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The differential impact of export and import trade on carbon dioxide emissions: A comparative analysis between African and European countries

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ABSTRACT

This study examines the effects of export and import trade on carbon dioxide (CO2) emissions in 49 African and 37 European countries from 2005-2021 using World Development Indicators (WDI). Export and import trade has a differential effect on CO2 emissions in both Africa and Europe, though African countries generally have lower emissions than European countries with an increasing trend. Trade is crucial in both regions, but the environmental impact remains uncertain. The study emphasized the two-step system generalized method of moments (GMM) and a quadratic function. The results indicate that: 1) Export trade increases CO2 emissions in both regions in the short and long term. 2) Import trade reduces CO2 emissions in Africa in the short and long-term, but has no significant negative long-term impact in Europe except in the short run. 3) There was no evidence of an environmental Kuznets curve (EKC) but a U-shaped relationship between trade and CO2. 4) Early development witnesses the *halo effect*, which transitions to the *pollution haven hypothesis* after a turning point in both regions. The study recommends that both regions should adopt environmentally friendly trade policies that should aim at reducing CO2 in the export trade nexus.

Contribution/ Originality: The study compares import and export trade impacts on CO2 emissions. It also tests the validity of the Pollution Haven and Pollution Halo Hypotheses, determines trade threshold points affecting CO2 emissions, and examines the validity of the Kuznets Curve Hypothesis between trade and CO2 emissions in both regions.

1. INTRODUCTION

International trade is an essential and unavoidable activity for any nation, as it enables countries to access and consume goods for which they have a comparative disadvantage in production. However, cross-border trade can have an environmental impact if not properly regulated. Many countries have implemented environmental policies at trade borders to prevent the exchange of high-emission goods. This helps mitigate the environmental damage of international trade, promoting a more sustainable global economy (Thuy & Nguyen, 2022). Liu, Anwar, Irmak, and Pelit (2022) revealed that rising CO2 emissions from trade have consequences like reduced food production, biodiversity loss, and increased mortality rates. Hence, reducing emissions from the exportation and importation of goods is a global concern for environmental sustainability and climate change (Duodu & Mpuure, 2023).

Both the African and European continents actively participate in the global trade ecosystem, engaging in a diverse array of export and import activities. However, the nature of their trade relationships often exhibits asymmetric dynamics. African countries tend to export a greater proportion of primary products, such as raw materials and agricultural goods, to their European counterparts. In contrast, European nations predominantly export manufactured and value-added products to the African market. To address this disparity and improve livelihoods, African nations have sought to establish diverse global trade relationships, diversifying export markets and reducing reliance on limited primary product exports (African Development Bank, 2022). Woolfrey and Karkare (2021) conducted a study which revealed a decline in the share of primary goods in African exports to the EU from 75% in 2008 to 65% in 2018. Over the same period, the share of manufactured goods in these exports increased from 23% to 31%. This gradual transition reflects African nations' efforts to diversify their export portfolios and move up the value chain, leveraging growing industrial and manufacturing capabilities to compete globally.

Trade has driven global greenhouse gas emissions, with African exports increasing by 200% since 1990, leading to a 61% rise in CO2 emissions. Thus, in terms of carbon dioxide equivalent, exports have fallen from 8.52 kilograms per US dollar in 1990 to 4.61kg per US dollar in 2017 (Keane, Mendez-Parra, Pettinotti, & Sommer, 2021). However, this increased volume of export trade has also presented the challenge of ensuring environmental sustainability (Saka, 2018).

Generally, African countries are considered relatively low emitters (Duodu & Mpuure, 2023). Africa's cumulative CO2 emissions from 1884 to 2021 were around 49.13 billion metric tons, accounting for over 1.73% of global emissions. These emissions primarily stem from fossil fuel combustion and cement production (Kamer, 2022a). In 2020, African countries were responsible for less than 3% of cumulative global CO2 emissions. The top African emitters are South Africa, Egypt, Algeria, Nigeria, and Libya, with South Africa being the highest at 436 million metric tons in 2021, followed by Egypt at 250 million metric tons (Doris, 2023).

In contrast, in 2022, the EU produced 2.73 billion metric tons of CO2 emissions, down from 2.74 and 2.57 billion tons in 2021 and 2020, respectively (Saifaddin, 2022). Germany is the main CO2 emitter in the EU due to its heavy reliance on coal, which emits almost 50% more CO2 than natural gas (Ian, 2023). Other significant emitters include Italy, France, and Poland. In 2021, Africa's CO2 emissions from fossil fuels and industry were 3.55, accounting for 3.9% of global emissions, while Europe's were 21.16, accounting for 7.3% (Kamer, 2022b; Tiseo, 2023).

Despite the fact that EU emits more CO2 emissions than African countries, African countries are highly vulnerable to climate change effects like rising temperatures, droughts, and floods (Andriamahery, Danarson, & Qamruzzaman, 2022; Espoir & Sunge, 2021). This is due to Africa's economic reliance on climate-sensitive activities and its low adaptive capacity compared to other regions (African Climate Policy Centre, 2013).

With the rise in CO2 emissions, both regions are initiating and implementing different trade policies to combat CO2 emissions. In 2019, the EU launched the European Green Deal, aiming to make Europe climate-neutral by 2050. Also, in 2021, they adopted a Climate Law, setting a target of reducing net greenhouse gas emissions by at least 55% by 2030 (European Commission, 2023; European Commission, 2019). It has further taken laudable action to align its trade and investment policies with its climate agenda, particularly in Africa, by introducing legislation like the Carbon Border Adjustment Mechanism (CBAM) and the reform of the European Emissions Trading System (ETS). To protect the supply of important industrial materials (Buckley, 2023) the EU has also made faster progress on the Net-Zero, Industry Act (NZIA) and the Critical Raw Material Act (CRMA). These laws aim to stop deforestation and improve due diligence in value chains.

Similarly, Africa faces environmental challenges like land degradation, deforestation, and biodiversity loss. However, African nations are taking steps to implement restoration projects. These initiatives benefit the environment and nearby communities. For instance, the implementation of reforestation and agroforestry programs contributes to carbon sequestration, flood prevention, biodiversity enhancement, and energy supply for the rural poor.

They also improve land use and watershed management, supporting sustainable living and conservation (Favretto, Dougill, Stringer, Afionis, & Quinn, 2018). Also, the African Union's Agenda 2063 prioritizes sustainable development and climate-resilient economies (African Union, 2015).

The relationship between trade and CO2 emissions is an important research topic. The study by Duodu and Mpuure (2023) though currently retracted as of April 2024, examined trade's impact on emissions in Sub-Saharan Africa. This study aims to compare the effects of export and import trade on CO2 emissions in African and European countries. Specifically, it seeks to:1. Test the Pollution Haven and Pollution Halo hypotheses in the context of trade and emissions. 2. Determine the threshold points at which export and import trade begin to impact CO2 emissions. 3. Examine the validity of the Kuznets Curve hypothesis. 4. Ascertain the monotonic relationship between trade and CO2 emissions. By addressing these objectives, this study aims to provide a more comprehensive understanding of the complex interplay between trade and carbon dioxide emissions, both in Africa and in Europe. The findings will supplement the existing body of research, such as the studies by Adams and Opoku (2020); Mignamissi, Tebeng, and Tchinda (2024) and Saka (2018) for Africa, as well as Ho and Njindan (2019); Mutascu and Sokic (2020) and Nwaeze et al. (2023) for Europe.

2. THEORETICAL AND EMPIRICAL LITERATURE

The traditional theory that has been widely used to establish the nexus between trade and CO2 emissions is the pollution haven hypothesis (PHH) (Adams & Opoku, 2020; Duodu & Mpuure, 2023). This theory posits that countries with lax environmental regulations may attract pollution-intensive industries as companies seek to minimize the costs associated with compliance. This is particularly true in developing economies with weak environmental policies who experience an influx of dirty industries leading to increased CO2 emissions and environmental degradation (Yakubu & Musah, 2022). Past empirical investigations have validated the PHH (Acheampong, Adams, & Boateng, 2019; Asongu & Odhiambo, 2021; Duodu, Kwarteng, Oteng-Abayie, & Frimpong, 2021; Duodu & Mpuure, 2023; Yakubu & Musah, 2022).

Studies on the relationship between trade and environmental pollution have yielded mixed results. This is due to the complexities involved, including differences in research methods, variables, and timeframes across case studies (Ewane & Ewane, 2023). However, many studies found trade reduces emissions, highlighting its potential for sustainability (Appiah, Worae, Yeboah, & Yeboah, 2022; Dauda et al., 2021; Karedla, Mishra, & Patel, 2021; Khan, Weili, & Khan, 2022; Zhang et al., 2017). On the other hand, other authors found an increasing effect of trade on CO2 emissions (Chhabra, Giri, & Kumar, 2023; Ertugrul, Cetin, Seker, & Dogan, 2016; Ewane & Ewane, 2023; Sajeev & Kaur, 2020), while others have contradictory results (Keho, 2016; Mignamissi et al., 2024; Sun, Clottey, Geng, Fang, & Amissah, 2019; Wang & Zhang, 2021).

