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Asymmetric Impact of Trade Openness on CO2 Emission: Evidence from Kenya

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A R T I C L E I N F O

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A B S T R A C T

This study examines the asymmetric impact of trade openness (TO) on CO_2 emissions in Kenya over the period from 1990 to 2020. The growing pressure on both developing and developed countries to reduce their carbon footprints, alongside the accelerating push for globalization – with TO as a key driver – motivates this research. The primary objective is to determine whether TO contributes to carbon emissions and whether this impact exhibits asymmetry. The study employs the non-linear ARDL (NARDL) approach to examine this relationship. The results indicate that, in the long run, both positive and negative shocks to trade openness do not have a statistically significant impact on carbon emissions. However, in the short run, positive shocks and carbon emissions move in the same direction, whereas negative shocks and carbon emissions move in opposite directions. Overall, the findings suggest that the effects of negative shocks are more pronounced than those of positive shocks. These findings suggest that TO significantly influences Kenya's carbon emissions in the short term but not in the long term. Therefore, policymakers in Kenya should account for the short-term environmental impacts of TO when designing strategies to reduce the country's carbon footprint.

1. Introduction

Climate change has sparked increased global interest in identifying mitigation strategies before irreversible damage occurs. The United Nations has highlighted this urgency by including climate action – Goal 13, "Take urgent action to combat climate change and its impacts"– among the 17 Sustainable Development Goals (SDGs) to be achieved by 2030. In addition to the SDGs, the Paris Agreement, which came into effect in 2016 and has been signed by most developed and developing countries, underscores the international commitment to addressing greenhouse gas emissions. Kenya signed both the SDGs and the Paris Agreement, thereby committing to the reduction of greenhouse gas emissions. The country has demonstrated its commitment to climate action through the adoption and implementation of various climate-focused policies and initiatives. The launch of carbon credit trading in Kenya marked a significant step toward holding companies accountable for their environmental impact in the production of goods.

This step also ensures responsible production from the businesses and quickens the adoption of green production techniques. However, despite the concerted effort that has been made in fighting greenhouse gas emissions, the country also endeavours to advance economic development that entails an increase in manufacturing activities known to increase greenhouse emissions. Among the policy advancements encapsulated by Vision 2030, boosting the manufacturing sector, diversification of export products and moving away from export of primary products have been identified as important. Thus, trade has been earmarked to bring financial flows that would help the country achieve the development goals projected in Vision 2030 and the SDGs. The study aims to answer two questions as follows: i) What is the impact of TO on carbon emission in Kenya; and ii) Is the asymmetric impact of TO on carbon emission valid for Kenya? The findings from this study will assist Kenya in positioning trade in the development agenda without compromising the fight against greenhouse gas emissions.

A vast body of literature exists on the symmetric relationship between trade and carbon emissions. Most of the studies found trade to positively influence carbon emissions. This is achieved through an increase in production that may put pressure on businesses to use unfriendly production methods that reduce production costs and increase profit margins. These studies assumed the effect of trade on CO_2 emission is the same for both negative and positive changes in trade (Mahmood and Zakaria, 2019; Fan et al., 2019; Dou et al.,

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2021; Chhabra, Giri, and Kumar, 2023). However, some studies that focused on the symmetric effect of trade on carbon emissions also found conflicting results where TO was found to have a negative effect on CO_2 emissions (Goswami et al., 2023; Karedla, Mishra and Patel, 2021; Sin-Yu and Njindan, 2019). The inconclusive results point to the importance of a country-by-country examination. The results from these studies are also questionable given the growing literature pointing to a possibility of negative and positive changes in trade having a different impact on carbon emission. However, a dearth of literature has examined the nature of the relationship using the asymmetric approach (see, Wang, Zhang and Li, 2023; Udeagha and Breitenbach, 2023; Mahmood, Maalel and Zarrad, 2019). This study departs from the extant literature by re-examining the effect of TO on carbon emission using the NARDL approach. This method enables analysis of both long-run and short-run relationships, which is particularly important when policy decisions are sensitive to time horizons. Additionally, the NARDL model enables the detection of asymmetries by distinguishing between the effects of positive and negative shocks to trade openness on CO_2 emissions.

The NARDL approach used in this study has great advantages in that the approach is robust in small samples and variables included in the model do not have to be integrated of the same order. Kenya has been selected for this study, given that it is among the first African countries to launch the trade in carbon credits. This suggests that many countries view Kenya as a model for advancing economic development while protecting the climate. Kenya has also implemented deliberate policies to actively reduce the environmental impact of its economic development activities. The country understands the intertwined and intricate role that climate plays in achieving the Vision of the country.

The remainder of the study is organised as follows: Section 2 reviews the country-specific literature, while Section 3 focuses on the empirical literature. Section 4 presents the empirical model specification and estimation techniques, while Section 5 provides the empirical analysis and discussion of the results. Finally, Section 6 concludes the study.

