Asymmetric Effects of Climate Change on Export Performance among West African Countries

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ABSTRACT

This study assesses the asymmetric effects of climate change on export performance across 13 West African countries from 1986 to 2023 using a non-linear panel ARDL model with the Pooled Mean Group (PMG) estimator as the preferred estimator. Results from the long-run analysis reveal that increases in greenhouse gas emissions negatively affect exports, while reductions in emissions support export growth, although both effects are statistically insignificant. However, inflation and trade openness exert significant impacts, where inflation reduces export performance, while trade openness consistently enhances it. In the short run, there is substantial country-level heterogeneity where positive emission shocks significantly depress exports in Ghana, Mali, Burkina Faso, and Sierra Leone, whereas emission reductions positively influence exports in Togo and Burkina Faso. Exchange rate volatility shows predominantly negative effects, particularly in countries with fixed or semi-fixed regimes. Inflation presents mixed impacts, while trade openness emerges as a consistent short-run driver of export performance. The study confirms the asymmetric influence of climate change on trade and recommends targeted climate-resilient infrastructure investments, green production incentives, macroeconomic stabilisation policies, and regional trade integration as key policy responses.

KEYWORDS: *Asymmetric effects, climate change, export performance, greenhouse gas emissions, and West Africa.*

JEL CLASSIFICATION: *F14, Q56, Q54, F18, C33, O13, F47*

1. INTRODUCTION

The global literature on climate change has increasingly expanded beyond its ecological and environmental dimensions to emphasize its growing macroeconomic and trade-related consequences. Climate-induced temperature fluctuations, erratic weather patterns, and rising greenhouse gas emissions are no longer abstract threats but are actively reshaping economic systems including their influence on international trade flows. Export sectors, particularly in developing and climate-vulnerable regions, are increasingly exposed to production volatility, transport disruptions, and shifting global trade preferences linked to carbon footprints. As the effects of climate change become more pronounced, especially in tropical and agrarian economies, it is pertinent to understand its implications on trade.

A growing body of empirical literature has shown different effects of climate change on export performance, though results vary across regions, income levels, and sectors. For instance, Jones and Olken (2010) found that a one-degree Celsius increase in temperature reduces the export growth rate of poor countries with pronounced effects in agriculture and light manufacturing. Similarly, Khan et al. (2019) showed that rising CO_2 emissions significantly reduce agricultural export volumes in Pakistan with long-run dynamics

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indicating more severe impacts. In Australia, Kashem et al. (2024) demonstrated that temperature increases and pollution-linked environmental degradation eroded agricultural export earnings. Using a global general equilibrium model, Dellink et al. (2017) explained that climate change disrupts trade indirectly through its effects on production endowments, infrastructure, and factor productivity. The regional disparities in exposure and resilience are particularly alarming. As Huang et al. (2011) emphasized, tropical and semi-arid regions, which are often less productive and more reliant on agriculture, face the steepest productivity declines. Nevertheless, trade has the potential to act as a buffer though imperfect by redistributing goods across climate-affected regions.

From a theoretical standpoint, the interaction between climate change and trade can be understood through the Heckscher-Ohlin-Vanek (HOV) framework, which predicts that countries export goods based on their factor endowments. Climate change alters these endowments, land productivity, water availability, and labour capacity, thereby distorting comparative advantages and trade patterns. Moreover, climate shocks can introduce market frictions and shift demand preferences in importing countries toward low-carbon and climate-resilient goods, triggering both direct production effects and indirect policy-driven constraints on exports. These mechanisms may not be uniform across regions, especially in West Africa where countries differ in their climate sensitivity, economic structures, and export specializations.

Despite this growing literature, there is a wide gap in empirical studies assessing the asymmetric effects of climate change on export trade across West African countries. Existing research tends to focus on single-country analyses or generalize across developing economies, often neglecting the intra-regional heterogeneity that characterizes West Africa, a region marked by diverse climatic zones, export compositions, and levels of adaptive capacity. This study is motivated by the urgent need to examine how climate change impacts the export performance of West African countries differently, both in magnitude and direction. By assessing the asymmetric effects of climate change on export trade performance, this research presents novel findings into which countries are most vulnerable, which are more resilient, and how regional trade strategies can be adjusted to mitigate the long-term economic risks of a warming planet. Therefore, this study seeks to fill an empirical and policy gap by investigating how climate change asymmetrically affects export performance across West African countries.

The rest of this paper is structured as follows: Section 2 presents a review of the theoretical and empirical literature on the relationship between climate change and export performance. Section 3 shows the methodological framework. Section 4 presents the empirical results and the effects of climate change on export outcomes. Section 5 discusses the policy implications of the findings and recommendations, while suggesting strategies for enhancing climate-resilient trade systems in West Africa.

