{2,cts} = &\beta_0 + \beta_1 VAX1_{cts} + \beta_2 VAX2_{cts} + \beta_3 VAX3_{cts} + \beta_4 FDI_{cts} + \beta_5 FDI^2_{cts} \\ &+ \beta_6 GDPpc_{cts} + \beta_7 ENER_{cts} + \beta_8 EAST_{cts} + \varepsilon_c + u_s \end{aligned} \tag{8}$$

where c, t and s subscripts refer to the country, time and sectoral dimensions, respectively. Also, CO_2 is a measure of emissions intensity over GDP (tons of emissions per thousand dollars produced). The variables $VAX1$, $VAX2$ and $VAX3$ represent the different trade flows specified in expressions (4), (5) and (6), all of them as the share of the corresponding sectoral gross exports. The variable *FDI* corresponds to the ratio of inward foreign direct investment stock to GDP for each country and sector available, while FDI^2 is its square value. The variable *GDPpc* corresponds to GDP per capita. *ENER* corresponds to the ratio of sectoral energy consumption to GDP. *EAST* is a dummy variable which aims to identify Eastern European countries. Finally, ε_c and u_s refer to country and sector errors, respectively. The statistics are summarized in Table 2. A description of the variables and corresponding sources can also be found in Table 6 in Appendix 2.

The inclusion of the square of the FDI stock is intended to allow testing of PHH and the PH. If a significant inverted U-shaped relationship is found between these variables (FDI stock and its square) and the ratio of emissions to GDP, one hypothesis or the other will be verified depending on where each country-sector pair is located with respect to the turning point of the curve. The PHH would be upheld on the ascending section, while the PH would be sustained on the descending section.

Estimating a mixed multilevel model is more appropriate given the structure of the data (Verbeke & Molenberghs, 2000; Vonesh & Chinchilli, 1997). All variables included were studied for three dimensions: geographical, sectoral, and temporal. The data showed a hierarchical structure between countries and sectors, with the latter nested in the former. Random effects were applied to hierarchically structured elements (countries and sectors).

4 Results and discussion

This section presents and discusses the main findings of the empirical analysis. The first subsection shows some of the figures that made it possible to characterize the productive structure of EU countries in terms of their external relations (both intra and extra-EU trade) and the associated environmental impact. The second subsection shows the estimation results based on the method and model described earlier.

4.1 Descriptive analysis

The present analysis employs the methodology and indicators outlined in Sect. 3 to analyze significant aspects of the participation of EU28 countries in GVCs.

In Fig. 1, the domestic value-added exports to gross exports ratios are presented for each member country in 1995 and 2015. It should be recalled that *VAX1* flow represents domestic value-added exported as final goods, which is a trade flow that does not correspond to GVCs. The sum of *VAX2* and *VAX3* flows represents trade in GVCs by grouping together all domestic value-added exports of intermediate goods (both those that are consumed in the importing country (*VAX2)* and those that are re-exported by that country (*VAX3*)).

Figure 1 reveals a twofold characteristic of the European value chain. First, the value-added exported according to GVC theory (right side of the figure) was more relevant than the value-added directly exported as traditional trade for all countries considered. To be more precise, it should be noted that $VAX2+3$ is not an exhaustive representation of the total GVC trade, as it only considers the domestic value-added flows exported by a country and does not account for the re-imported and re-exported flows. These flows usually represent a small proportion of the total exported value-added, which is why they have been omitted.

Second, between 1995 and 2015, the evolution of value-added flows was not similar for all countries. In terms of direct value-added exports (*VAX1*), roughly half of the countries experienced an increase in their share, while for gross exports that include indirect value-added flows ($VAX2+3$), most countries showed a reduction in their share. This reveals lower participation in GVCs from the perspective of domestic value-added. However, it does not necessarily imply lower total participation in GVCs, since a decrease in exported domestic value-added (whether in the form of GVCs or not) usually implies an increase in exported foreign value-added.

A useful measure of foreign value-added embodied in gross exports is the VS index, which was developed by Hummels et al. (2001) and improved by Koopman et al. (2014) (see Fig. 2). The initial VS index assumes some important restrictions. First, it considers that intermediate inputs intensity between sectors of an economy is constant. Second, it assumes that there is no bilateral trade in intermediate goods. The modified VS index proposed by Koopman et al. (2014) removes these constraints. In an MRIO setting, the VS index can be obtained as indicated in expression (7).

In 2015, most of the countries analyzed had a VS index greater than 30% of their domestic gross exports, and those that decreased their share of domestic value-added in gross exports tended to increase their share of foreign value-added. The exception (a reduction in both domestic and foreign exported value-added, as presented in Figs. 1 and 2) implies increasing shares of reimported and reexported value-added, which are also GVC trade flows.

To assess the environmental impact of the EU28 countries, the ratio between sectoral CO_2 emissions and the value-added generated by each sector is presented below (see Fig. 3). Value-added to CO_2 is an emissions intensity, obtained from GDP instead of total output. Therefore, it reflects the tons of CO_2 emitted per thousand dollars of value-added generated.

Figure 3 reveals two facts. First, most Eastern European countries appear as the highest polluters per thousand dollars of GDP, especially in the early years of the sample, but with remarkable differences throughout the selected period. Second, in this group of countries and in the overall sample, CO_2 emissions have declined over time relative to the value-added generated. Although most Eastern European economies are still relatively more polluting than other member countries, they are also the group with the greatest decrease in their environmental impacts.

To complete this overview on the trade and environmental structure of the EU28, a brief description of the main sectoral characteristics is presented next. To illustrate the data, the information is organized for the EU28 economies as a single group. Figure 4 left describes the most dynamic export sectors in the European Union, based on the sum of the three value-added flows defined in expressions (4), (5) and (6) to total EU28 gross exports. Figure 4 right represents CO_2 sectoral emissions to GDP ratio, as for countries in Fig. 3.