On an increasing impact, Saka (2018) examined the effect of external trade on CO2 emissions in Africa across income groups. Using an augmented STIRPATN model to measure the ecological elasticity of variables, the results show that a 1% increase in net trade led to significant emission rises, more pronounced in low-income (1.68%) and lower-middle-income (2.45%) countries than upper-income (1.01%) countries. Similarly, Adams and Opoku (2020) examine the effect of trade from 1995–2014 in 22 sub-Saharan African countries. The GMM results revealed that trade has a positive impact on CO2 emissions, underscoring the need for policymakers to consider the environmental implications of trade policies in the region. Dauda et al. (2021) revealed that increased trade activity can indeed exacerbate environmental pollution in Sub-Saharan Africa, validating the Pollution Haven Hypothesis (PHH). This finding is further corroborated by the work of Hdom and Fuinhas (2020), who uncovered a direct correlation between trade volume and carbon dioxide emissions in Brazil. Their study demonstrated that as the Brazilian economy engages in greater trade, it becomes more polluted. Studies by Chhabra et al. (2023) on BRICS (Brazil, Russian, Indian, China, and South Africa) nations and Mutascu and Sokic (2020) on Europe found that trade openness increases carbon dioxide emissions in both the short and long run. Andrews et al. (2020) using the mean group (MG) and augmented mean group (AMG) methods also had a similar result in EU-18 countries. These findings collectively highlight the environmental implications of expanding trade activities, emphasizing the need for sustainable trade practices to minimize adverse environmental impact.

Other studies have found that international trade can have a reducing impact on carbon dioxide (CO2) emissions. Asongu and Odhiambo (2021) examined 49 sub-Saharan African (SSA) countries from 2000 to 2018 and discovered increased trade leads to decreased CO2 emissions. Sun et al. (2020) also found that trade has reducing effect on CO2 emissions in 18 SSA countries, identifying evidence of an environmental Kuznets curve. Karedla et al. (2021) determined that trade openness has a negative effect on CO2 emissions in India over 45 years. Similarly, Tawiah, Zakari, and Khan (2021) found that foreign direct investment and imports have a negative effect on CO2 emissions in 50 African countries, while exports have a detrimental impact. Ali, Law, and Zannah (2016) also found that trade openness reduced CO2 emissions in Nigeria from 1971 to 2011 using the ARDL approach, while Iheonu, Anyanwu, Odo, and Nathaniel (2021) in a study of 34 SSA countries revealed that external trade enhances environmental pollution. Okelele, Lokina, and Ruhinduka (2022) concluded that increasing trade openness in SSA improves environmental pollution by reducing the ecological footprint. Duodu and Mpuure (2023), on the other hand, found that total trade reduces pollution by 0.10% and 0.79% in the short and long run, respectively, in 33 sub-Saharan African countries from 1990 to 2020. Sohag, Al Mamun, Uddin, and Ahmed (2017) using 82 developing nations from 1980 to 2012, revealed that CO2 is reduced by 0.3 for each percentage increase in trade.

Ho and Njindan (2019) analyzed 17 Central and Eastern European countries from 1994 to 2004 and found that trade openness reduces CO2 emissions in the long run up to a certain level beyond which high trade openness may worsen emission. They also found evidence of the Environmental Kuznets Curve (EKC) hypothesis. Nwaeze et al. (2023) similarly reported that trade openness negatively affects CO2 emissions in a panel of 12 European tourist countries from 1995 to 2018. Leitão (2021) investigation of the effect of trade on carbon dioxide emissions in some European countries from 1995 to 2015 using various econometric methods such as fully modified ordinary least square (FMOLS), dynamic ordinary least square (DOLS), and two-stage least square regression (TSLS), revealed that increased external trade could improve environmental quality by mitigating climate change. Likewise, Leitão, Koengkan, and Fuinhas (2022) also looked at the impact of intra-industry trade (IIT) on Portuguese carbon dioxide (CO2) emissions. Using an ARDL framework, they found a negative relationship between IIT and Portuguese CO2 emissions. Carlos and Lorente (2020) established a relationship between economic growth, renewable energy, tourism arrivals, trade openness, and carbon dioxide emissions in the European Union (EU-28). Using different methods of investigation such as FMOLS, DOLS, and GMM-System estimator, their empirical findings showed that trade openness and renewable energy reduce climate change and improve environmental degradation. Similarly, Shpak, Ohinok, Kulyniak, Sroka, and Androniceanu (2022) examined the effect of macroeconomic indicators, including exports, imports, and GDP (gross domestic product) on CO2 emissions in the EU from 1970 to 2020. Using least squares regression, their findings confirmed that exports, imports, and GDP are negatively related to CO2 emissions. This is consistent with the findings of Hu and Xu (2022) research, which indicates that China's expansion of its export trade has improved energy and emissions efficiency, suggesting that global trade dynamics can play a role in enhancing environmental sustainability.

The research findings presented by Fanelli and Ortis (2020); Valodka, Snieska, and Ramírez (2020) and Lim, Hong, Yoon, Chang, and Cheong (2021) also collectively paint a promising picture of the EU's progress in addressing its environmental impact. Fanelli and Ortis (2020) study revealed that the decrease in domestic emissions can be attributed to the replacement of local products with imported goods. Valodka et al. (2020) found that the outsourcing of clothing production has led to the offshoring of CO2 emissions, while the study by Lim et al. (2021) highlights the promising growth of low-carbon industries within the EU, which is expected to reduce the region's reliance on energy imports.

Some authors have found a heterogeneous conclusion between trade and environmental pollution. Mignamissi et al. (2024) employed a two-stage least squares (2STLS) approach to uncover the varying impacts of trade openness on CO2 emissions in different parts of Africa. Their analysis revealed that increased trade openness led to higher CO2 emissions in North Africa, South Africa, and West Africa, while the opposite effect was observed in East and Central Africa. This suggests that the factors such as economic structure, energy mix, and environmental policies may influence the relationship between trade and environmental pollution, which is not uniform across the African continent. Similarly, the study by Asongu and Odhiambo (2021) examined the relationship between trade openness, foreign direct investment (FDI), and CO2 emissions in a sample of 49 sub-Saharan African (SSA) countries. Their findings indicate that as trade openness increased, CO2 emissions also rose proportionately, while they reduced proportionately to FDI increases. The researchers also found evidence of a Kuznets curve, which implies that the relationship between trade openness and CO2 emissions is not linear and may exhibit a U-shaped pattern. These research findings highlight the importance of considering regional and contextual factors when examining the complex interplay between economic activities such as trade and environmental outcomes. Ewane and Ewane (2023) found that trade openness and foreign direct investment (FDI) can have varying effects, reducing CO2 emissions in the short run but increasing them in the long run in sub-Saharan Africa from 1975 to 2020. They also found a U-shaped relationship between trade openness and CO2. Luo, Qu, and Hu (2022) examined the effect of trade on environmental pollution in 30 Chinese provinces from 2002 to 2019 and found that trade expansion can be favorable to China's environmental position through market incentive-based restrictions. However, they also noted that export trade can negatively impact the environment through technological advancements and changes in energy infrastructure.

Similarly, Alfred and Haug (2019) found rising imports increased emissions in Turkey, but rising exports reduced emissions. Dauda et al. (2021) showed trade openness increased emissions in some African countries (e.g., South Africa and Mozambique) but decreased it in others (e.g., Algeria and Kenya). Furthermore, Sun, Tariq, Haris, and Mohsin (2019) using FMOLS and VECM examined the effect of trade openness on CO2 emissions in the Belt and Road regions from 1991 to 2014. They observed negative impacts of trade openness on emissions in Southeast Asia and Europe but positive impacts in Southeast Asia, Central Asia, the Middle East/Africa, and South Asia. However, some studies found no significant relationship between trade and CO2 emissions (Adebayo, Awosusi, Kirikkaleli, Akinsola, & Mwamba, 2021; Yameogo, Omojolaibi, & Dauda, 2021; Zerbo, 2017).