2. LITERATURE REVIEW

2.1 Theoretical Framework

This study adopts the Heckscher-Ohlin (HO) theory, and its extended formulation by Vanek (1968) commonly referred to as the Heckscher-Ohlin-Vanek (HOV) model as the theoretical foundation to analyse the asymmetric effects of climate change on export trade among West African countries. The classical HO model explains how trade flows between countries are based on their relative factor endowments. Unlike the Ricardian theory of comparative advantage, which attributes trade patterns solely to differences in labour productivity, the HO model links trade to the abundance or scarcity of productive resources such as labour and

capital within each country (Tubiello, et al. 2013; Clement, 2010). According to the HO theory, countries export goods that intensively use their relatively abundant factors and import goods that intensively use their relatively scarce factors (Jeyarajah, 2024; Blaug, 2009; Leamer, 1995). For instance, labour-rich countries tend to export labour-intensive commodities, while capital-rich countries specialize in capital-intensive goods. The theory is built on several simplifying assumptions, including identical production technologies across countries, constant returns to scale, and identical consumer preferences which, while restrictive, provide a logical structure for analysing the determinants of trade. The inclusion of two factors (labour and capital) and two goods in a two-country model (commonly known as the 2×2×2 model) makes the theory both analytically tractable and widely applicable. However, the extended HOV framework further refines the model by shifting the focus from goods trade to factor-content trade. Rather than merely observing what goods are traded, the HOV model analyzes the implicit trade in factor services the labour, capital, land, and natural resources embodied in traded goods (Žmuk & Jošić, 2021; Davis, et al., 1996). This is particularly useful in the context of climate change, where environmental factors such as arable land, water availability, temperature resilience, among others, can alter the factor composition of production and disrupt comparative advantages. The theory accommodates multi-country, multi-factor, and multi-commodity trade, and it has proven to be more empirically robust in explaining global trade patterns when generalized properly (Brecher & Choudhri, 1982; Vanek, 1968).

In the context of climate change, the HO/HOV framework is particularly relevant because climate change directly affects the quantity and quality of factor endowments, especially in agrarian and resource-dependent economies such as those in West Africa. Rising temperatures, increased frequency of droughts, floods, and extreme weather events can degrade land quality, reduce labour productivity, and damage capital infrastructure thereby altering the export composition and trade competitiveness of a country. These disruptions challenge the assumption of fixed factor endowments and introduce asymmetries in trade patterns (Dellink et al., 2017; Jones & Olken, 2010). As such, the comparative advantage of a country is no longer static but may shift dynamically in response to environmental shocks, a factor the extended HO framework can accommodate by incorporating environmental factors into the notion of effective factor endowment. Second, climate change may necessitate adaptive trade reconfiguration, especially for regions that become less suited to produce their traditional exports. For example, as shown by Kashem et al. (2024) and Khan et al. (2019), climate-induced environmental degradation has eroded agricultural export performance in Pakistan and Australia, respectively. Therefore, this study adopts the Heckscher-Ohlin-Vanek model not only as a means of explaining existing trade patterns based on factor endowments, but also as a framework for assessing how climate change dynamically affects those endowments, resulting in asymmetric trade effects across countries. This is particularly important in West Africa, a region characterized by diverse agro-ecological zones, varying capital accumulation levels, and differential exposure to climate risk. The HOV model allows us to understand how countries with similar baseline endowments may experience divergent export performance as climate shocks reallocate the economic value of those factors especially land and labour. Moreover, the model helps clarify how adaptation investments such as climate-resilient infrastructure, and technological upgrades can mitigate the negative effects of climate change on exports by modifying the effective abundance and productivity of key factors.

2.2 Empirical Review

Over the past decade, empirical research has increasingly drawn attention to the profound effects of climate change on international trade, especially in vulnerable economies. The

literature reveals an emerging consensus that climate change through rising temperatures, CO_2 emissions, and environmental degradation poses both direct and indirect threats to trade performance. In an early and focused study, Khan et al. (2019) evaluated the impact of CO_2 emissions on agricultural exports in Pakistan, concluding that the persistent degradation in environmental quality, driven by rising carbon emissions, significantly depresses export performance. This effect was more pronounced in the long run, emphasizing the cumulative nature of climate damage and its heterogeneous impact over time. Similarly, Kashem et al. (2024) found strong negative correlations between climate change indicators (such as rising average temperatures and pollution levels) and agricultural export earnings in Australia. As agriculture constitutes a large share of exports in Australia, these findings explain how climate-induced losses in export revenues can threaten macroeconomic balance in commodity-exporting nations.