2. Country-based literature review

2.1 The dynamics of trade openness and carbon emission in Kenya

The National Trade Policy was developed in alignment with Kenya's national blueprint, Vision 2030.The policy was part of the country's effort to include trade activities with the new requirements in the new constitution (Ministry of Industry, Trade and Cooperatives, 2017). The National Trade Policy has the main objective of transitioning the export sector to an innovative and coordinated pad where trade would spearhead economic development and eliminate socioeconomic challenges (Ministry of Industry, Trade and Cooperatives, 2017). The trade policy builds on the momentum gained from the 1980s when the country moved from import substitution and the opening of the economy to international trade. The overall goal of the trade policy is to unleash the country's potential in domestic, regional and global markets. The policy redressed limited diversification, limited trade finance, limited negotiating capacity, increase in non-tariff barriers, low-value addition in production and reliance on the export of primary products and insufficient infrastructure to support trade needs (Ministry of Industry, Trade and Cooperatives, 2017). The Trade Policy was accompanied by legal and regulatory reforms designed to create an enabling environment for achieving its objectives. Previously, complex legal frameworks and a cumbersome licensing system hindered prospective businesses from operating effectively in the export sector.

The Kenyan government recognised the importance of new and growing businesses in the export sector and the spillover effects they have on the wider economy through forward and backward linkages. In line with efforts to simplify doing business, the alignment of National and Government business license fees was made, and a one-stop shop was established for wholesale trade (Ministry of Industry, Trade and Cooperatives, 2017).

Kenya is a signatory to bilateral, multilateral and international trade agreements. These agreements create a platform for mutually beneficial trade (Ministry of Industry, Trade and Cooperatives, 2017). A strategy of creating export cheaper through some of the tariff benefits that come with the agreements. Some of the agreements include Cross border trade associations that encourage small businesses to participate in cross-border trade; East Africa Community (EAC), Common Market for Eastern and Southern Africa (COMESA), Tripartite FTA (COMESA, EAC and SADC), African Growth and Opportunity Act (AGOA) of 2000, EAC EU EPA, several bilateral trade agreements with developing and developed countries (Ministry of Industry, Trade and Cooperatives, 2017). With the trade agreements backed with a supportive legal and legislative framework, Kenya has managed to boost exports and get preferential treatment. Exports as a percentage of GDP fluctuated between 20% and 38% of GDP between 1990 and 2021 (World Bank, 2024). A decline in exports was recorded in 2012 and the country never recovered until 2022 (World Bank, 2024). COVID-19 exacerbated the decline where 9,6% of GDP was recorded, the lowest over the study period. On the import side, fluctuations were recorded throughout the study period with an average of 29% (World Bank, 2024). This is slightly higher than the average exports during the same period. For most years since 1990, Kenya has imported more than it has exported to other countries (World Bank, 2024). Figure 1 shows the trends in exports and imports from 1990 to 2021.

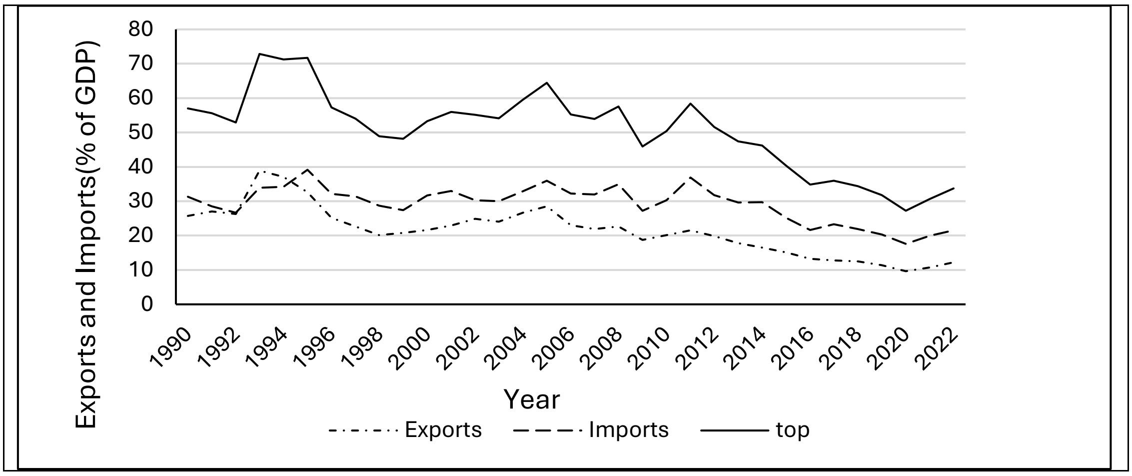

Figure 1. Trends in exports and imports, trade openness 1990 – 2021
Source: World Bank (2024)

Figure 1 reports the trends in trade during the study period. Kenya imported more than it exported to other countries during the study period (World Bank, 2024). Exports and imports declined consistently from 2011 to 2020, a year that coincides with the COVID-19 pandemic. Trade openness exhibited a downward trend during the study period, suggesting more work needs to be done to reverse the trend.