3. METHODOLOGY

3.1. Data and Variables Definitions

The study uses World Bank unbalance panel data from 2005-2021 for 49 African and 37 European countries. The time period and country selection were determined by data availability and the study's objectives. Carbon dioxide emissions in metric tons were used to measure environmental pollution as in previous empirical research (Duodu et al., 2021; Duodu & Mpuure, 2023; Ewane & Ewane, 2023; Zheng, Wang, Mak, Hsu, & Tsang, 2021) while exports and imports defined in percentage of GDP are the main explanatory variables. Foreign direct investment (FDI), renewable energy consumption (REC) as a percentage of total final energy consumption, and economic growth (GDP) as measured in dollars are control variables. FDI is measured by net inflows (share of GDP), economic growth by GDP, and REC by share of total final energy consumption. For previous studies that utilized these variables in their analyses, see (Acheampong et al., 2019; Duodu et al., 2021; Duodu & Mpuure, 2023; Ewane & Ewane, 2023).

Tables 1 and 2 summarize the variables and correlations. Africa's average CO2 emissions are 1.49 metric tons, while Europe's are 7.11, indicating higher emissions in Europe. Africa's mean values for export, import, FDI, GDP, and REC are 29.7, 36.7, 4.4, 23.4, and 60.7, respectively, compared to Europe's 59.0, 58.9, 18.6, 25.3, and 19.8. The correlation matrices show no exact serial correlation among the variables in both regions.

Table 1. Descriptive statistics and correlation matrix for African countries.

Variables	Obs.	Mean	Std. dev.	Min.	Max.	
CO_2	735	1.143	1.99	0.021	10.4	
X	754	29.692	16.16	0.46	89.224	
M	754	36.719	14.707	0.297	87.466	
FDI	811	4.362	7.954	-18.9	103	
logGDP	816	23.375	1.565	18.757	27.069	
REC	728	60.727	30.302	0.06	97.42	
Correlation matrix						
Variables	CO_2	X	M	FDI	GDP	REC
CO_2	1.000					
X	0.500	1.000				
M	0.042	0.489	1.000			
FDI	-0.075	0.176	0.436	1.000		
logGDP	0.387	0.094	-0.287	0.056	1.000	
REC	-0.689	-0.465	-0.241	0.075	-0.306	1.000

Table 2. Descriptive statistics and correlation matrix for European countries.

Variables	Obs.	Mean	Std. dev.	Min.	Max.	
CO_2	1080	7.589	4.589	0.466	31.272	
X	1288	49.111	29.625	5.166	211.433	
M	1288	50.198	25.763	8.223	176.687	
FDI	1257	12.1848	86.931	-1303.13	1282.63	
logGDP	1378	25.048	2.008	20.030	29.09	
REC	1070	16.280	14.725	0	62.37	
Correlation matrix						
Variables	CO_2	X	M	FDI	GDP	REC
CO_2	1.000					
X	0.374	1.000				
M	0.145	0.936	1.000			
FDI	-0.030	0.299	0.355	1.000		
logGDP	0.140	-0.283	-0.489	-0.199	1.000	
REC	-0.373	-0.310	-0.260	0.161	-0.227	1.000

4. PRELIMINARY PANEL DATA TEST

4.1. Cross Sectional Dependence Test

When working with panel data, preliminary tests like cross-sectional dependence, stationarity, and cointegration are essential. Panel data can be affected by cross-sectional dependence, leading to biased results if an unobserved factor is present (Pesaran, 2007). The Pesaran cross-sectional dependence (CD) test is a crucial step in panel data analysis to ensure the validity and reliability of the findings (Duodu & Mpuure, 2023). This study used the Pesaran (2015) CD test to account for cross-sectional correlation. The test statistic is defined below:

$$CD=\sqrt{\frac{2H}{M(M-1)}}\left[\sum_{j=i+1}^{M-1}\sum_{j=i+1}^{M} Tij\right];\ CD\sim M\,(0,1)$$

Where Tij denotes cross-sectional dependence between countries i and j, M is the cross-sectional unit and H is the time dimension (Duodu & Mpuure, 2023). Table 3 reveals that the model is suffering from cross-sectional correlation as the null hypothesis is rejected.

Table 3. Cross sectional dependence (CD) test and slope heterogeneity test.

Variables	CD test	p-values	CD test	P-value
	SSA		Europe	
Co2	34.845	0.000	33.318	0.000
Export	8.387	0.000	42.425	0.000
Import	6.628	0.000	40.723	0.000
GDP	77.537	0.000	53.083	0.000
FDI	1.909	0.056	13.843	0.000
REC	35.044	0.000	56.954	0.000
Slope heterogeneity test	Test	p-value	Test	p-value
Model	-1.494	0.035	-2.143	0.032

4.2. Unit Root Test

Ascertaining stationarity is primordial to avoid spurious regression (Gujarati, 2004). The existence of cross-sectional dependence test in Table 3 makes the second-generation unit root test suitable for the study as it accommodates CD data. Since the first-generation unit root tests assume there is no CD among cross-sectional units, it becomes invalid in this case (Duodu & Mpuure, 2023). Hence, the study utilized the Pesaran (2007), cross-sectional augmented IPS (CIPS), which is a second-generation panel unit root test, and Pesaran (2003) cross-sectional augmented Dickey-Fuller (CADF) test. PESCADF module runs the t-test for unit roots in heterogenous panels with cross-section dependence. Equation 1 presents the CADF statistic.

$$\Delta\gamma_{it}=\partial_i+\emptyset_i y_{it-1}+\varphi_i\bar{\gamma}_{t-1}+\sum_{j=0}^{t}\beta_{ij}\,\Delta\bar{\gamma}_{t-1}+\sum_{j=1}^{t}y_{ij}\Delta\bar{\gamma}_{t-1}+\varepsilon_{it}\quad(1)$$

Where $\bar{\gamma}$ is the lagged levels cross − sectional dependent variables averages *and* $\Delta\bar{\gamma}$ *is the* first difference in cross-sectional dependent variable averages. The CIPS test statistic can be derived from Equation 1 as follows;

$$\text{CIPS}=\frac{1}{M}\sum_{i=1}^{M}CADF_i$$

Where $\mathrm{CADF_i}$ is the t-statistic obtained from Equation 1.

From Table 4, both regions exhibit a mixed order of integration. That is at levels and first difference stationarity. Due to gaps in the sample, this study did not utilize the CIPS method.

Table 4. Second generation unit root test.

PESCADF unit root test				
Region	**Variable**	**Statistic at levels**	**Statistics at first difference**	**Decision**
Europe	Co2	-2.224***	----	I(0)
	X	0.633	-2.980***	I(1)
	M	-0.164	-3.978***	I(1)
	FDI	-2.171	---	I(0)
	GDP	1.407	-3.929***	I(1)
	REC	-1.403	-2.281***	I(1)
Africa	Co2	-1.247	-2.577***	I(1)
	X	-2.743	----	I(0)
	M	-1.304	-6.576***	I(1)
	FDI	-2.659***	----	I(0)
	GDP	-3.833***	----	I(0)
	REC	-1.403	----	I(0)
5% CV= -2.110				

Note: *** indicates a 1% level of significance. CO_2= Carbon dioxide, X=Export, M=Import, X=Export, M=Imports, FDI=Foreign direct investment, REC=Renewable energy consumption, GDP=Economic growth.

5. ESTIMATION TECHNIQUE

This study will rest on two estimation techniques; the system GMM and quadratic modeling. The study uses Blundell and Bond (1998) GMM system to examine the differential effect of export and import trade on CO2 emissions. The rationale for using this approach is that it corrects for endogeneity when more instruments are introduced to improve efficiency. It also builds a system of two equations and uses orthogonal deviation by minimizing data loss. In addition, the system GMM is suitable for panel samples on N>T, particularly for large N and small T, which is applicable in this study. The instrument validity test of Hansen (1982) and the second-order serial correlations of Arellano-Bond test were utilized to check for consistency of the estimates to make sure there is instrument validity and absence of second-order serial correlation. To examine the long run effect of export and import on environmental pollution, the long-run coefficients are obtained from the shor-run parameters following the study of Duodu and Mpuure (2023) and applying the delta method of Papke and Wooldridge (2005). The mathematical computation of Papke and Wooldridge (2005) long-run coefficient is given in Equation 2.

$$\beta_k \div [1\text{-}\phi] \qquad (2)$$

ϕ =is the parameter of the lag dependent variables and β_k are the long run parameters obtained from short run estimates.

The choice between difference and system GMM was ascertained using the Bond (2002) rule of thumb, which states if after running the difference GMM estimator and the coefficients are lower than the fixed effect (FE) estimates or very close to the FE estimates, it suggests that the difference GMM estimates are downward biased because of weak instrumentation. Hence, the system GMM should be the ideal estimator. The pooled OLS estimate for φ (the parameter to be estimated) is considered an upper bound estimate, and fixed effect estimates are lower bound estimates. Therefore, Table 5 indicates a downward bias in the GMM estimate, leading to preference for the system GMM. The two-step system GMM is also particularly suitable as it controls for heteroscedasticity and serial correlation.