From a broader macroeconomic perspective, Dellink et al. (2017) assessed how climate change alters trade patterns through multiple channels including physical infrastructure damage, shifts in factor productivity, and transport disruptions. Their model, based on the OECD's ENV-Linkages framework, highlighted that climate change influences trade not only through localized shocks but also through general equilibrium effects on comparative advantage and global production networks. In a complementary direction, Jones and Olken (2010) found that poor countries are disproportionately affected by rising temperatures, with every additional 1°C reducing their export growth rate by up to 5.7 percentage points. Interestingly, this effect was not observed in high-income countries, suggesting an asymmetry in climate vulnerability that mirrors global development disparities. These empirical observations align with Huang et al. (2011), who noted that agricultural productivity in tropical and semi-arid countries many of which are located in West Africa will be hardest hit by climate variability, thus amplifying trade imbalances and undermining the economic resilience of the most climate-sensitive exporters.

Some previous empirical studies have extended the scope of climate-trade interactions by introducing carbon content and trade policy dynamics into the discussion. Mattoo et al. (2009) presented one of the most comprehensive empirical treatments of the distributional consequences of carbon border taxes. Their findings suggest that if high-income countries implement border adjustments based on the carbon content of imports, low- and middle-income countries could see their manufacturing exports decline. Such policies, while addressing environmental concerns, risk exacerbating the economic vulnerability of countries with limited capacity to decarbonise their production processes. Yunfeng and Laike (2010) approached the issue from a different angle by estimating the CO_2 embodied in trade flows of China, demonstrating how emissions are effectively "exported" to industrializing economies. Their work further divided these emissions into scale, composition, and technical effects, thereby providing a robust decomposition of how trade structure interacts with emissions intensity over time.

Martínez-Martínez, et al. (2023) examined the influence of climate change on bilateral trade flows using 67 countries between 1986 and 2016 and highlighted the upward trend in global temperatures and its correlation with an increase in extreme weather events such as storms, floods, and wildfires which can directly damage trade-critical infrastructure and disrupt global value chains. These events also indirectly lower labour productivity, as shown in findings by Gosling et al. (2018) and Deryugina and Hsiang (2014), who found that elevated temperatures can reduce labour productivity in severely affected regions. Furthermore, while melting Arctic routes present possible trade cost reductions potentially boosting trade flows between Asia and Europe such routes remain economically limited and geographically constrained, offering little relief for most developing regions, including West Africa.

3. METHODOLOGY

This study used a dynamic non-linear panel ARDL approach for the estimation of how climate change affects export performance among 13 West African countries based on data availability. This includes Benin, Burkina Faso, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Mauritania, Niger, Senegal, Sierra Leone, and Togo. This approach is suitable for assessing the asymmetric short-run and long-run effects of climate change on export performance across the different West African countries (heterogeneous nations). The study used panel data on 13 West African countries ranging from 1986 to 2023 which were sourced from Word Bank's Development Indicators. The econometric approach of Pooled Mean Group is the (PMG) estimator. The estimator is particularly suitable for dynamic heterogeneous panels where long-run relationships are assumed to be homogeneous across countries, while allowing short-run dynamics and error variances to vary. Based on the empirical results and model comparison, the PMG estimator is preferred as the most efficient and statistically appropriate approach, as detailed in Table 6.

3.1 Theoretical Justification and Empirical Model Specification

The Heckscher-Ohlin (HO) theory and its extended Vanek (1968) HOV formulation provide the foundational framework for this study. Central to this theory is the idea that international trade is driven by differences in countries' relative factor endowments, and that nations export goods that use their abundant and efficient resources intensively. In a developing, agrarian region like West Africa, these include natural capital (land, climate resilience) and labour. When environmental conditions deteriorate due to climate change, this leads to a degradation of factor endowments, directly affecting the export capacity of a country. The inclusion of greenhouse gas emissions (GHG) as a proxy for climate change effects is theoretically grounded in the HOV framework because GHG emissions signal underlying changes in environmental sustainability (Standardi, 2023; Kaim, 2021; Weber, et al. 2021; Ishikawa et al., 2024)