Only six of the twenty sectors accounted for at least 2% of total EU28 gross exports, of which four were manufacturing sectors and two were services. The role of financial and related services is particularly noteworthy, reflecting the progress of economic financialization. After that, transportation (freight and passenger) stood out among services. In manufacturing sectors, electrical and machinery appliances, petroleum, chemical and related products, metals production and transportation equipment sectors were prominent for their export dynamism in value-added.

Figure 4 (right panel) shows the environmental impacts associated with these sectors in terms of CO_2 emissions. As for countries in Fig. 3, the impact of all sectors decreased over the analysis period, revealing improved environmental efficiency. Manufacturing sectors generally have higher emissions rates than services sectors. From the perspective of international trade, the sectors that simultaneously maintain high export dynamism in terms of domestic value-added and a high emissions volume per dollar produced should be given special attention when designing trade and environmental policies. As a point of great relevance, the four manufacturing sectors with the highest export dynamism mentioned above were among those with the highest associated emissions rate. From here, we move on to Sect. 4.2 and an analysis of how GVC exerts a special influence on CO_2 emissions intensity.

4.2 Estimation results and discussion

This subsection presents the results of the mixed multilevel estimation (Sect. 3, Expression (8)) for 28 countries and 21 sectors, based on Eora and Eurostat data during the 1995–2015 period (Table 3). The estimation results confirm an inverted U-shaped curve for the ratio of FDI stock to GDP. Both the inward FDI stock over GDP (0.035, significant at 1%) and its square (− 2.26E-07, significant at 1%) were significant. This means that there is a critical point around 8.7E4. Countries with a FDI stock over GDP below that level tend to increase CO_2 emissions; above that level, countries tend to control CO_2 emissions. This means that countries depending more on FDI tend to adopt more flexible policies on controlling CO_2 emissions.

Other relevant findings also emerged. First, the control variable (energy consumption over GDP, ENER) behaved as expected (significant with a positive sign: 41.1892, significant at 1%). As the reviewed literature suggests, this finding corroborates the line of insight noticing that economies more energy-consuming tend to control less CO_2 emissions. Second, foreign trade variables had challenging results. Traditional trade (VAX1) got an estimated coefficient which is not significant. However, both variables linked to GVC trade got estimated coefficients which are statistically significant. The VAX2 (simple GVC) variable was found as generating an increasing relationship with respect to the ratio of emissions to GDP, while VAX3 (complex GVC) is characterized by an inverse relationship.

Table 2 Summary statistics
Source: Authors, based on Eora and Eurostat statistics

	Mean	Std. Dev	Min	Max
CO_2	1.02684	4,15674	0.00322	150.711
VAX1	0.15298	8.36384	0.11459	0.62864
VAX2	0.24348	11.5837	0.03574	0.73869
VAX3	0.06369	2.98572	0.00443	0.27065
FDI	4.54E+00	184.871	− 2.28089	16263.49
FDI^2	34195.43	2657775	6.38E-11	2.61E+08
ENER	0.017801	0.07592	− 0.000892	2.47716
EAST (dummy)	–	–	0	1
GDPpc	1071.794	1828.471	0.006361	33593.99

Missing data represented by a "0" value was not included as a minimum. Negative values for energy consumption imply a higher amount of energy produced than energy consumed by a specific sector. Number of observations: 12,348

According to our interpretation, this happens because VAX2 and VAX3 followed opposite trends throughout the analysis period, as already observed. While the former maintained a decreasing trajectory, the latter generally increased its share over gross exports among all countries considered. At the same time, CO_2 emissions as a percentage of GDP decreased over the analysis period. Therefore, we are favoring the claim that complex GVC cannot be disconnected from reduction in CO_2 emissions. These findings highlight the necessity of conducting more in-depth research into the impact of GVCs on the environment, given that the global nature of these chains enables more developed nations to sustain or even boost their material consumption levels without significant environmental consequences, as the most environmentally harmful production processes may be relocated elsewhere. At the same time, the results suggest that different types of participation in these chains can lead to different impacts.

Third, the dummy variable for Eastern European countries was significant with a positive sign (0.58757, significant at 1%), indicating that the growth patterns of these economies continued to generate increasing CO_2 emissions. An additional estimation model (Appendix 1) was applied to test up to which year this variable was significant, revealing a change in its behavior from 2003 onwards. This coincides with the adjustments undertaken by most of the Eastern European countries that joined the EU in 2004.

Finally, no significant relationship was found between GDP per capita and emissions intensity. This aligns with the estimated Rho index (interclass correlation), which suggests that belonging to a specific country is not particularly significant for detailing the volume of CO_2 emissions per unit of value-added generated. However, when considering the Rho index for the specific sectors of each country, a more significant correlation was found between belonging to a sector and carbon emissions. This relationship explains about 56% of the variance of the residuals. Therefore, in terms of policy designs, these results show that community policies must be more focused on economic sectors' specificities rather than on national policies.