Additionally, since our interest is also to find out the turning points and test the validity of the polo hypothesis, pollution heaven hypothesis, and Kutznet curve hypothesis, we employ a quadratic function, which also allows us to determine the monotonic relationship between the variables (Adeleye, Akam, Inuwa, James, & Basila, 2023).

Table 5. Choice between system and difference GMM.

Estimators	Coefficient Africa	Coefficient Europe
Pooled OLS	0.959	0.959
Fixed effect model	0.851	0.792
One step system GMM	0.106	1.003
Two step system GMM	0.063	1.009
One step different GMM	-0.001	0.018
Two step different GMM	0.006	-0.027

6. EMPIRICAL SPECIFICATION

Empirically, the system GMM of Blundell and Bond (1998) is specified as follows;

$$Iny_{it} = \varphi Iny_{it-1} + \beta \times'_{it} + \beta z'_{it} + \delta_t + \varepsilon_{it} \qquad (3)$$

Where; X is the control variables and Z is the explanatory variables, δ_t are the year's dummies, *and* ε_{it} is the error term. Hence, the *Iny* is a function of its lag, a function of a set of control variables, explanatory variables, and year's dummies.

With regards to quadratic function, adopting the empirical model of Duodu and Mpuure (2023) which has a time frame of 30 years in 33 SSA countries, this study collapsed the model by specifying environmental pollution to be a function of export, import, FDI, REC, and GDP. The model is expressed in Equation 4:

$$EP_{it} = \varphi_0 + \varphi_1 EP_{it-1} + \varphi_2 X_{it-1} + \varphi_3 M_{it-1} + \varphi_4 FDI_{it-1} + \varphi_5 REC_{it-1} + \varphi_6 logGDP_{it-1} + \delta_t + \varepsilon_{it} \qquad (4)$$

Where; EP= environmental pollution, X=export, M=import, FDI=foreign direct investment, REC=renewable energy consumption, and GDP=economic growth. The $\varphi_0, \ldots, \varphi_6$ are individual variable parameters to be estimated while δ_t and ε_{it} are defined the same as in Equation 1.

To establish the turning point, we incorporate the research of Adeleye et al. (2023). We have specified a model where carbon dioxide emission is expressed as a linear function of independent and control variables.

$$C02_{it} = \varphi_0 + \varphi_1 X_{it} + \varphi_2 FDI_{it} + \varphi_3 REC_{it} + \varphi_4 logGDP_{it} + \mu \qquad (5)$$

$$C02_{it} = \varphi_0 + \varphi_1 M_{it} + \varphi_2 FDI_{it} + \varphi_3 REC_{it} + \varphi_4 logGDP_{it} + \mu \qquad (6)$$

The square term of export and import trade are included in Equation 5 and 6 to find evidence of export trade-EKC and import trade-EKC as shown below.

$$C02_{it} = \varphi_0 + \varphi_1 X_{it} + \varphi_2 (X_t)^2 + \varphi_3 FDI_{it} + \varphi_4 REC_{it} + \varphi_5 logGDP_{it} + \mu \qquad (7)$$

$$C02_{it} = \varphi_0 + \varphi_1 M_{it} + \varphi_2 (M_t)^2 + \varphi_3 FDI_{it} + \varphi_4 REC_{it} + \varphi_5 logGDP_{it} + \mu \qquad (8)$$

Where $\varphi_1, \varphi_1, \varphi_3, \varphi_4$ are the parameters to be estimated while μ is the error term. The different relationships that can be tested are listed below;

$\varphi_1 < 0$, $\varphi_2 > 0$, the relationship is a U-shaped.

$\varphi_1 > 0$, $\varphi_2 < 0$, indicates inverse U-shaped relationship.

$\varphi_1 > 0$, $\varphi_2 > 0$, indicates monotonically increasing linear relationship.

$\varphi_1 < 0$, $\varphi_2 < 0$ indicates monotonically decreasing linear relationship.

$\varphi_1 = 0$, $\varphi_2 = 0$, indicates level relationship.

However, the process of identifying the turning point involves outcome $\varphi_1 < 0$, $\varphi_2 > 0$ which can be obtained by taking the first derivatives of Equation 7 and 8 and setting the equation to zero as follows;

$$\frac{\partial C02}{\partial X} = \varphi_1 + (\varphi_2 * 2)X = 0$$

$$\varphi_1 = -(\varphi_2 * 2)X \rightarrow X^* = -o.5\frac{\varphi_1}{\varphi_2}$$

$$\frac{\partial C02}{\partial M} = \varphi_1 + (\varphi_2 * 2)M = 0$$

$$\varphi_1 = -(\varphi_2 * 2)M \rightarrow M^* = -o.5\frac{\varphi_1}{\varphi_2}$$

Where X^* *and* M^* represents the threshold of export trade and import trade respectively. The export trade or import trade turning point of this curve is computed as follows;

$$\hat{\tau} = (0.5\, {}^{\hat{\varphi}_1}/_{\hat{\varphi}_2}) \qquad (9)$$

To ascertain the comparative analysis of the differential impact of export and import trade on environmental pollution, Equations 4, 7, and 8 are estimated for both African and European countries. The GMM long run coefficients will be generated from the significance of the short-run coefficient.

Table 6. The two-step system GMM estimates.

Africa		**Europe**	
Variables	**Coefficient**	**Variables**	**Coefficient**
Shortrun estimates			
L.co2	0.719*** (0.028)	L.co2	0.901*** (0.101)
X	0.0149*** (0.001)	X	0.046** (0.024)
M	-0.016*** (0.002)	M	-0.065** (0.029)
FDI	0.003 (0.003)	FDI	0.002* (0.001)
logGDP	-0.181* (0.038)	logGDP	-0.518** (0.213)
REC	-0.009	REC	-0.021

Africa		**Europe**	
Variables	**Coefficient**	**Variables**	**Coefficient**
	(0.002)		(0.014)
Constant	10.80 (7.967)	Constant	-26.19*** (27.63)
Years dummies	Yes	Years dummies	yes
Long-run estimates			
X	0.053*** (0.004)	X	0.464 *** (0.272)
M	-0.055*** (0.006)	M	-0.662 (0.447)
logGDP	-0.645*** (0.189)	FDI	0.021 (0.022)
		logGDP	-5.239 4.824
No of observations	622	No of observations	950
Number of groups	46	Number of groups	35
Number of instrument	19	Number of instrument	34
AR(2)	0.122	AR(2)	0.302
Sergan p-value	0.638	Sergan p-value	0.547
Hansen p-value	0.264	Hansen p-value	0.311

Note: *** indicates 1% level of significance, ** 5% level of significance, and * 1% level of significance.

The findings presented in Table 6 demonstrate a significant positive impact that previous CO2 emissions have on current emissions in both African (0.719) and European (0.901) countries. This emphasizes the critical need for these regions to implement stringent environmental policies and measures to effectively reduce their carbon footprints. These results are consistent with past empirical investigations (Duodu & Mpuure, 2023; Ewane & Ewane, 2023). The analysis also reveals that export trade has an increasing effect on CO2 emissions in both Africa (0. 015) and Europe (0. 046). Specifically, a 1 percent change in export trade leads to a 1.5 percent increase in CO2 emissions in Africa and a 4.6 percent increase in Europe in the short run at 1 and 5 percent significance levels, respectively. The long-term impact is even more substantial, with exports contributing to a 5.3 percent increase in CO2 emissions in Africa and a staggering 46.4 percent increase in Europe, both at a 1 percent significance level. This implies that these regions' exports basket favor products with high carbon emission intensities. Several factors influence the carbon intensity of African exports, such as energy-intensive oil extraction and mining operations, which generate significant greenhouse gas emissions. Also, large-scale livestock farming, deforestation, and intensive agriculture produce substantial amounts of carbon dioxide. In addition, many African countries heavily depend on fossil fuels for electricity, adding to the overall carbon intensity (De Melo & Solleder, 2023).

This is also similar to European export products, as shipping export products across long distances generates CO2 emissions, especially when using transportation like ships, trucks, or planes that run on fossil fuels. Walker et al. (2019) revealed that ships are accountable for more than 18% of nitrogen oxide pollution. Manufacturing industries, including petroleum refining, steel production, and cement making, are the second largest CO2 contributors in the EU (Panagiotopoulou, Stavropoulos, & Chryssolouris, 2022). The EU's 2023 reports showed that energy-intensive industries contributed up to 22% of total greenhouse gas emissions in 2019 (European Commission, 2023). This conflicts with the EU's goals of reducing net emissions by 55% by 2030 and achieving net zero by 2050. In the case of Africa, the conclusion supports the findings of De Melo and Solleder (2023) who found that the export basket of Africa is skewed towards high CO2 intensity products, while in Europe the result is true with that of Mutascu and Sokic (2020) who revealed that in both the short and long run, trade openness increases CO2 emissions.