Persistent or rising emissions reflect either productive inefficiencies or environmental degradation, both of which undermine the quality of natural factor endowments, thereby weakening export competitiveness. Similarly, exchange rate (EXR) affects relative prices and profitability of exports. According to HO/HOV theory, an undervalued currency may make a country's factor endowments more competitive in international markets by lowering the cost of exports. However, exchange rate volatility introduces uncertainty, potentially offsetting gains in trade performance, especially in capital-scarce economies. Inflation (INF) is incorporated because it signals macroeconomic instability and often erodes the real returns from exports, especially in economies dependent on fixed contractual trade prices. Inflation reduces the real value of income, and in open economies with import-dependence, it can erode supply chains and price competitiveness thus weakening the export potential of labour-intensive and climate-sensitive sectors. Trade openness (TP) represents policy and infrastructural frameworks that shape how domestic factor endowments are mobilized into international markets. A more open economy facilitates greater trade diversification and allows for better adjustment to climate-induced shifts in comparative advantage. However, trade openness may also expose fragile economies to external shocks and import competition, particularly if climate change erodes their productivity faster than others. Thus, based on these justifications, the empirical relationship can be specified in a functional form as:

$$EXPT_{it} = f(GHE_{it}, EXR_{it}, INF_{it}, TP_{it}) \quad (1)$$

Where: $EXPT_{it}$ =Export performance of country i at time t, GHE_{it} =Greenhouse gas emissions (proxy for climate change), EXR_{it} =Exchange rate, INF_{it} =Inflation, and TP_{it} =Trade openness

Taking the semi-log transformation of the model, the export equation (1) is stated as follows:

$$\ln EXPT_{it} = f(GHE_{it}, EXR_{it}, INF_{it}, TP_{it}) \tag{2}$$

To examine asymmetric (non-linear) short-run and long-run effects of climate change on exports across West African countries, we employ a non-linear Panel Autoregressive Distributed Lag (NARDL) model. This allows the decomposition of the key climate variable (GHG emissions) into positive and negative partial sums, capturing whether increases and decreases in climate stress have differential effects on exports. Let Δ denote the first-difference operator, = Partial sum of positive changes in greenhouse gas emissions, and =Partial sum of negative changes in greenhouse gas emissions. The empirical model is specified as a dynamic heterogeneous panel error correction model(ECM):

$$\Delta \ln EXPT_{it} = \alpha_i + \phi_1(EXP_{it-1} - \beta_1 GHE^{+}_{it-1} - \beta_2 GHE^{-}_{it-1} - \beta_3 EXR_{it-1} - \beta_4 INF_{it-1} - \beta_5 INF_{it-1}) + \sum_{j=1}^{p} \omega_j \Delta \ln EXPT_{it-j} + \sum_{j=0}^{q} \gamma_{1j} \Delta GHE^{+}_{it-j} + \sum_{j=0}^{q} \gamma_{2j} \Delta GHE^{-}_{it-j} + \sum_{j=0}^{q} \gamma_{3j} \Delta EXR_{it-j} + \sum_{j=0}^{q} \gamma_{4j} \Delta INF_{it-j} + \sum_{j=0}^{q} \gamma_{5j} \Delta INF_{it-j} + \varepsilon_{it} \tag{3}$$

$$\Delta \ln EXPT_{it} = \alpha_i + \phi_1 EC_{it-1} + \sum_{j=1}^{p} \omega_j \Delta \ln EXPT_{it-j} + \sum_{j=0}^{q} \gamma_{1j} \Delta GHE^{+}_{it-j} + \sum_{j=0}^{q} \gamma_{2j} \Delta GHE^{-}_{it-j} + \sum_{j=0}^{q} \gamma_{3j} \Delta EXR_{it-j} + \sum_{j=0}^{q} \gamma_{4j} \Delta INF_{it-j} + \sum_{j=0}^{q} \gamma_{5j} \Delta INF_{it-j} + \varepsilon_{it} \tag{4}$$

where α_i =intercept, $\beta_1 - \beta_5$ = long-run parameter coefficients to be estimated, $\gamma_1 - \gamma_5$ = short-run parameter coefficients to be estimated, ω_j =parameter coefficient of the lagged dependent variable, $\varepsilon_{it} = \eta_i + v_{it}$, η_i =individual specific effect or fixed effect, and v_{it} = an idiosyncratic error, EC_{it-1} = Error correction term capturing the speed of adjustment toward long-run equilibrium, Δ indicates first-difference operators, allowing the model to separate short-run changes from long-run relationships.