The findings suggest an inverted U-shaped relationship between FDI-to-GDP ratio and emissions intensity, indicating conformity with PHH or the PH depending on the country-sector pair's position on the curve. Though this relationship was found for the EU28 countries, the estimation results indicate that the tipping point is still distant. From the entire

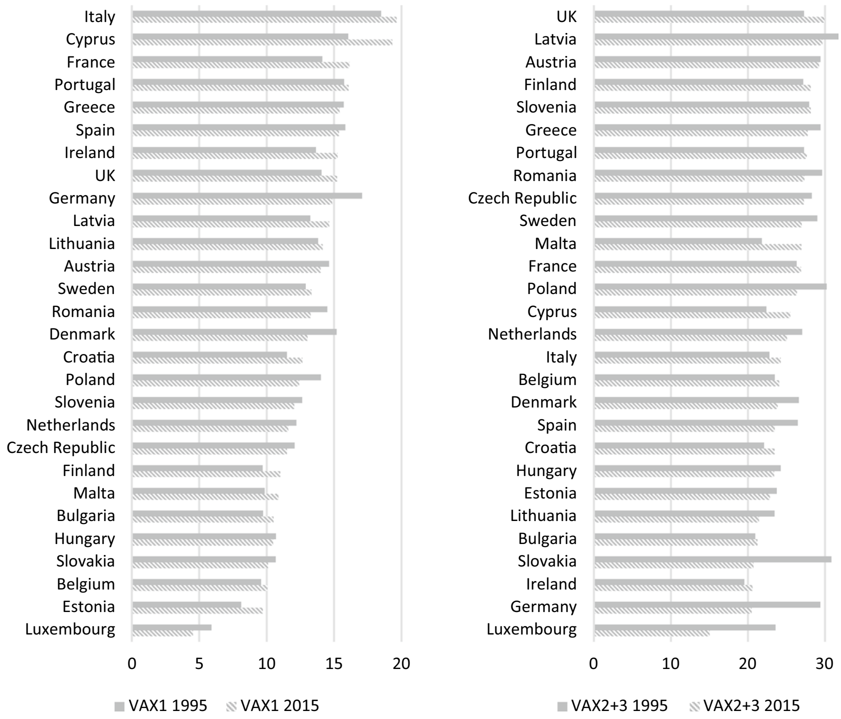

Fig. 1 Value-added flows ratio to gross exports (%), EU28 countries, 1995 and 2015. *Note*: VAX1 represents domestic value-added exports as final goods (traditional trade) and VAX2+3 represents domestic value-added exports of intermediate goods. *Source*: Authors, based on Eora statistics

sample, only one sector was located on the decreasing section of the curve in two specific years (retail trade in Sweden, 1996 and 2004). The lack of consistent values for the same sector over a prolonged period in the decreasing segment implies that the results demonstrate overall conformity with the Pollution Haven Hypothesis (PHH) in the dataset.

These results are in line with the similar findings of Balsalobre-Lorente et al. (2019) for MINT countries, indicating that higher levels of FDI end up favoring emissions reductions. They also corroborate the results of Christoforidis and Katrakilidis (2021), as discussed in the literature review. The results of Shahbaz et al., (2019a, 2019b) point in the same direction for North African countries, suggesting detrimental effects on the environment derived from low levels of FDI and a decoupling of the two variables for high investment levels.

Although these three papers included the quadratic term of FDI, many other studies have reported a positive and significant association between FDI and environmental degradation without looking for the presence of an inverted U-shaped curve. For example, Rana and Sharma (2018) found that while FDI was helping to increase growth levels in India, it was also increasing the volume of emissions generated. Other recent contributions reporting a positive relationship between FDI and emissions (to some extent or some degree of development) include those of Adeel-Farooq et al. (2021), An et al. (2021), and Zheng and Sheng (2017).

The impact of the relationship between FDI and emissions appears to vary across different cases. For instance, Shahbaz et al., (2019a, 2019b) on Vietnam did not find a significant

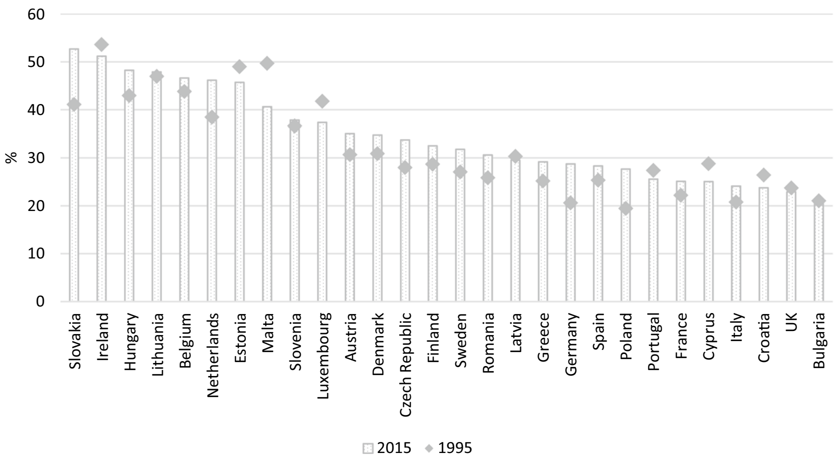

Fig. 2 Vertical specialization (VS) index, EU28 countries, 1995 and 2015. *Source*: Authors, based on Eora statistics

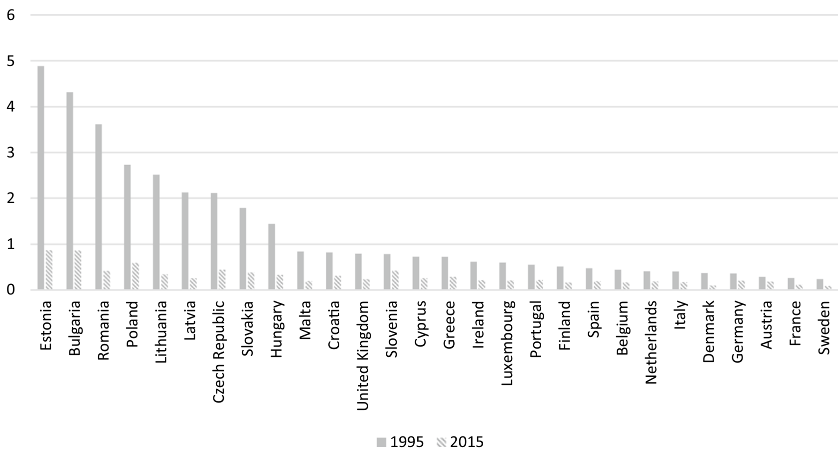

Fig. 3 Tons of CO_2 per thousand dollars of value-added. *Source*: Authors, based on Eora statistics

relationship between FDI and CO_2 emissions. Similarly, Albulescu et al. (2019), and Bulus and Koc (2021) have raised concerns about the validity of PHH in certain regions by not finding a clear relation of the impact of FDI on emissions.