Imports (goods produced in other countries) were found to have a significant negative effect on CO2 emissions in Africa (-0.016) in the short run at a 1 percent significance level. Specifically, a 1 percent change in African countries' importation of goods reduces CO2 emissions by 0.2 percent at the 1% significance level. The reducing effect is greater in the long run (0.055). Hence, exports and imports have a heterogeneous impact on the environment in Africa.

Importing European goods can help reduce Africa's CO2 emissions. Trade can drive sustainable development by adopting cleaner technologies, energy-efficient practices, and sustainable supply chains. The findings are consistent with the research conducted by Tawiah et al. (2021) which revealed that imports can have a negative impact on CO2 emissions across 50 African countries.

In Europe, imports were found to be negative and significant to environmental pollution in the short run only by 6.5%. However, it had a negative (-0.662) but insignificant impact in the long run. The findings are consistent with those of Leitão (2021) and Nwaeze et al. (2023) who both concluded that trade negatively affects CO2 in the EU.

EU countries are promoting environmentally friendly products from Africa and other parts of the world, driven by a commitment to sustainability and economic development. The EU has initiatives to promote sustainable practices in goods imported from Africa and other regions. Its trade agreements with African countries, such as the Economic Partnership Agreements (EPAs) and the African, Caribbean, and Pacific Group of States (ACP), often include provisions related to sustainable development, environmental protection, and social standards. These agreements aim to encourage responsible production and trade practices, including environmental sustainability. The EU also has regulations like the EU Timber Regulation (EUTR) and Conflict Minerals Regulation to address environmental and social issues in imported goods. These regulations target illegal logging, responsible mineral sourcing, and meeting environmental and social standards. Compliance with these regulations helps advance sustainability in supply chains and trade relations with African countries, which reduces overall CO2.

Concerning control variables, only GDP was found to have a significant negative impact on CO2 in Africa in the short run, but in Europe, GDP contributes to reducing CO2, while FDI positively increases CO in the short run. However, in the long run, the reducing impact of GDP (0.645) is greater in African countries, which indicates that economic growth policies are environmentally friendly. In essence, African countries promote green economic growth. The findings are consistent with those of Duodu et al. (2021) who revealed that economic growth promotes environmental pollution.

AR (2) p-values in both Africa (0.586) and Europe (0.553) are insignificant, indicating that there is no second-order serial correlation and the moment conditions are correctly specified in both models. Therefore, we cannot reject the null hypothesis. The Hansen test in Africa (0.261) and Europe (0.249) also indicates there is instrument validity in both regions.

Furthermore, the results of the Sargan tests indicate the correct specification of the models and the validity of the instruments. The slope heterogeneity test of Pesaran and Yamagata (2008) for both models reported in Table 3 revealed that the model does not suffer from slope heterogeneity bias using territorial-based CO2 emissions at the 5% significance level.

The linear result of export trade in Africa and Europe negatively affects environmental degradation (see Appendices 1 and 3). Furthermore, their square term is positive and significant, indicating a U-shaped relationship exists. The turning point of export trade in Africa occurs at 26.82 (see Appendix 4) while that of Europe occurs at 19.59 (see Appendix 2). This implies that both Africa and Europe witness a decrease in CO2 at an early stage of production, but once a threshold point is attained, the effect on the environment escalates. This indicates that at 26.82% and 19.59% turnaround points, carbon emissions start to increase. Hence, the early development stage supports the *halo effect hypothesis*, while the *pollution haven hypothesis* sets in after the turning point.

Similarly, both the linear and square terms of import in Africa and Europe are negative and positive, respectively. According to Appendices 2 and 4, the turning points for the countries are 47.78% and 56.48%. This indicates that after these thresholds, the negative impact of imports on the environment starts to increase. The positive rise in environmental degradation in Africa after the turning point is due to the relocation of high-polluting firms from developed countries with strict environmental regulations to developing countries with lax regulations (Chang, Dong, Sui, & Chu, 2019; Doytch & Uctum, 2016). These findings are consistent with Ewane and Ewane (2023) who in quadratic modelling framework found a U-shape relationship between trade openness and CO2 emission in SSA. The environmental pressure of export and import trade in Africa is conventional because they are non-high-income countries with increased pollution.

Europe may experience a temporary decrease in CO2 emissions from export and import trade before a turning point due to various environmental initiatives and investments such as cleaner technologies, renewable energy sources, efficient transportation networks, and sustainable production methods. However, the post-turning point period could see an increase in emissions driven by factors such as economic growth, globalization, demand from partners with increasing CO2 emissions, and shifts in policy priorities (Steinhauser, Kittová, & Khúlová, 2024). They also revealed that EU exports and imports have a growing similarity with partner countries whose CO2 emissions are rising.

7. CONCLUSION AND RECOMMENDATION

This comprehensive study has provided valuable insights into the complex relationship between international trade and environmental pollution across two distinct regions-Africa and Europe. The researchers have employed robust econometric techniques, including the two-step system GMM and quadratic function, to rigorously analyzed unbalanced panel data spanning 49 African countries and 37 European countries over the period of 2005 to 2021. The analysis reveals that export trade has a positive impact on carbon emissions in both Africa and Europe, indicating that the expansion of export-oriented activities may contribute to increased environmental degradation in the short and long run. Conversely, the study found that import trade has a decreasing effect on CO2 emissions in Africa both in the short and long term. This suggests that the importation of goods and services may lead to cleaner production processes and more environmentally friendly technologies. Also, the European region exhibited a negative effect of import trade on CO2 emissions in the short run, though this impact became negative and insignificant in the long run. The conclusions warrant the following recommendations:

Both countries should adopt stringent environmental policies to effectively counter the deteriorating impact of export trade on the environment. This proactive approach can involve implementing robust environmental assessment mechanisms such as life cycle assessment (LCA) and material flow analysis (MFA), which can provide valuable insights into the detrimental aspects of export trade activities. By thoroughly examining the environmental implications throughout the entire product life cycle, policymakers can make informed decisions to mitigate the negative environmental impacts. Furthermore, the adoption of renewable energy technologies such as solar fuels and biofuels by local firms in African countries for the fabrication of export goods and services can significantly contribute to ensuring environmental sustainability. This shift towards cleaner and more sustainable production methods can help minimize the carbon footprint associated with export-oriented industries. Additionally, both regions should consider implementing a comprehensive CO2 emission reduction strategy that specifically targets the production of export and import goods. This could include promoting green technologies through measures such as removing tariffs on environmentally friendly products. By incentivizing the use of green technologies, both countries can make meaningful strides towards environmental sustainability in their trade activities.

List of Abbreviations:

CO2	Carbon dioxide
X	Export
M	Import
FDI	Foreign Direct Investment
REC	Renewable Energy Consumption
GDP	Gross Domestic Product

GMM	Generalized Method of Moments
PHH	Pollution Haven Hypothesis
SSA	Sub Saharan Africa
EKC	Environmental Kuznets Curve
CADF	*Cross-sectional Augmented Dickey-Fuller*
EU	European Union
LCA	life Cycle Assessment (LCA)
MFA	Material Flow Analysis
WDI	World Development Indicators

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REFERENCES

Acheampong, A. O., Adams, S., & Boateng, E. (2019). Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? *Science of the Total Environment*, *677*, 436-446. https://doi.org/10.1016/j.scitotenv.2019.04.353

Adams, S., & Opoku, E. E. O. (2020). Trade and environmental pollution in Africa: Accounting for consumption and territorial-based emissions. *Environmental Science and Pollution Research*, *27*, 44230-44239. https://doi.org/10.1007/s11356-020-10328-8

Adebayo, T. S., Awosusi, A. A., Kirikkaleli, D., Akinsola, G. D., & Mwamba, M. N. (2021). Can CO2 emissions and energy consumption determine the economic performance of South Korea? A time series analysis. *Environmental Science and Pollution Research*, *28*(29), 38969-38984. https://doi.org/10.1007/s11356-021-13498-1

Adeleye, B. N., Akam, D., Inuwa, N., James, H. T., & Basila, D. (2023). Does globalization and energy usage influence carbon emissions in South Asia? An empirical revisit of the debate. *Environmental Science and Pollution Research*, *30*(13), 36190-36207. https://doi.org/10.1007/s11356-022-24457-9

African Climate Policy Centre. (2013). *Vulnerability to climate change in Africa: Challenges and recommendations for Africa. ClimDev-Africa*. Retrieved from http://www.climdev-africa.org

African Development Bank. (2022). *African development bank group bank group ' S strategy for addressing fragility and building resilience in Africa (2022-2026)*. Retrieved from https://www.afdb.org/sites/default/files/2023/04/27/en-afdb-fragility-strategy_1.pdf

African Union. (2015). *Agenda 2063. The African we want.* Addis Abba, Ethiopia: Air University, 1-174.