2.2 Dynamics in carbon emission

The Kenyan government understands the sensitivity between environmental health and socioeconomic advancement. The need to advance socioeconomic goals in a sustainable environment that supports current and future generations shapes the environmental policy of the country. This has resulted in the drafting of policies that support a clean environment in all facets. The National Environmental Policy of 2013 encompasses environmental degradation aspects from sound, high population growth, unsustainable production patterns, transport pollution and soil quality. The main objective of the policy was to provide a framework for sustainable management of Kenya's environment and natural resources (Republic of Kenya, 2013). The Environmental Management and Coordination Act No.8 of 1999 and the Sessional Paper No.6 of 1999 were among the first pieces of legislation focusing on environmental law (Republic of Kenya, 2013). The Constitution of Kenya 2010 embodied sustainable development.

To support the move to preserve the environment, Kenya initiated the Nationally Determined Contribution (NDC) which was updated to cover 2020-2030 (FAOLEX Database, 2020). The main objective of the NDC is to abate greenhouse gas emissions by 32% by 2030 (FAOLEX Database, 2020). This goal aligns with Sustainable Developments Goals where climate is part of the goals. This is achieved with a focus on energy, agriculture, land use, and waste sectors that deal with carbon dioxide, nitrous oxide and methane, among other hazardous gases (FAOLEX Database, 2020). One of the strategies to reduce carbon emissions is a drive to renewable energy in electricity generation and tree coverage of 10% of the land use and the use of clean, efficient and sustainable energy technologies (FAOLEX Database, 2020). The UNDP Low Emission and Climate Resilient Development in Kenya (LECRD) helps to advance the agenda on a clean environment and reduction of the country's carbon footprint; and provide a long-term sustainable solution to a resilient climate (UNDP, 2023). Kenya is part of the signatories to the Paris Agreement, which entered into force on 4 November 2016, where a commitment was made to reduce global greenhouse gas emissions and a call for developed countries to assist developing countries in the journey to reducing greenhouse gas emissions (United Nations, 2024). The determination of the Kenyan government to reduce greenhouse gas emissions and stick to the Paris Agreement and the SDGs saw the launch of a carbon market – the CYNK which opened with more than 2 million in carbon futures credits (Energy Monitor, 2023).

There has been a gradual increase in carbon emission when measured by carbon emission metric tonnes per capita from 1990 to 2017 (World Bank, 2024). A slight decline was recorded from 2018 to 2021, evidence of the policies and programmes put in place to reduce greenhouse emissions (World Bank, 2024). This is a positive development given that Vision 2030 and the Big Four agenda identified manufacturing as an important sector in achieving economic development (World Bank, 2024). Figure 2 reports emission trends in Kenya from 1990 – 2021.

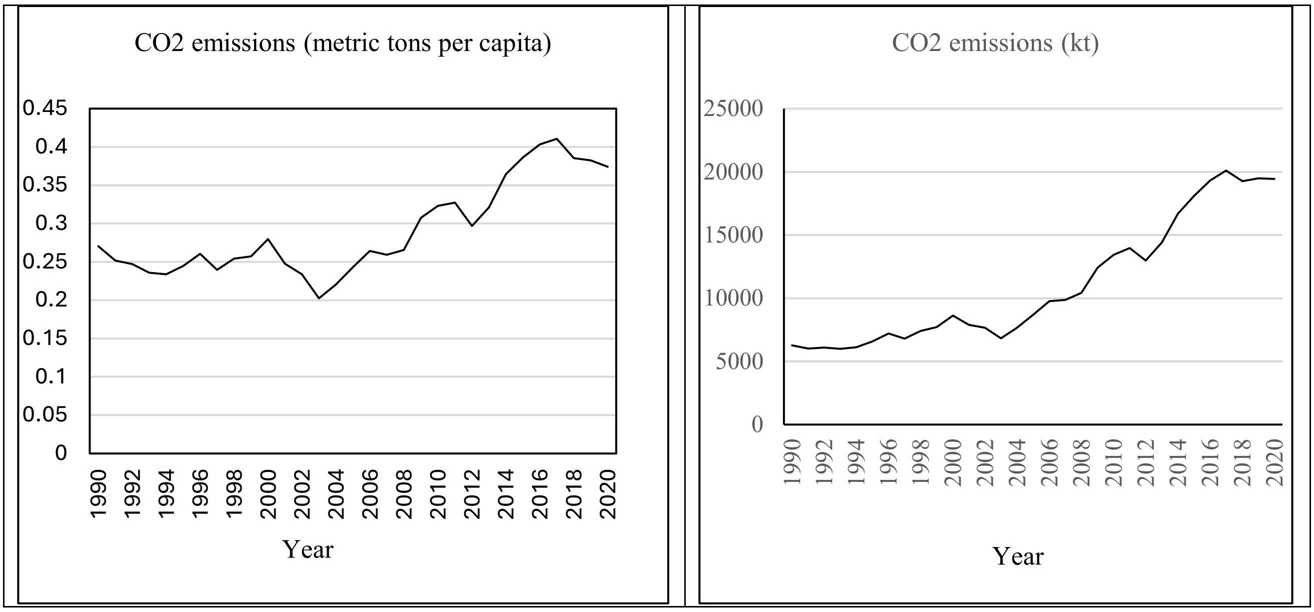

Figure 2. Trends in Carbon emission in Kenya 1990 – 2021

Source: World Bank (2024)