From the combined results of Table 3 and Appendix 1, it can be concluded that a pollution haven was present during the first years of the analysis period in the EU based on the relocation of certain tasks to Eastern European countries. However, belonging to the group of Eastern European economies lost relevance over time as an explanatory factor for CO_2 emissions. One possible explanation for this trend is that these countries have been implementing the EU's common environmental regulations, leading to an improvement in their environmental performance. Nevertheless, when compared to other European countries,

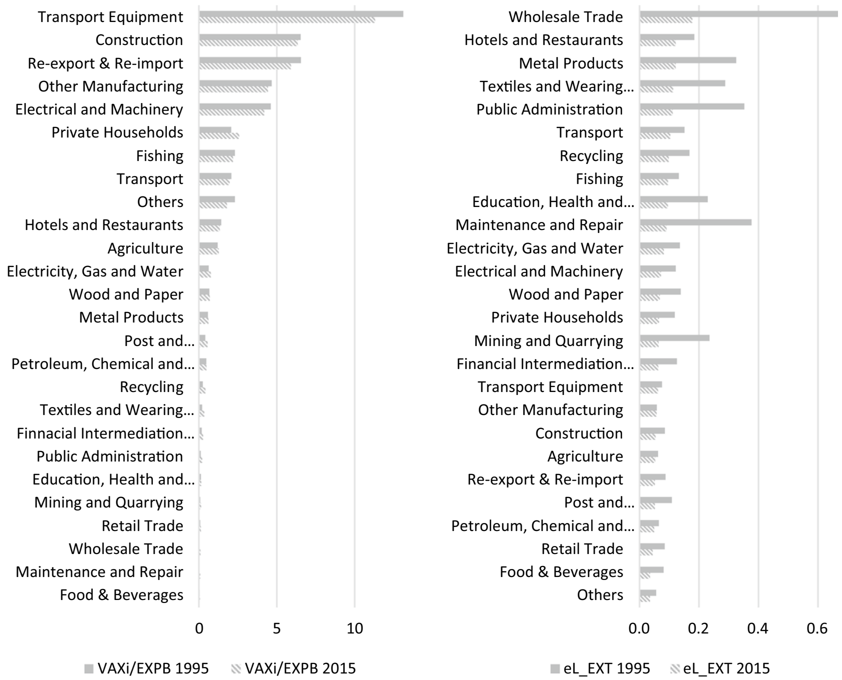

Fig. 4 Value-added exports over gross exports (%, left) and CO_2 exported to GDP emissions (tons of CO_2 per thousand dollars, right) for the EU28 exports, 1995 and 2015. *Note*: The "Electricity, Gas, and Water" category was omitted because its relatively high emissions to GDP ratio in 1995 hindered visualization of the other sectors. See sector list in Appendix 2. *Source*: Authors, based on Eora statistics.

they still exhibit relatively high levels of pollution, as discussed in subSect. 4.1. The auxiliary estimate in Table 4 corroborates the results in Table 3 in support of PHH, especially for the early years of the sampling period.

We recognize these findings as particularly challenging insights into the integration process. If these patterns tend to exist in the early phases of integration, we can track additional stimuli to better understand how this evidence is justified. Are entrant countries more interested in exhibiting impressive growth rates than respecting environmental constraints? Or are these countries more permissive about deregulation practices that can jeopardize transparency and equality across sectors and territorial communities? We consider these questions relevant as topics for further research and in designing policies to restrict potentially pernicious socio-economic patterns.

5 Conclusions

The original purpose of this paper was to investigate the potential existence of a pollution haven in the EU, with a particular focus on Eastern European countries that were integrated during the analysis period. Specifically, this study aimed to test the hypothesis that trade liberalization and foreign capital flows may have shifted the most environmentally

Table 3 Estimation results. Dependent variable: CO_2 emissions to GDP (tons per thousand dollars) *Source*: Authors, based on Eora and Eurostat statistics

Variable	Coefficient	Standard error	Z	
VAX1	0.0001938	0.003957	[0.05]	
VAX2	0.037804	0.004861	[7.78]*	
VAX3	− 0.14596	0.018101	[− 8.06]*	
FDI	0.0035	0.000381	[9.19]*	
FDI^2	− 2.26E−07	2.52E−08	[− 8.96]*	
ENER	41.1892	0.321765	[128.01]*	
EAST	0.58757	0.1554806	[3.78]*	
GDPpc	− 6.24E−07	0.00002	[− 0.03]	
β_0	.06193	0.142521	[0.49]	
Random effects parameters	Estimate	Standard error	95% confidence interval	
Country	2.5E−09	0.000000513	6.90E−184	9.00E + 165
Sector	3.151834	0.1935846	2.794363	3.555035
var(residual)	2.434569	0.0318051	2.373024	2.497711
RHO (sector|country)	56.42%	N. sectors (per country)	21	
LR test, prob > chi	0	Years	1995–2015	
N. countries	28			

*Indicates significance at 1%

damaging production tasks from more developed countries to the recently integrated and less developed economies, potentially turning Eastern Europe into a source of polluting production inputs for the European value chain.