Alfred, A., & Haug, M. U. (2019). The role of trade and FDI for CO2 emissions in Turkey: Nonlinear relationships. *Energy Economics*, *81*, 297–307. https://doi.org/https://doi.org/10.1016/j.eneco.2019.04.006

Ali, H. S., Law, S. H., & Zannah, T. I. (2016). Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO 2 emissions in Nigeria. *Environmental Science and Pollution Research*, *23*, 12435-12443. https://doi.org/10.1007/s11356-016-6437-3

Andrews, K. T., Long, X., Lamini, D., Claudia, N. M., Florence, A.-T., & Isaac, A. M. (2020). The influence of trade openness on environmental pollution in EU-18 countries. *Environmental Science and Pollution Research*, *27*(6), 35535–35555. https://doi.org/https://doi.org/10.1007/s11356-020-09718-9

Andriamahery, A., Danarson, J. H., & Qamruzzaman, M. (2022). Nexus between trade and environmental quality in Sub-Saharan Africa: Evidence from panel GMM. *Frontiers in Environmental Science, 10*, 986429. https://doi.org/10.3389/fenvs.2022.986429

Appiah, K., Worae, T. A., Yeboah, B., & Yeboah, M. (2022). The causal nexus between trade openness and environmental pollution in selected emerging economies. *Ecological Indicators*, *138*, 108872. https://doi.org/10.1016/j.ecolind.2022.108872

Asongu, S., & Odhiambo, N. M. (2021). Trade and FDI thresholds of CO2 emissions for a Green economy in Sub-Saharan Africa. *International Journal of Energy Sector Management*, *15*(1), 227-245. https://doi.org/10.1108/ijesm-06-2020-0006

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115-143. https://doi.org/10.1016/s0304-4076(98)00009-8

Bond, S. R. (2002). Dynamic panel data models: A guide to micro data methods and practice. *Portuguese Economic Journal*, *1*, 141-162. https://doi.org/10.1007/s10258-002-0009-9

Buckley, T. (2023). EU ' s new net zero industry & critical raw materials acts dramatically escalate pressure on Australia to seize once-in-a-century cleantech opportunity. *Climate Energy Finance*, *3*(9), 1–4.

Carlos, N., & Lorente, D. B. (2020). The linkage between economic growth, renewable energy, tourism, CO2 emissions, and international trade: The evidence for the European Union. *Energies*, *13*(18), 4838.

Chang, C.-P., Dong, M., Sui, B., & Chu, Y. (2019). Driving forces of global carbon emissions: From time-and spatial-dynamic perspectives. *Economic Modelling*, *77*, 70-80. https://doi.org/10.1016/j.econmod.2019.01.021

Chhabra, M., Giri, A. K., & Kumar, A. (2023). Do trade openness and institutional quality contribute to carbon emission reduction? Evidence from BRICS countries. *Environmental Science and Pollution Research*, *30*(17), 50986-51002. https://doi.org/10.1007/s11356-023-25789-w

Dauda, L., Long, X., Mensah, C. N., Salman, M., Boamah, K. B., Ampon-Wireko, S., & Dogbe, C. S. K. (2021). Innovation, trade openness and CO2 emissions in selected countries in Africa. *Journal of Cleaner Production*, *281*, 125143. https://doi.org/10.1016/j.jclepro.2020.125143

De Melo, J., & Solleder, J. M. (2023). The landscape of CO2 emissions across Africa: A comparative perspective. *The World Economy*, *46*(11), 3392-3418. https://doi.org/10.1111/twec.13498

Doris, D. S. (2023). *Production-based carbon dioxide (CO2) emissions in Africa in 2021, by country (in metric tons)/ Statista*. Retrieved from https://www.statista.com/statistics/1268395/production-based-co2-emissions-in-africa-by-country/

Doytch, N., & Uctum, M. (2016). Globalization and the environmental impact of sectoral FDI. *Economic Systems*, *40*(4), 582-594. https://doi.org/10.1016/j.ecosys.2016.02.005

Duodu, E., Kwarteng, E., Oteng-Abayie, E. F., & Frimpong, P. B. (2021). Foreign direct investments and environmental quality in Sub-Saharan Africa: The merits of policy and institutions for environmental sustainability. *Environmental Science and Pollution Research*, *28*, 66101-66120. https://doi.org/10.1007/s11356-021-15288-1

Duodu, E., & Mpuure, D. M.-N. (2023). RETRACTED ARTICLE: International trade and environmental pollution in Sub-Saharan Africa: Do exports and imports matter? *Environmental Science and Pollution Research*, *30*(18), 53204-53220. https://doi.org/10.1007/s11356-023-26086-2

Ertugrul, H. M., Cetin, M., Seker, F., & Dogan, E. (2016). The impact of trade openness on global carbon dioxide emissions: Evidence from the top ten emitters among developing countries. *Ecological Indicators, 67*, 543-555. https://doi.org/10.1016/j.ecolind.2016.03.027

Espoir, D. K., & Sunge, R. (2021). Co2 emissions and economic development in Africa: Evidence from a dynamic spatial panel model. *Journal of Environmental Management*, *300*, 113617. https://doi.org/10.1016/j.jenvman.2021.113617

European Commission. (2023). *Greenhouse gas emissions from manufacturing: What difference across countries?* Retrieved from https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/greenhouse-gas-emissions-manufacturing-what-difference-across-countries-2023-09-29_en

European Commisssion. (2019). Reflection paper: Towards a sustainable Europe by 2030. . In (pp. 1-125): EC. https://doi.org/10.2775/676251.

Ewane, E. B., & Ewane, E. I. (2023). Foreign direct investment, trade openness and environmental degradation in SSA countries. A quadratic modeling and turning point approach. *American Journal of Environmental Economics*, *2*(1), 9-18. https://doi.org/10.54536/ajee.v2i1.1414

Fanelli, T., & Ortis, A. (2020). Climate change: A new European union approach is needed. In Capitalism, Global Change and Sustainable Development. *Springer Proceedings in Business and Economics*, *4*, 141-147. https://doi.org/10.1007/978-3-030-46143-0_9

Favretto, N., Dougill, A. J., Stringer, L. C., Afionis, S., & Quinn, C. H. (2018). Links between climate change mitigation, adaptation and development in land policy and ecosystem restoration projects: Lessons from South Africa. *Sustainability*, *10*(3), 779. https://doi.org/10.3390/su10030779

Gujarati, D. N. (2004). *Basic econometrics*. New York: McGraw-Hill Companies.

Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica*, *50*(4), 1029-1054. https://doi.org/10.2307/1912775

Hdom, H. A., & Fuinhas, J. A. (2020). Energy production and trade openness: Assessing economic growth, CO2 emissions and the applicability of the cointegration analysis. *Energy Strategy Reviews*, *30*, 100488. https://doi.org/10.1016/j.esr.2020.100488

Ho, S.-Y., & Njindan, I. B. (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

Hu, J., & Xu, S. (2022). Analysis of energy efficiency in China's export trade: A perspective based on the synergistic reduction of CO2 and SO2. *Energy Reports*, *8*, 140-155. https://doi.org/10.1016/j.egyr.2022.01.148

Ian, T. (2023). *Carbon dioxide emissions in the European Union from 1965 to 2022 (in million metric tons)/ Statista*. Retrieved from https://www.statista.com/statistics/450017/co2-emissions-europe-eurasia/

Iheonu, C. O., Anyanwu, O. C., Odo, O. K., & Nathaniel, S. P. (2021). Does economic growth, international trade, and urbanization uphold environmental sustainability in Sub-Saharan Africa? Insights from quantile and causality procedures. *Environmental Science and Pollution Research*, *28*, 28222-28233. https://doi.org/10.1007/s11356-021-12539-z

Kamer, L. (2022a). *Africa: Cumulative CO2 emissions. In Statista.* Retrieved from https://www.statista.com/statistics/1307271/cumulative-co2-emissions-in-africa/

Kamer, L. (2022b). *Africa share in global CO2 emissions*. Retrieved from https://www.statista.com/statistics/1287508/africa-share-in-global-co2-emissions/

Karedla, Y., Mishra, R., & Patel, N. (2021). The impact of economic growth, trade openness and manufacturing on CO2 emissions in India: An autoregressive distributive lag (ARDL) bounds test approach. *Journal of Economics, Finance and Administrative Science*, *26*(52), 376-389. https://doi.org/10.1108/jefas-05-2021-0057

Keane, J., Mendez-Parra, M., Pettinotti, L., & Sommer, L. (2021). *The climate and trade nexus in Africa: Climate change and the transformation of African trade*. Retrieved from ODI Report:

Keho, Y. (2016). Trade openness and the environment: A time series study of ECOWAS countries. *Journal of Economics and Development Studies*, *4*(4), 61-69.