Figure 2 reports the trends in carbon emission measured by metric tonnes per capita and kiloton (kt). The two measures exhibit an upward trend in the level of carbon emission in Kenya (World Bank, 2024). This does not come as a surprise, given the emphasis that has been placed on the manufacturing sector under the Big Four agenda. This is likely to positively affect carbon emissions, especially at a time when the country is in the teething stage of renewable energy use. The launch of the carbon credit market is likely to reverse this trend in the future.

3. Empirical Literature Review

The link between carbon emission and trade has ignited a lot of interest, especially now that climatic changes have threatened to reverse the gains made in economic development in both developing and developed countries. Two prominent theories are commonly associated with the relationship between trade and carbon emissions: the Environmental Kuznets Curve (EKC) and the Pollution Haven Hypothesis (Wang, Zhang and Li, 2023; Taylor, 2005). The pollution-haven hypothesis postulates that when enterprises from industrialised countries establish plants overseas, they will always look for countries with cheap factors of production and lax environmental policies. This results in high carbon emissions that are not accounted for in the production decisions of these enterprises. The EKC postulates that countries always experience an increase in pollution with industrialisation and economic development until they reach a turning point. These theories highlight a positive relationship between industrialization and economic development and carbon emission. It is important to highlight that the turning point proposed under the EKC curve varies from one country to the other, based on stylised factors. Thus, the pressure from the international community to reduce carbon footprint and adopt green production technologies is likely to quicken the turning point in most countries that are taking steps to reduce carbon emissions. The empirical literature on the impact of trade on carbon emission is divided with one strand of literature pointing to a positive impact, while another pointing to a negative impact. Empirical studies on the effect of trade on carbon emission using linear and non-linear techniques are reviewed.

Wang, Zhang and Li (2023) examined the effect of TO, export and import diversification on CO_2 emissions in G20 countries using 1997 to 2019 data. The study found the effect of trade on carbon emission to be asymmetric. TO was found to increase CO_2 emissions through its impact on industrial structure, while it contributed to a decrease in CO_2 emissions via technological progress. Trade openness was found to increase CO_2 emissions at 10%-50% quantile and reduce carbon emissions at 80% - 90% quantile levels. Udeagha and Breitenbach (2023), in a study on the asymmetric relationship between TO and CO_2 emissions in SADC countries, using data from 1960-2020, found mixed results on asymmetric behavior between TO and CO_2 emissions. The Long-run asymmetry was found for Madagascar, Mozambique, Tanzania, and Botswana; while short-run and long-run asymmetry was found for Namibia, South Africa and Comoros; and symmetric behavior was confirmed for Zimbabwe, Seychelles, Mauritius, Malawi, Zambia and Angola, Lesotho and Democratic Republic of Congo. Mahmood, Maalel and Zarrad (2019) in a study on the asymmetric effect of TO on CO2 emission and the environmental Kuznets curve (EKC) hypothesis for Tunisia using data from 1971-2014, the study found asymmetric effects of TO on carbon emission. The study confirmed the EKC hypothesis for Tunisia with the turning point at about 292.4 billion constant USD of GDP. In the same spirit, Mahmood and Zakaria

(2019) in a study on the impact of trade on pollution in China, found trade to increase pollution in China. The study also found TO to cause carbon emissions. Lin (2017) found the same results in a study on China using 312 Prefectures and data from 2004-2011.

Chhabra, Giri and Kumar (2023), in a study on BRICS countries, using data from 1991 to 2019 and the modern dynamic common correlated effects (DCCE) approach, found that TO contributes to environmental degradation. Derindag et al. (2023) studied the relationship between foreign TO, foreign direct investment and carbon emission for India using sixteen years of data from twenty industrial sectors. Trade openness was found to increase carbon emissions in sectors with lower carbon intensity, while it had the opposite effect in high carbon-intensity sectors. Dou et al. (2021) examined the effect of TO on regional carbon emissions in the China–Japan–South Korea Free Trade Area using data from 1970 to 2019. Trade openness was found to positively affect the greenhouse effect. Imports were found to contribute to increased carbon emissions, while exports reduced carbon emissions. Fan et al. (2019), in a study of the relationship between TO and carbon emission for China's 20 industrial sectors, found high TO to be associated with a reduction in the intensity of carbon emission.