By achieving these goals, this research contributes to the literature on pollution havens by analyzing the case of the European market from the perspective of GVCs. The study identifies a pollution haven within the EU and provides empirical evidence that the integration of Eastern European countries has led to an increase in polluting activities in these territories, which act as suppliers of some environmental damaging production inputs to the European value chain. These findings provide important insights into the complex relationship between trade liberalization, GVCs, and environmental sustainability in the EU and further expand the literature on PHH.

The novelty of this work is twofold. Firstly, it involves the compilation and examination of a comprehensive database comprising 28 countries and 21 sectors across the period of 1995–2015, tested in three dimensions including country, sectoral, and temporal. This made it possible to perform a mixed multilevel estimation in which sectors were nested within countries. Second, by integrating value-added trade flows into the estimation model, we tried to capture the influence of GVCs on carbon emissions. Furthermore, the inclusion of the quadratic term of the foreign direct investment (FDI) to gross domestic product (GDP) ratio allows for the detection of an inverted U-shaped curve. The incorporation of this feature enables the simultaneous estimation of pollution haven hypothesis (PHH) and pollution haven (PH), making this work a valuable contribution to the literature. The empirical analysis revealed divergent trends in value-added flows, with most countries reducing their share of gross exports in GVC trade while some increased their share of traditional trade. When looking at intra-European trade, intensified internal trade flows were observed. The share of foreign value-added in exports also increased in some European countries. In terms of environmental impacts, the analysis found a decrease in the ratio of carbon emissions to GDP over time at both national and sectoral levels. However, Eastern European economies generally had higher emission levels, and some manufacturing sectors showed the greatest impact. As stated before, an inverted “U” shaped curve was found for the EU. An assessment of the tipping point reveals that it has not yet been reached, so that further increases in FDI would lead to higher levels of emissions which asks for proper policies. The results indicate that Eastern European countries have significantly higher emissions volume compared to other members of the Union. However, an additional estimation to check the chronological relevance of this condition suggests that belonging to Eastern Europe was not particularly significant after 2003, just before most of these countries joined the EU in 2004.

The impact of value-added trade flows on carbon emissions showed mixed results. Traditional trade volume did not have any relationship with carbon emissions. The impact of GVC participation on the environment varies depending on the specific type of chain involved. Simple value chain trade flows (VAX2) are characterized by greater participation from European countries, while complex value chain flows (VAX3) involve more extensive flows and greater participation from foreign countries. While an increase in these flows could lead to a reduction in environmental impacts in European territory, it may not necessarily imply the same globally. Adopting a consumption perspective to deduce environmental responsibilities reveals that greater participation in complex GVCs could actually increase environmental damage. This is because more developed European countries increase their consumption levels without necessarily increasing their emissions, thanks to the production configuration of complex GVCs.

As environmental concerns continue to rise, and there is a growing need to reduce material consumption, particularly in regions like the EU that heavily rely on external resources, several policy recommendations can be proposed. Firstly, as proposed by Awan, Gölgeci, et al. (2022a) and Awan, Sroufe, et al. (2022b), it would be highly beneficial to apply the principles of circular economy policies to GVCs from both macroeconomic and business management perspectives. From a producer’s standpoint, integrating circular economy principles involves enhancing product reparability conditions and warranty periods, as well as promoting product redesign to optimize material recovery. In some cases, it may also be advantageous to reformulate business models away from conventional individual consumption patterns towards shared-use models. From a consumption perspective, European policies are significant as they can provide incentives for importing products that meet circularity and sustainability standards. These measures can be implemented both within the European domestic market and in its agreements with third countries.

To conclude, this research leads to recommend the analysis of three additional areas of investigation. Firstly, we propose expanding the database to include the major trading partners of European nations. This would allow for a more comprehensive analysis of the European chain observed in this study. Secondly, we recommend exploring alternative metrics for CO_2 emissions, specifically economic evaluations. This approach will provide a more nuanced understanding of the complex relationships between value-added trade and CO_2 emissions. Thirdly, we suggest investigating the relationship between GVCs and circular economy, including the challenges of integrating both concepts and the potential of implementing circularity policies under GVCs. We propose adopting a dual perspective of consumption and production when considering the environmental effects of foreign trade.

Appendix 1

See Table 4.

Table 4 Additional estimation model. Dummy significance over time *Source*: Authors, based on Eora and Eurostat statistics

	VAX1	*VAX2*	*VAX3*	*FDI*	*FDI*^{2}	*ENER*	*GDPpc*	β_0
Coefficient	– 0.004321	0.013372	– 0.04671	0.00348	– 2.25E-07	40.4318	0.0000106	0.14904
Z value	[– 1.07]	[2.18]**	[– 2.02]**	[9.17]*	[– 8.96]*	[123.03]*	[0.48]	[0.98]

Dummy significance over time	Coefficient	Z value	Dummy significance over time	Coefficient	Z value	RHO (sector|country)	56.25%
1995	1.3807	[6.9]*	2006	0.2144	[1.05]	LR test, prob > chi^2	0
1996	1.0895	[5.44]*	2007	0.3304	[1.61]	N. countries	28
1997	1.1496	[5.74]*	2008	0.35665	[1.74]	N. sectors (per country)	21
1998	0.6867	[3.43]*	2009	0.30155	[1.46]	Years	1995–2015
1999	0.7988	[3.98]*	2010	0.32841	[1.61]		
2000	0.5149	[2.55]*	2011	0.31999	[1.56]		
2001	0.7044	[3.5]*	2012	0.22111	[1.08]		
2002	0.4288	[2.13]**	2013	0.21024	[1.03]		
2003	0.5289	[2.63]*	2014	0.19760	[0.97]		
2004	0.2885	[1.43]	2015	0.22931	[1.12]		
2005	0.3298	[1.63]					

*Indicates significance at 1%

**Indicates significance at 5%

Appendix 2

See Tables 5 and 6.