Khan, H., Weili, L., & Khan, I. (2022). Environmental innovation, trade openness and quality institutions: An integrated investigation about environmental sustainability. *Environment, Development and Sustainability*, 1-31. https://doi.org/10.1007/s10668-021-01590-y

Leitão, N. C. (2021). The effects of corruption, renewable energy, trade and CO2 emissions. *Economies*, *9*(2), 62. https://doi.org/10.3390/economies9020062

Leitão, N. C., Koengkan, M., & Fuinhas, J. A. (2022). The role of intra-industry trade, foreign direct investment, and renewable energy on Portuguese carbon dioxide emissions. *Sustainability*, *14*(22), 15131. https://doi.org/10.3390/su142215131

Lim, B., Hong, K., Yoon, J., Chang, J.-I., & Cheong, I. (2021). Pitfalls of the EU's carbon border adjustment mechanism. *Energies*, *14*(21), 7303. https://doi.org/10.3390/en14217303

Liu, L., Anwar, A., Irmak, E., & Pelit, I. (2022). Asymmetric linkages between public-private partnership, environmental innovation, and transport emissions. *Economic Research-Ekonomska Istraživanja, 35*(1), 6519-6540. https://doi.org/10.1080/1331677x.2022.2049979

Luo, H., Qu, X., & Hu, Y. (2022). The mechanism of the impact of export trade on environmental pollution: A study from a heterogeneous perspective on environmental regulation from China. *Sustainability, 14*(24), 16330. https://doi.org/10.3390/su142416330

Mignamissi, D., Tebeng, P. E. X., & Tchinda, M. A. D. (2024). Does trade openness increase CO2 emissions in Africa? A revaluation using the composite index of Squalli and Wilson. *Environment Systems and Decisions*, 1-29. https://doi.org/10.1007/s10669-023-09962-7

Mutascu, M., & Sokic, A. (2020). Trade openness-CO2 emissions nexus: A wavelet evidence from EU. *Environmental Modeling & Assessment, 25*(3), 411-428. https://doi.org/10.1007/s10666-020-09689-8

Nwaeze, N. C., Okere, K. I., Ogbodo, I., Muoneke, O. B., Ngini, I. N. S., & Ani, S. U. (2023). Dynamic linkages between tourism, economic growth, trade, energy demand and carbon emission: Evidence from EU. *Future Business Journal, 9*(1), 16. https://doi.org/10.1186/s43093-023-00193-5

Okelele, D. O., Lokina, R., & Ruhinduka, R. D. (2022). Effect of trade openness on ecological footprint in Sub-Saharan Africa. *African Journal of Economic Review, 10*(1), 209-233.

Panagiotopoulou, V. C., Stavropoulos, P., & Chryssolouris, G. (2022). A critical review on the environmental impact of manufacturing: A holistic perspective. *The International Journal of Advanced Manufacturing Technology*, 1-23. https://doi.org/10.1007/s00170-021-07980-w

Papke, L. E., & Wooldridge, J. M. (2005). A computational trick for delta-method standard errors. *Economics Letters, 86*(3), 413-417. https://doi.org/10.1016/j.econlet.2004.07.022

Pesaran, H. (2003). *A simple panel unit root test in the presence of cross section dependence*, . Retrieved from Cambridge Working Papers in Economics No. 0346, Faculty of Economics (DAE), University of Cambridge:

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*(2), 265-312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews, 34*(6-10), 1089-1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics, 142*(1), 50-93. https://doi.org/10.1016/j.jeconom.2007.05.010

Saifaddin, G. (2022). *EU CO2 emissions by country 2022. Statista.* Retrieved from https://www.statista.com/statistics/1171389/co2-emissions-european-union/

Sajeev, A., & Kaur, S. (2020). Environmental sustainability, trade and economic growth in India: Implications for public policy. *International Trade, Politics and Development, 4*(2), 141-160. https://doi.org/10.1108/itpd-09-2020-0079

Saka, A. (2018). The relationship between net trade and carbon dioxide emissions in Africa. *Studies in Business and Economics, 21*(1), 5–22. https://doi.org/https://doi.org/10.29117/sbe.2018.0104

Shpak, N., Ohinok, S., Kulyniak, I., Sroka, W., & Androniceanu, A. (2022). Macroeconomic indicators and CO2 emissions in the EU region. *Amfiteatru Economic, 24*(61), 817-830.

Sohag, K., Al Mamun, M., Uddin, G. S., & Ahmed, A. M. (2017). Sectoral output, energy use, and CO 2 emission in middle-income countries. *Environmental Science and Pollution Research, 24*, 9754-9764. https://doi.org/10.1007/s11356-017-8599-z

Steinhauser, D., Kittová, Z., & Khúlová, L. (2024). Relationship between CO2 emissions and trade: The case of the EU. *Intereconomics, 59*(1), 41-47. https://doi.org/10.2478/ie-2024-0009

Sun, H.-P., Tariq, G., Haris, M., & Mohsin, M. (2019). Evaluating the environmental effects of economic openness: Evidence from SAARC countries. *Environmental Science and Pollution Research, 26*, 24542-24551. https://doi.org/10.1007/s11356-019-05750-6

Sun, H., Clottey, A. S., Geng, Y., Fang, K. C. K., & Amissah, J. (2019). Trade openness and carbon emissions: Evidence from belt and road countries. *Sustainability, 11*(9), 2682. https://doi.org/10.3390/su11092682

Sun, H., Enna, L., Monney, A., Tran, D. K., Rasoulinezhad, E., & Taghizadeh-Hesary, F. (2020). The long-run effects of trade openness on carbon emissions in Sub-Saharan African countries. *Energies, 13*(20), 5295. https://doi.org/10.3390/en13205295

Tawiah, V. K., Zakari, A., & Khan, I. (2021). The environmental footprint of China-Africa engagement: an analysis of the effect of China–Africa partnership on carbon emissions. *Science of the Total Environment, 756*, 143603. https://doi.org/10.1016/j.scitotenv.2020.143603

Thuy, D. P. T., & Nguyen, H. T. (2022). Effects of trade openness on environmental quality : Evidence from developing countries. *Research Square*, 1–27. https://doi.org/https://doi.org/10.21203/rs.3.rs-1479740/v1

Tiseo, L. (2023). *GHG emissions in the EU.* Retrieved from https://www.statista.com/topics/4958/emissions-in-the-european-union/#topicOverview

Valodka, I., Snieska, V., & Ramírez, M. A. L. (2020). Impact of the international trade on the EU clothing industry carbon emissions. *Engineering Economics, 31*(3), 314–322. https://doi.org/10.5755/j01.ee.31.3.25012

Walker, T. R., Adebambo, O., Feijoo, M. C. D. A., Elhaimer, E., Hossain, T., Edwards, S. J., . . . Taylor, S. (2019). Environmental effects of marine transportation. In World seas: an environmental evaluation. In (2nd ed., pp. 505-530): Elsevier. https://doi.org/doi:10.1016/B978-0-12-805052-1.00030-9.

Wang, Q., & Zhang, F. (2021). The effects of trade openness on decoupling carbon emissions from economic growth–evidence from 182 countries. *Journal of Cleaner Production, 279*, 123838. https://doi.org/10.1016/j.jclepro.2020.123838

Woolfrey, S., & Karkare, P. (2021). *The future for Africa's trade with Europe: Factors affecting the long-term relevance of the European market for African exports.* Retrieved from ECDPM Discussion Paper No. 306:

Yakubu, I. N., & Musah, A. (2022). FDI and environmental sustainability nexus: Testing the pollution haven hypothesis in the presence of regulatory quality. *International Journal of Advanced Research in Economics and Finance, 4*(3), 287-295. https://doi.org/10.55057/ijaref.2022.4.3.25

Yameogo, C. E., Omojolaibi, J. A., & Dauda, R. O. (2021). Economic globalisation, institutions and environmental quality in Sub-Saharan Africa. *Research in Globalization, 3*, 100035. https://doi.org/10.1016/j.resglo.2020.100035

Zerbo, E. (2017). Income-environment relationship in Sub-Saharan African countries: Further evidence with trade openness. *Environmental Science and Pollution Research, 24*, 16488-16502. https://doi.org/10.1007/s11356-017-9303-z

Zhang, Q., Jiang, X., Tong, D., Davis, S. J., Zhao, H., Geng, G., . . . Streets, D. G. (2017). Transboundary health impacts of transported global air pollution and international trade. *Nature, 543*(7647), 705-709. https://doi.org/10.1038/nature21712