Although many of the studies reviewed pointed to the positive impact of TO on carbon emission, there is a strand of literature that found a negative relationship between the two. For example, Goswami et al. (2023) investigated the impact of TO, economic growth, energy consumption and urbanisation on carbon emission in India using the ARDL approach and data from 1980 to 2021. In the short run, a negative relationship was found between TO and carbon emission and a positive relationship between the two in the long run. Karedla, Mishra and Patel (2021) using the ARDL approach and data from 1971 to 2016, found TO to significantly reduce carbon emissions. Sin-Yu and Njindan (2019), in a study on 17 Central and Eastern European countries, and using data from 1994-2014, found TO to reduce carbon emissions in the long run, but increase carbon emissions in the short run.

The reviewed studies present mixed results regarding the impact of TO on carbon emissions, regardless of whether symmetric or asymmetric estimation techniques were employed. These divergent findings reflect underlying country-specific structural and policy-related factors. This variation underscores the need to examine the specific nature of this relationship in the context of Kenya.

4. Estimation Techniques

Model Specification and data

The general model used in this study is expressed as follows:

$$Co2 \;=\; f(\mathrm{TO}, \mathrm{Y}, \mathrm{URB}, \mathrm{INF}, \mathrm{INV}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where:

CO_2 = Carbon emissions

TO = Trade openness

Y = Economic growth

URB = Urbanisation

INV = Investment

This study employs the NARDL model to account for the possible non-linear relationship between TO and CO_2 emissions. Since the NARDL model captures both positive and negative shocks in trade openness (TO), the TO variable can be decomposed into +ve and -ve partial sums as follows:

$$TO_t = \rho_0 + TO_t^+ \; + TO_t^- \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

$$TO_t^+ = \textstyle\sum_{J=1}^{t} \Delta TO_t^+ = \displaystyle\sum_{j=1}^{t} \max\left(\Delta TO_j; 0\right) \ldots\ldots\ldots\ldots \quad (3)$$

$$TO_t^- = \textstyle\sum_{J=1}^{t} \Delta TO_t^- = \displaystyle\sum_{j=1}^{t} \min\left(\Delta TO_j; 0\right) \ldots\ldots\ldots\ldots \quad (4)$$

Based on Equation 4, the NARDL model can be expressed as:

$$\begin{aligned}\Delta CO2_t = \psi_0 &+ \sum_{i=1}^{p} \psi_{1i} \Delta Co2_{t-i} + \sum_{i=0}^{q1} \psi_{2i}^{+} \Delta TO_{t-i}^{+} + \sum_{i=0}^{q2} \psi_{3i}^{-} \Delta TO_{t-i}^{-} + \sum_{i=0}^{q3} \psi_{4i} \Delta Y_{t-i} \\ &+ \sum_{i=0}^{q4} \psi_{5i}\, \Delta URB_{t-i} + \sum_{i=0}^{q5} \psi_{6i} \Delta INV_{t-i} + \alpha_1 CO2_{t-1} + \alpha_2^{+} TO_{t-1}^{+} + \alpha_3^{-} TO_{t-1}^{-} \\ &+ \alpha_4 Y_{t-1} + \alpha_5 URB_{t-1} + \alpha_5 INV_{t-1} + \mu_{2t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)\end{aligned}$$

Where:
ψ_0 = constant; $\psi_1 - \psi_6$= short-run coefficients; $\alpha_1 - \alpha_6$ = long-run coefficients; and μ_{2t} = white noise error term.

In the above equation, the null hypothesis (H_0) is: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$, while the alternative hypothesis (H_1) is: $\alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq 0$.

Based on Equation 5, the short-run parameters can be obtained using the following NARDL-ECM representation.

$$\Delta CO2_t = \psi_0 + \sum_{i=1}^{p} \psi_{1i} \Delta Co2_{t-i} + \sum_{i=0}^{q1} \psi_{2i}^{+} \Delta TO_{t-i}^{+} + \sum_{i=0}^{q2} \psi_{3i}^{-} \Delta TO_{t-i}^{-} + \sum_{i=0}^{q3} \psi_{4i} \Delta Y_{t-i} + \sum_{i=0}^{q4} \psi_{5i}\, \Delta URB_{t-i} + \sum_{i=0}^{q5} \psi_{6i} \Delta INV_{t-i} + \lambda ECM_{t-1} + \mu_{3t} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6)$$

Where: ECM = Error correction term.

In this context, the ECM is used to capture the short-run deviations from the long-run equilibrium and to estimate the speed at which these deviations are corrected over time. In order to test for the existence of short-run and long-run asymmetries, the Wald test is applied to the estimated model. Finally, the asymmetric cumulative dynamic multiplier will be used to establish how carbon emissions (CO_2) respond to changes in increases or decreases in TO (see Shin et al., 2014).