Table 5 List of sectors *Source*: Authors, based on Eora statistics

Agriculture, forestry, and fishing	Construction
Mining and quarrying	Maintenance and repair
Food & beverages	Wholesale trade
Textiles and wearing apparel	Retail trade
Wood and paper	Hotels and restaurants
Petroleum, chemical and non-metallic mineral products	Transport
Metal products	Post and telecommunications
Electrical and machinery	Financial intermediation and business activities
Transport equipment	Public administration
Other manufacturing	Education, health and other services
Electricity, gas and water	

Table 6 List of variables *Source*: Authors

Variable	Description	Source
CO_2	CO_2 intensity obtained as the ratio of CO_2 emissions to GDP	Own elaboration based on Eora
VAX1	Exports of final goods as a share of gross exports	
VAX2	Value added exported as an intermediate good consumed as a final good in the importing country as a share of gross exports	
VAX3	Value added exported as an intermediate good and re-exported by the importing country as a percentage of gross exports	
FDI	Stock of foreign direct investment inflows as a share of GDP	Eurostat (FDI) and Eora (GDP)
FDI^2	Square of the previous item	
ENER	Energy intensity obtained as the ratio of energy consumption to GDP	Own elaboration based on Eora
EAST	Dummy variable that identifies Eastern European countries with a "1"	–
GDPpc	GDP per capita	Eora (GDP) and World Bank (Population)

All variables have been obtained for all European countries and the sectors detailed in Table 5

Acknowledgements The authors would like to express their gratitude to the editor and the anonymous reviewers for their valuable comments, which have greatly contributed to enhance the quality of this research.

Author contributions HC-R: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing—Original Draft, Project administration. PRM: Methodology, Software, Validation, Formal analysis, Resources, Writing—Review & Editing, Supervision. ÓR-M: Conceptualization, Validation, Resources, Writing—Review & Editing, Visualization, Supervision.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This research has been supported by the ICEDE research group, Galician Competitive Research Group ED431C 2022/15 financed by Xunta de Galicia; and by the National Funds of the FCT—Portuguese Foundation for Science and Technology within the project «UIDB/03182/2020».

References

Adeel-Farooq, R. M., Riaz, M. F., & Ali, T. (2021). Improving the environment begins at home: Revisiting the links between FDI and environment. *Energy, 215*, 119150. https://doi.org/10.1016/j.energy.2020.119150

Albulescu, C. T., Tiwari, A. K., Yoon, S.-M., & Kang, S. H. (2019). FDI, income, and environmental pollution in Latin America: Replication and extension using panel quantiles regression analysis. *Energy Economics, 84*, 104504. https://doi.org/10.1016/j.eneco.2019.104504

An, H., Razzaq, A., Haseeb, M., & Mihardjo, L. W. W. (2021). The role of technology innovation and people's connectivity in testing environmental Kuznets curve and pollution heaven hypotheses across the Belt and Road host countries: New evidence from Method of Moments Quantile Regression. *Environmental Science and Pollution Research, 28*(5), 5254–5270. https://doi.org/10.1007/s11356-020-10775-3

Arndt, S. W., & Kierzkowski, H. (2001). *Fragmentation: New production patterns in the world economy*. Oxford University Press.

Awan, U., Gölgeci, I., Makhmadshoev, D., & Mishra, N. (2022a). Industry 4.0 and circular economy in an era of global value chains: What have we learned and what is still to be explored? *Journal of Cleaner Production, 371*, 133621. https://doi.org/10.1016/j.jclepro.2022.133621

Awan, U., Sroufe, R., & Bozan, K. (2022b). Designing value chains for Industry 4.0 and a circular economy: A review of the literature. *Sustainability, 14*(12), 7084. https://doi.org/10.3390/su14127084

Azhar, A. K. M., & Elliott, D. R. J. R. (2007). Trade and specialisation in pollution intensive industries: North–South evidence. *International Economic Journal, 21*(3), 361–380. https://doi.org/10.1080/10168730701529926

Balsalobre-Lorente, D., Gokmenoglu, K. K., Taspinar, N., & Cantos-Cantos, J. M. (2019). An approach to the pollution haven and pollution halo hypotheses in MINT countries. *Environmental Science and Pollution Research, 26*(22), 23010–23026. https://doi.org/10.1007/s11356-019-05446-x

Balsalobre-Lorente, D., Ibáñez-Luzón, L., Usman, M., & Shahbaz, M. (2022). The environmental Kuznets curve, based on the economic complexity, and the pollution haven hypothesis in PIIGS countries. *Renewable Energy, 185*, 1441–1455. https://doi.org/10.1016/j.renene.2021.10.059

Birdsall, N., & Wheeler, D. (1993). Trade policy and industrial pollution in Latin America: Where are the pollution havens? *The Journal of Environment & Development, 2*(1), 137–149. https://doi.org/10.1177/107049659300200107

Bommer, R. (1995). Environmental policy and industrial competitiveness: The pollution-haven hypothesis reconsidered. *Review of International Economics, 7*(2), 342–355. https://doi.org/10.1111/1467-9396.00168

Borin, A., Mancini, M., & Taglioni, D. (2021). *Countries and Sectors in Global Value Chains* [Working Paper]. World Bank. Doi: https://doi.org/10.1596/1813-9450-9785

Bulus, G. C., & Koc, S. (2021). The effects of FDI and government expenditures on environmental pollution in Korea: The pollution haven hypothesis revisited. *Environmental Science and Pollution Research, 28*(28), 38238–38253. https://doi.org/10.1007/s11356-021-13462-z