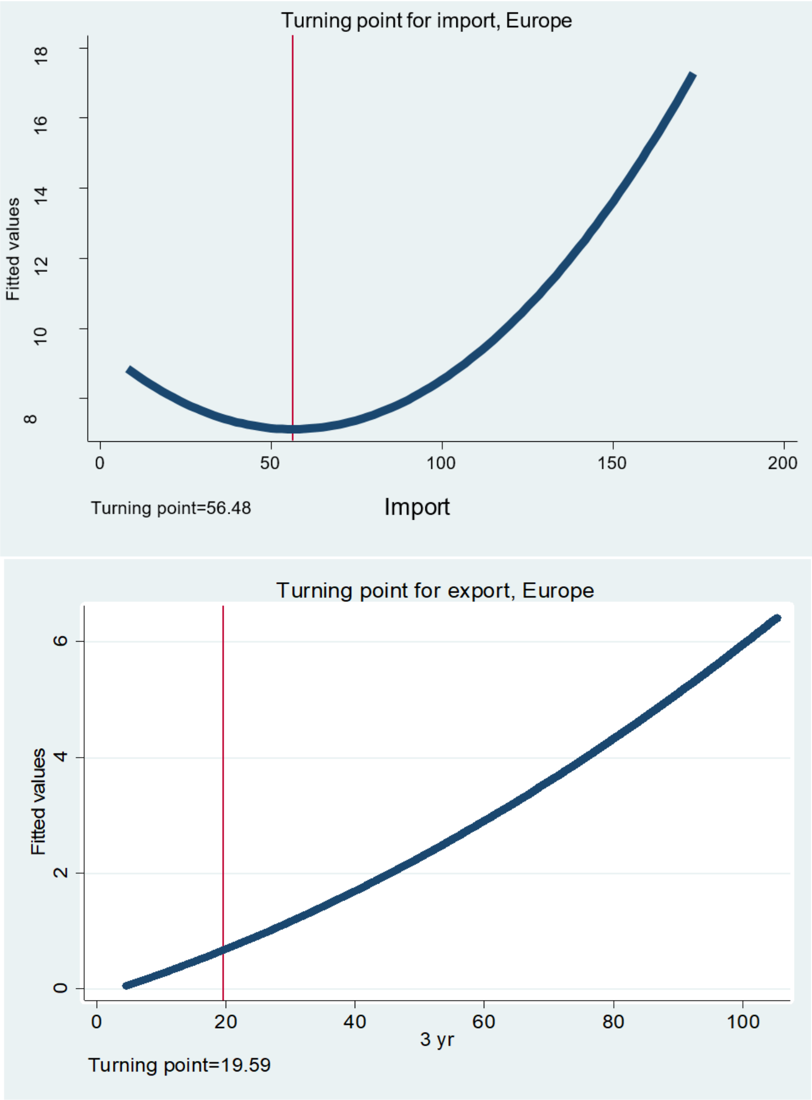
Zheng, S., Wang, R., Mak, T. M., Hsu, S.-C., & Tsang, D. C. (2021). How energy service companies moderate the impact of industrialization and urbanization on carbon emissions in China? *Science of the Total Environment, 751*, 141610. https://doi.org/10.1016/j.scitotenv.2020.141610

Appendixes

Appendix 1. Linear and nonlinear regression for Europe.

Variables	Import equation estimates		Export equation estimates		
	Linear	Non linear	Variables	Linear	Non linear
M	-0.021** (0.009)	-0.077*** (0.019)	X	-0.048*** (0.006)	-0.029*** (0.012)
M2		0.001*** (0.001)	X2		0.001*** (0.025)
Turning point		56.480	Turning point		19.590
FDI	-0.007***	-0.011* (0.005)	FDI	-0.016*** (0.004)	-0.017*** (0.004)
logGDP	0.456*** (0.069)	0.333*** (0.079)	logGDP	0.479*** (0.046)	0.477*** (0.046)
REC	-0.0978*** (0.012)	-0.098*** (0.009)	REC	-0.084*** (0.009)	-0.085*** (0.009)
Constant	-3.551 (2.268)	2.503 (2.378)	Constant	-5.664*** (1.331)	-5.411*** (1.271)
Observations	970	970	Observations	970	970
R-squared	0.1559	0.181	R-squared	0.235	0.235

Note: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

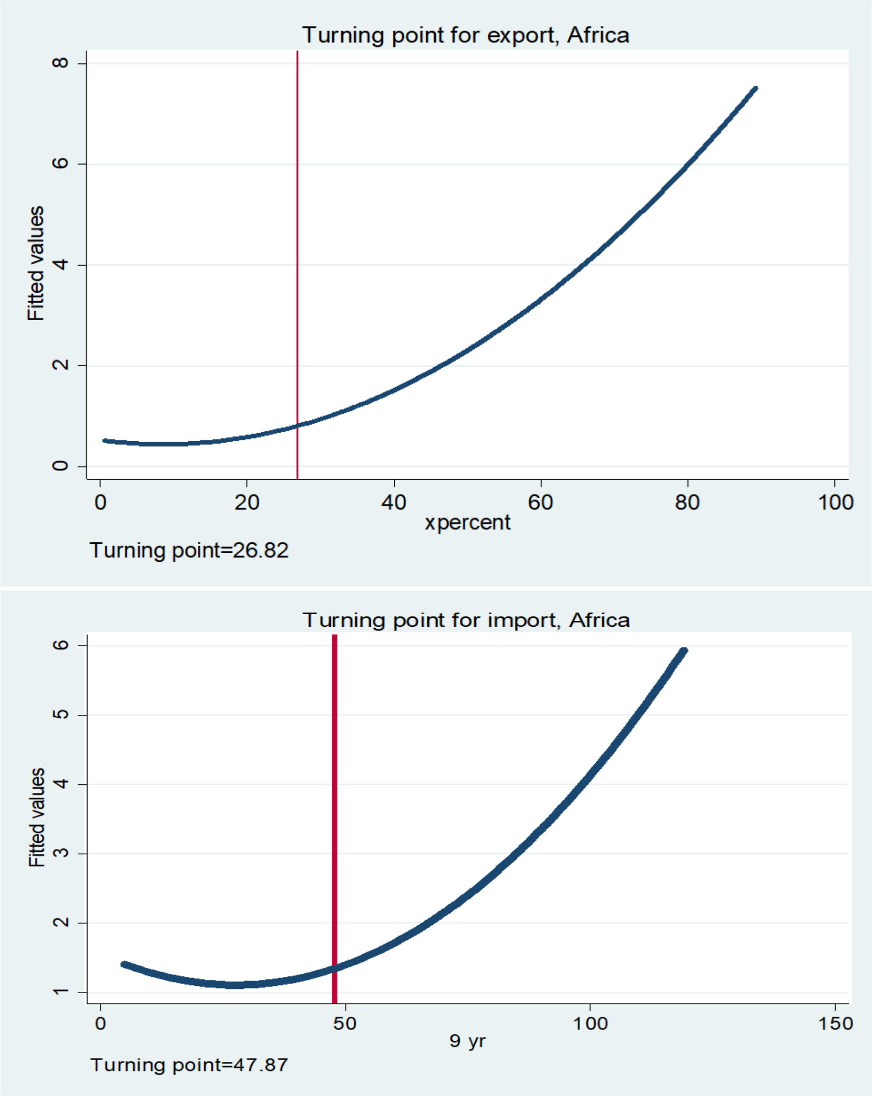


Appendix 2. Turning points for export and import in Europe.

Appendix 3. Linear and Nonlinear regression for Africa.

Variables	Export equation estimates			Import equation estimates	
	Linear	Non linear		Linear	Non linear
X	-0.035*** (0.004)	-0.089*** (0.007)	M	-0.005 (0.004)	-0.059*** (0.009)
X2		0.002*** (0.001)	M2		0.001*** (7.72e-05)
Turning point		26.82	Turning point		47.87
FDI	-0.014* (0.008)	-0.017*** (0.008)	FDI	0.0154 (0.009)	-0.032 (0.051)
logGDP	0.232*** (0.041)	0.308*** (0.041)	logGDP	0.206*** (0.038)	0.003 (0.012)
REC	-0.029*** (0.002)	-0.029*** (0.002)	REC	-0.039*** (0.002)	0.263*** (0.074)
Constant	-3.542*** (0.902)	-4.285*** (0.872)	Constant	-1.597* (0.884)	-0.039*** (0.003)
Observations	669	669	Observations	669	633
R-squared	0.611	0.650	R-squared	0.537	o.569

Note: Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.



Appendix 4. Turning points for export and import in Africa.