The study utilised annual data from 1990 to 2020, sourced from the World Bank's online database. The definition of variables and measurements are presented in Table 1.

Table 1. Definitions of variables and data sources

Variables	Definitions of variables /Measurements
CO_2 – Carbon emissions	CO_2 emissions per capita
TO - Trade openness	Trade (% of GDP)
Y - Economic growth	GDP per capita
URB - Urbanisation	Urban population growth (annual %)
INV - Investment	Gross fixed capital formation (% of GDP)

5. Data Analysis and Discussion of Results

5.1 Unit root test results

The results of the unit root tests are reported in Table 2.

Table 2. Stationarity results for all variables

	Dickey-Fuller Generalised Least Square (DF-GLS)		Phillips-Perron (PP)		Zivot-Andrews (ZAURoot)			
Variable	Level	Δ	Level	Δ	Level	Break	Δ	Break
lCO2	-1.995	-4.634***	-2.276	-6.240***	-3.786**	2001	__	__
lTO	-0.033	-4.591***	-1.678	-5.738***	-3.499	2011	-8.818***	2006
lY	-2.265	-3.928**	-2.377	-3.447*	-4.750**	2002	__	__
lURB	-2.280	-3.150*	-1.203	-5.656***	-5.142***	2006	__	__
lINF	-4.460***	__	-4.332***	__	-5.574***	2003	__	__
lINV	-2.865	-5.362***	-3.121	-8.419***	-3.828**	2005	__	__

*Notes: *, ** and *** denote statistical significance at 10%, 5% and 1% levels, respectively. Δ denotes first difference.*

As shown in Table 2, all variables are either I(0) or I(1), and none is integrated of order two or higher. This finding is confirmed by the three-unit root tests used in this study: the Zivot-Andrews (ZA) test, the DF-GLS test, and the Phillips-Perron (PP) test. Additionally, the Brock, Dechert, and Scheinkman (BDS) test was conducted to assess the presence of nonlinearity in the time series. The BDS results, presented in Table 3, provide evidence of nonlinearity across all variables included in the analysis.

Table 3. BDS Test results for nonlinearity

Variables	BDS Statistic					
	Dimension 2	Dimension 3	Dimension 4		Dimension 5	Dimension 6
	BDS Statistic	P-value	BDS Statistic	P-value	BDS Statistic	P-value BDS
Statistic	P-value	BDS Statistic	P-value			
	0.137***	0.000	0.205***	0.000	0.228***	0.000
	0.209***	0.000	0.157***	0.000		
	0.097***	0.000	0.093***	0.000	0.056***	0.000
	0.049***	0.000	0.037***	0.000		
	0.147***	0.000	0.214***	0.000	0.235***	0.000
	0.216***	0.000	0.153***	0.000		
	0.154***	0.000	0.228***	0.000	0.248***	0.000
	0.239***	0.000	0.191***	0.000		
	0.055***	0.001	0.090***	0.001	0.095***	0.003
	0.098***	0.004	0.083** 0.013			
	0.078***	0.000	0.125***	0.000	0.150***	0.000
	0.159***	0.000	0.155***	0.000		

*Notes: *** and ** denote statistical significance at 1% and 5% leve1s, respectively.*

5.2 Cointegration results

The results of the bounds test for cointegration are summarised in Table 4.

Table 4. Bounds F-test results for cointegration – NARDL

F-Statistic			Cointegration Status		
3.772**			Cointegrated		
Asymptotic critical values for					
10%		5%		1%	
I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
2.12	3.23	2.45	3.61	3.15	4.43

*Notes: ** denotes statistical significance at 5% level.*

The cointegration results reported in Table 4 confirmed that cointegration exists among the variables included in our NARDL model. Hence, the ECM can now be included in the NARDL model to estimate the short-run and long-run coefficients. A summary of the results from the ECM-based NARDL is reported in Table 5.

Table 5. NARDL results - long-run and short-run coefficients

Dependent Variable is Y		
Panel A: Long-Run Results		
Regressor	**Coefficient**	**T-ratio [p-value]**
lTO^{+}	-0.792	-0.804 [0.442]
lTO^{-}	-1.202	-1.382 [0.200]
lY	-6.256	-1.644 [0.135]
lURB	-5.835**	-2.282 [0.049]
lINF	0.339*	1.860 [0.096]
lINV	1.442	1.681 [0.127]
Panel B: Short-Run Results		
Regressor	**Coefficient**	**T-ratio [p-value]**
C	25.330***	6.625 [0.000]
ΔlTO^{+}	0.465***	3.049 [0.014]
ΔlTO^{-}	-0.923***	-5.320 [0.001]
$\Delta lTO^{-}(-1)$	0.328	1.737 [0.117]
ΔlY	-0.892	-1.527 [0.161]
$\Delta lY(-1)$	2.741***	4.582 [0.001]
$\Delta lURB$	-2.182**	-2.318 [0.046]