Casella, B., Bolwijn, R., Moran, D. D., & Kanemoto, K. (2019). *Improving the Analysis of Global Value Chains: The UNCTAD-Eora Database* (SSRN Scholarly Paper ID 3624082). Social Science Research Network. https://papers.ssrn.com/abstract=3624082

Christoforidis, T., & Katrakilidis, C. (2021). Does foreign direct investment matter for environmental degradation? Empirical evidence from central-eastern European countries. *Journal of the Knowledge Economy*. https://doi.org/10.1007/s13132-021-00820-y

Copeland, B. R., & Taylor, M. S. (1994). North–South trade and the environment. *The Quarterly Journal of Economics, 109*(3), 755–787. https://doi.org/10.2307/2118421

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature, 42*(1), 7–71. https://doi.org/10.1257/002205104773558047

Destek, M. A., & Okumus, I. (2019). Does pollution haven hypothesis hold in newly industrialized countries? Evidence from ecological footprint. *Environmental Science and Pollution Research, 26*(23), 23689–23695. https://doi.org/10.1007/s11356-019-05614-z

Duan, Y., Ji, T., & Yu, T. (2021). Reassessing pollution haven effect in global value chains. *Journal of Cleaner Production, 284*, 124705. https://doi.org/10.1016/j.jclepro.2020.124705

Duarte, R., & Serrano, A. (2021). Environmental analysis of structural and technological change in a context of trade expansion: Lessons from the EU enlargement. *Energy Policy, 150*, 112142. https://doi.org/10.1016/j.enpol.2021.112142

Eskeland, G. S., & Harrison, A. E. (2003). *Moving to greener pastures: Multinationals and the pollution-haven hypothesis* (Policy, Research working paper N.º WPS1744; Policy, Research working paper). World Bank. http://documents.worldbank.org/curated/en/913101468757211604/Moving-to-greener-pastures-multinationals-and-the-pollution-haven-hypothesis

Feenstra, R. C. (1998). Integration of trade and disintegration of production in the global economy. *Journal of Economic Perspectives, 12*(4), 31–50.

Ge, Y., Hu, Y., & Ren, S. (2020). Environmental regulation and foreign direct investment: Evidence from China's eleventh and twelfth five-year plans. *Sustainability, 12*(6), 2528. https://doi.org/10.3390/su12062528

Gereffi, G. (2005). The global economy: Organization, governance, and development. *The Handbook of Economic Sociology, 2*, 160–182.

Gereffi, G. (2014). Global value chains in a post-Washington Consensus world. *Review of International Political Economy, 21*(1), 9–37. https://doi.org/10.1080/09692290.2012.756414

Gill, F. L., Viswanathan, K. K., & Karim, M. Z. A. (2018). The critical review of the pollution haven hypothesis (PHH). *International Journal of Energy Economics and Policy, 8*(1), 167–174.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353–377. https://doi.org/10.2307/2118443

Guzel, A. E., & Okumus, İ. (2020). Revisiting the pollution haven hypothesis in ASEAN-5 countries: New insights from panel data analysis. *Environmental Science and Pollution Research, 27*(15), 18157–18167. https://doi.org/10.1007/s11356-020-08317-y

Harrison, A. (1994). The role of multinationals in economic development: The benefits of FDI. *The Columbia Journal of World Business, 29*(4), 6–11. https://doi.org/10.1016/0022-5428(94)90028-0

Ho, S.-Y., & Iyke, B. N. (2019). Trade openness and carbon emissions: Evidence from central and eastern European countries. *Review of Economics, 70*(1), 41–67. https://doi.org/10.1515/roe-2018-0001

Hoffmann, R., Lee, C.-G., Ramasamy, B., & Yeung, M. (2005). FDI and pollution: A granger causality test using panel data. *Journal of International Development, 17*(3), 311–317. https://doi.org/10.1002/jid.1196

Hummels, D., Ishii, J., & Yi, K.-M. (2001). The nature and growth of vertical specialization in world trade. *Journal of International Economics, 54*(1), 75–96. https://doi.org/10.1016/S0022-1996(00)00093-3

Humphrey, J., & Schmitz, H. (2001). Governance in global value chains. *IDS Bulletin, 32*(3), 19–29. https://doi.org/10.1111/j.1759-5436.2001.mp32003003.x

Kersan-Škabić, I. (2019). The drivers of global value chain (GVC) participation in EU member states. *Economic Research-Ekonomska Istraživanja, 32*(1), 1204–1218. https://doi.org/10.1080/1331677X.2019.1629978

Koopman, R., Wang, Z., & Wei, S.-J. (2014). Tracing value-added and double counting in gross exports. *The American Economic Review, 104*(2), 459–494.

Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012). Mapping the structure of the world economy. *Environmental Science & Technology, 46*(15), 8374–8381. https://doi.org/10.1021/es300171x

Lenzen, M., Moran, D., Kanemoto, K., & Geschke, A. (2013). Building eora: A global multi-region input-output database at high country and sector resolution. *Economic Systems Research, 25*(1), 20–49. https://doi.org/10.1080/09535314.2013.769938

Leontief, W., & Strout, A. (1963). Multiregional input–output analysis. In En T. Barna (Ed.), *Structural Interdependence and Economic Development: Proceedings of an International Conference on Input-Output Techniques, Geneva, September 1961* (pp. 119–150). Palgrave Macmillan UK. Doi: https://doi.org/10.1007/978-1-349-81634-7_8

Leontief, W. W. (1937). Interrelation of prices, output, savings, and investment. *The Review of Economics and Statistics, 19*(3), 109–132. https://doi.org/10.2307/1927343

Leontief, W. (1951). *The structure of the american economy, 1919–1939: An empirical application of equilibrium analysis*. Oxford University Press.