ΔlURB(−1)	2.245**	2.682 [0.025]
ΔlINF	0.035**	2.319 [0.046]
ΔlINF(−1)	-0.092***	-5.648 [0.000]
ΔlINV	0.449***	3.199 [0.011]
ΔlINV(−1)	-0.549***	-3.029 [0.014]
ECM(−1)	-0.541***	-6.634 [0.000]
Panel C: Test statistics		
R- Squared	0.835	
R-Bar-Squared	0.703	
F-Statistic [Prob]	6.335 [0.000] ***	
Normality	0.236 [0.889]	
Serial Correlation	0.971 [0.425]	
Heteroscedasticity	1.420 [0.302]	
Functional Form	0.470 [0.512]	

Panel D: Long- and short-run asymmetry results

Test	F-statistic	P-value	Decision
W_{LR}	3.674	0.071*	Asymmetric
W_{SR}	3.237	0.089*	Asymmetric

Notes:

1) **, ** and *** denote significance levels at 10%, 5%, and 1%, respectively.*
2) *_+ and _- denote positive and negative shocks.*
3) W_{LR} *= long-run asymmetric test*
4) W_{LR} = short-run asymmetric test

The results reported in Table 5 show that positive shocks in TO significantly affect carbon emissions in the short run, but not in the long run. This finding has been confirmed by the coefficient of lTO^{+}in the CO_2 emissions equation, which is significant in the short run but insignificant in the long run. Likewise, negative shocks in TO have been found to affect carbon emissions in the short run but have no significant impact in the long run. This is also confirmed by the coefficient of lTO^{-} in the CO_2 emissions equation, which is statistically significant in the short-run model but not in the long-run model. However, in the short run, positive shocks (lTO^{+}) and carbon emissions move in the same direction; that is, increases in positive shocks lead to increases in carbon emissions. Conversely, negative shocks (lTO^{-}) and carbon emissions move in opposite directions, as indicated by the coefficient of (lTO^{-}) in the CO_2 equation.

Other results indicate that real GDP per capita (economic growth) has a positive lagged impact on carbon emissions in the short run, but its effect is insignificant in the long run. Although urbanisation has a negative impact on CO_2 emissions in the long run, its impact on carbon emissions in the short run is inconclusive. Likewise, the impact of inflation on carbon emissions is positive in the long but inconclusive in the short run. Finally, the impact of investment (proxied by gross domestic investment) on carbon emissions was found to be insignificant in the long run but inconclusive in the short run. The results of the Wald test, reported in Panel D, also show that there is a long-run and short-run asymmetric relationship in our model.

The dynamic multiplier graph, which shows the asymmetry resulting from the decomposition of openness owing to positive and negative shocks, is reported in Figure 3. As indicated in Figure 3, there is sufficient evidence to show some adjustments of carbon emissions to the equilibrium value due to positive and negative shocks in the long run. The study also employed the CUSUM and CUSUM of Square tests to assess the stability of the model. Overall, the study found the model to be stable throughout the study period, as shown in Figures 4 and 5.