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

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

Martínez-Zarzoso, I., Vidovic, M., & Voicu, A. M. (2017). Are the central east European countries pollution havens? *The Journal of Environment & Development, 26*(1), 25–50. https://doi.org/10.1177/1070496516670196

Porter, M. E. (1990). Competitive advantage of nations. *Competitive Intelligence Review, 1*(1), 14–14. https://doi.org/10.1002/cir.3880010112

Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *The Journal of Economic Perspectives, 9*(4), 97–118.

Rana, R., & Sharma, M. (2018). Dynamic causality testing for EKC hypothesis, pollution haven hypothesis and international trade in India. *The Journal of International Trade & Economic Development, 28*(3), 348–364. https://doi.org/10.1080/09638199.2018.1542451

Shahbaz, M., Balsalobre-Lorente, D., & Sinha, A. (2019a). Foreign direct Investment–CO_2 emissions nexus in Middle East and North African countries: Importance of biomass energy consumption. *Journal of Cleaner Production, 217*, 603–614. https://doi.org/10.1016/j.jclepro.2019.01.282

Shahbaz, M., Haouas, I., & Hoang, T. H. V. (2019b). Economic growth and environmental degradation in Vietnam: Is the environmental Kuznets curve a complete picture? *Emerging Markets Review, 38*, 197–218. https://doi.org/10.1016/j.ememar.2018.12.006

Shao, Q., Wang, X., Zhou, Q., & Balogh, L. (2019). Pollution haven hypothesis revisited: A comparison of the BRICS and MINT countries based on VECM approach. *Journal of Cleaner Production, 227*, 724–738. https://doi.org/10.1016/j.jclepro.2019.04.206

Shen, J., Wang, S., Liu, W., & Chu, J. (2019). Does migration of pollution-intensive industries impact environmental efficiency? Evidence supporting "Pollution Haven Hypothesis." *Journal of Environmental Management, 242*, 142–152. https://doi.org/10.1016/j.jenvman.2019.04.072

Singhania, M., & Saini, N. (2021). Demystifying pollution haven hypothesis: Role of FDI. *Journal of Business Research, 123*, 516–528. https://doi.org/10.1016/j.jbusres.2020.10.007

Sustainable Development Solutions Network, & Institute for European Environmental Policy. (2021). *Europe Sustainable Development Report 2021*. Sustainable Development Solutions Network. https://www.sdgindex.org/reports/europe-sustainable-development-report-2021/

Tsagkari, M., Gaona, A., Gonzalez, J.-F., & Järvinen, J. (2018). The evolution of carbon dioxide emissions embodied in international trade in Poland: An input-output approach. *Environmental Socio-Economic Studies, 6*(3), 36–43. https://doi.org/10.2478/environ-2018-0021

van Leeuwen, G., & Mohnen, P. (2017). Revisiting the porter hypothesis: An empirical analysis of green innovation for the Netherlands. *Economics of Innovation and New Technology, 26*(1–2), 63–77. https://doi.org/10.1080/10438599.2016.1202521

Verbeke, G., & Molenberghs, G. (2000). *Linear mixed models for longitudinal data*. Springer-Verlag. https://doi.org/10.1007/978-1-4419-0300-6

Vonesh, E., & Chinchilli, V. M. (1997). *Linear and Nonlinear Models for the Analysis of Repeated Measurements*. CRC Press. https://doi.org/10.1201/9781482293272

Wang, J., Wan, G., & Wang, C. (2019a). Participation in GVCs and CO_2 emissions. *Energy Economics, 84*, 104561. https://doi.org/10.1016/j.eneco.2019.104561

Wang, Z., Wei, S.-J., Yu, X., & Zhu, K. (2017). Measures of participation in global value chains and global business cycles (N.o w23222). *National Bureau of Economic Research*. https://doi.org/10.3386/w23222

Wang, X., Zhang, C., & Zhang, Z. (2019b). Pollution haven or porter? The impact of environmental regulation on location choices of pollution-intensive firms in China. *Journal of Environmental Management, 248*, 109248. https://doi.org/10.1016/j.jenvman.2019.07.019

Wang, H., Pan, C., Ang, B. W., & Zhou, P. (2021). Does global value chain participation decouple Chinese development from CO_2 emissions? A structural decomposition analysis. *The Energy Journal*, *42*(2). https://doi.org/10.5547/01956574.42.2.hwan

Yang, H.-Y. (2001). Trade liberalization and pollution: A general equilibrium analysis of carbon dioxide emissions in Taiwan. *Economic Modelling, 18*(3), 435–454. https://doi.org/10.1016/S0264-9993(00)00048-1

Yang, J., Guo, H., Liu, B., Shi, R., Zhang, B., & Ye, W. (2018). Environmental regulation and the pollution haven hypothesis: Do environmental regulation measures matter? *Journal of Cleaner Production, 202*, 993–1000. https://doi.org/10.1016/j.jclepro.2018.08.144

Zhang, Z., Zhu, K., & Hewings, G. J. D. (2017). A multi-regional input–output analysis of the pollution haven hypothesis from the perspective of global production fragmentation. *Energy Economics, 64*, 13–23. https://doi.org/10.1016/j.eneco.2017.03.007

Zheng, D., & Shi, M. (2017). Multiple environmental policies and pollution haven hypothesis: Evidence from China's polluting industries. *Journal of Cleaner Production, 141*, 295–304. https://doi.org/10.1016/j.jclepro.2016.09.091

Zheng, J., & Sheng, P. (2017). The Impact of foreign direct investment (FDI) on the environment: Market perspectives and evidence from China. *Economies, 5*(1), 8. https://doi.org/10.3390/economies5010008