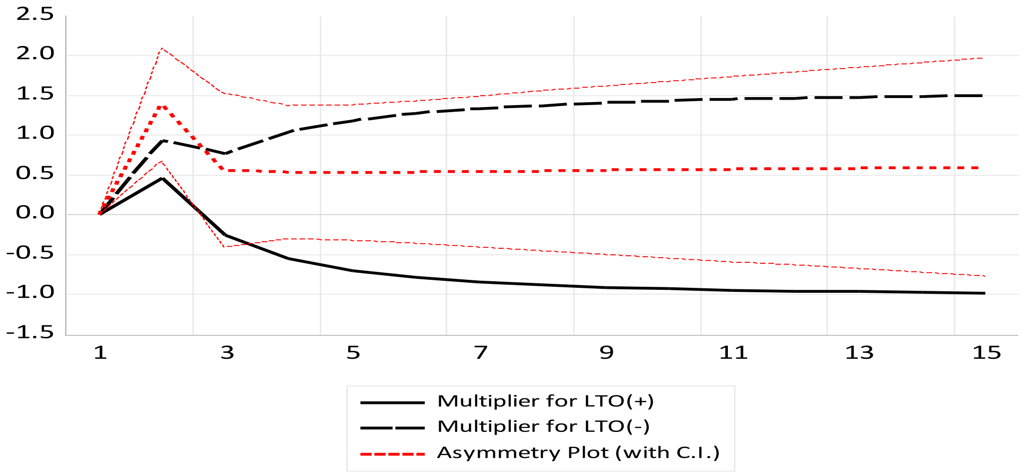

Figure 3. Dynamic multiplier graph

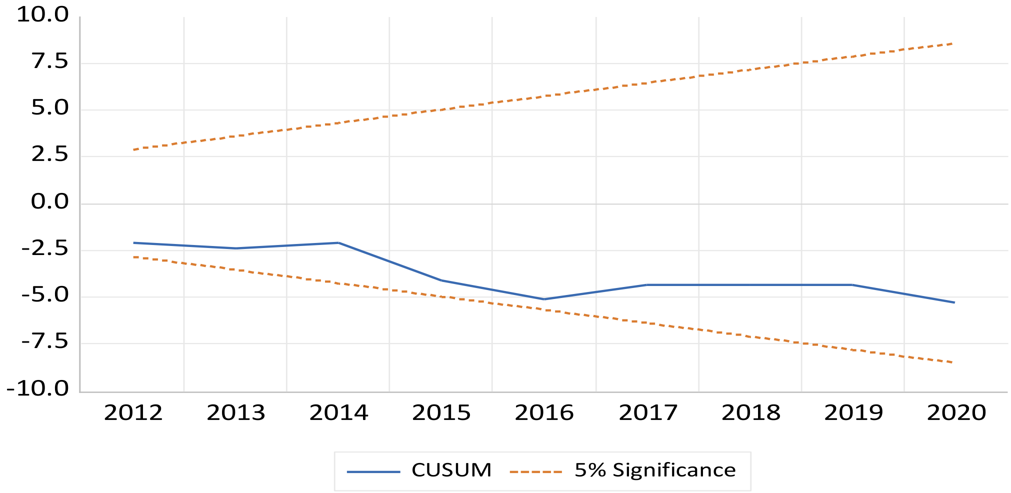

Figure 4. CUSUM plot

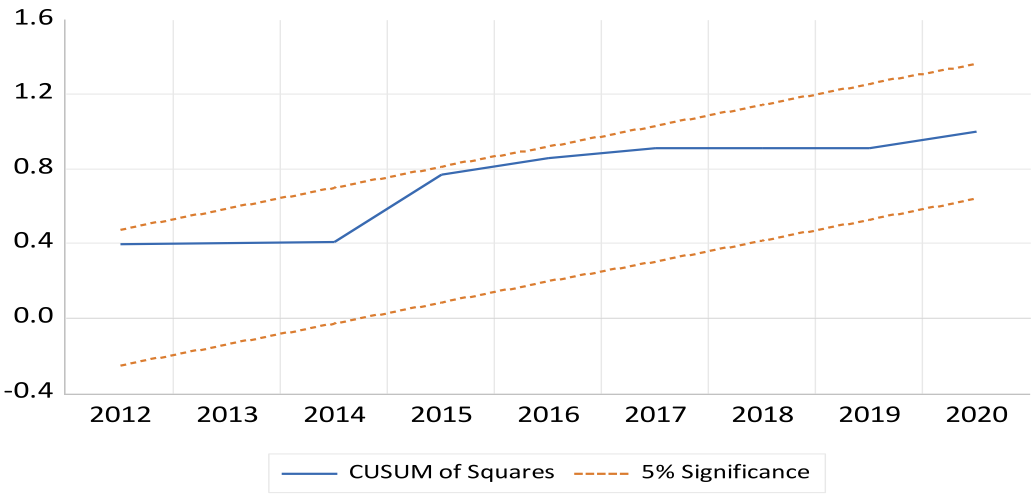

Figure 5. CUSUM of Squares Plot

6. Conclusion

This paper examines the asymmetric impact of trade openness (TO) on CO_2 emissions in Kenya, using data covering the period from 1990 to 2020. The paper employs a NARDL approach to examine this linkage. The results of the bounds test indicate the presence of a cointegration relationship among the variables included in the CO_2 equation. The BDS test findings also reveal that there is nonlinearity in the variables. The Wald test results for both short- and long-run asymmetries also provide evidence of an asymmetric relationship between TO and CO_2 emissions in Kenya. The NARDL results show that both positive and negative shocks in trade openness have no significant impact on CO_2 emissions in Kenya in the long run. However, in the short run, positive shocks (lTO^+) and CO_2 emissions move in the same direction, i.e., increases in positive shocks lead to an increase in carbon emissions. Unlike in the case of positive shocks, negative shocks to trade openness and CO_2 emissions were found to move in opposite directions, as indicated by the negative coefficient of (lTO^-). In addition, the results show that the effects of negative shocks are more pronounced than those of positive shocks. The findings of this study reveal that TO plays a significant role in the country's carbon emissions in the short run but not in the long run. It can be concluded that any short-term fluctuations in TO have a significant impact on carbon emissions. It is recommended that Kenya need to take measures to minimise carbon emissions associated with expansion in trade with other nations in the short run. Thus, the direction the country has taken to build capacity for renewable energy use among other less polluting sources of energy, is aligned to the findings of this study. Renewable energy exploration is likely to reduce the overreliance on fossil fuels, thereby mitigating the environmental degradation associated with fossil fuel exploration. Although necessary steps were taken to ensure the scientific rigour of the paper, future studies can benefit from expanding the study period and check the asymmetric impact of other variables on carbon emission, for example, economic growth and urbanization.

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