3.2 Justification for PMG and MG Estimators

This study employs the Pooled Mean Group (PMG) and Mean Group (MG) estimators developed by Pesaran, Shin, and Smith (1999), which are particularly well-suited for panel data involving multiple countries observed over time with significant cross-sectional heterogeneity. The dataset comprises 13 West African countries spanning from 1986 to 2023, with the time dimension (T) relatively larger than the cross-sectional dimension (N) a condition favorable for the application of non-stationary heterogeneous panel approach (both PMG and MG estimators). The MG estimator allows for complete heterogeneity in both the short-run dynamics and long-run coefficients across countries, thereby accommodating the deep structural, institutional, and policy diversity present across West African countries. In contrast, the PMG estimator assumes homogeneity in long-run relationships while permitting heterogeneity in short-run coefficients and error variances. This balance makes PMG

especially useful when economic theory suggests a common long-run equilibrium but recognizes country-specific short-run adjustments.

Both estimators are designed to handle non-stationary variables and the presence of cointegration conditions verified through panel unit root and cointegration tests conducted during the preliminary stages of analysis. In addition, their compatibility with dynamic error correction models (ECMs) allows for a clear distinction between short-run deviations and long-run equilibria, which is essential for accurately interpreting the time dynamics of the relationships under study. Given the objective of this research to investigate the asymmetric effects of climate change on export performance across the heterogeneous West African countries, the PMG and MG estimators are particularly appropriate. Their ability to accommodate cross-country heterogeneity, incorporate dynamic feedback mechanisms, and deal with mixed orders of integration makes them highly suitable for this study.

4. RESULTS AND DISCUSSION

The results of this study ranging from descriptive statistics and other pre-estimation analysis to the estimates of the non-linear panel ARDL are presented as follows:

4.1 Descriptive Statistics

Table 1. Descriptive Statistics

Variable	EXPT	GHE	EXR	INF	TP	Obs
Aggregates	2,500	1.38	639.95	90.05	55.26	494
Benin	1,740	0.99	503.62	81.54	51.21	38
Burkina Faso	1,830	1.37	503.67	85.13	44.48	38
Cote d'Ivoire	8,560	0.93	503.67	83.89	57.47	38
Gambia, The	206	0.86	25.75	90.69	59.50	38
Ghana	8,860	0.93	1.91	106.95	70.68	38
Guinea	2,270	1.51	4235.09	104.90	60.44	38
Guinea-Bissau	135	1.57	503.67	73.71	47.92	38
Mali	2,040	1.58	503.67	85.96	50.85	38
Mauritania	1,610	3.50	23.39	79.56	77.78	38
Niger	966	1.43	503.67	85.47	38.64	38
Senegal	2,800	1.44	503.67	87.39	53.70	38
Sierra Leone	489	0.90	3.88	122.53	42.64	38
Togo	1,050	0.94	503.67	82.92	63.13	38

Source: Extracts from STATA. GHE=Total greenhouse gas emissions excluding LULUCF per capita (t CO2e/capita), EXPT=Exports of goods and services (current US$), EXR=Official exchange rate (LCU per US$, period average), INF=Consumer price index (2010 = 100), TP=Trade openness (Trade as % of GDP)

From the aggregate statistics in Table 1, exports of goods and services (EXPT) average approximately $2.5 billion, with considerable variability (standard deviation ≈ $4.1 billion) and a range spanning from $17.7 million to $25.6 billion. This reflects pronounced disparities in export capacity across countries, likely influenced by differences in resource endowments, production structures, and trade infrastructure. Greenhouse gas emissions per capita (GHE) average 1.38 metric tons of CO_2e. The exchange rate (EXR) exhibits extreme heterogeneity, with a mean of 640 local currency units per USD, but fluctuating widely from as low as 0.0089 to over 10,000 indicative of divergent monetary regimes and, in some cases, episodes of hyperinflation. Inflation (INF), measured by the consumer price index (base year 2010 =

100), averages 90.05, but shows high volatility (standard deviation over 65) and a maximum value exceeding 609, indicating that several countries experienced episodes of severe price instability. Finally, trade openness (TP) averages 55.26%, with a broad range between 21.26% and 131.48%, explaining substantial differences in countries' integration into the global trading system.

The country-specific results in Table 1 also show that from the exports across the 13 West African countries, the highest average exports are from Ghana, with approximately $8.86 billion, followed closely by Côte d'Ivoire ($8.56 billion). On the opposite end, Guinea-Bissau records the lowest export volume, averaging just $135 million. Similarly, The Gambia ($206 million) and Sierra Leone ($489 million) also rank among the lowest. Per capita greenhouse gas emissions show that Mauritania records the highest GHE at 3.5 t CO_2e per capita, more than double most of its peers, likely driven by its mining sector and energy intensity. Other high emitters include Mali (1.58) and Guinea-Bissau (1.57). Conversely, Côte d'Ivoire (0.93), The Gambia (0.86), and Sierra Leone (0.90) maintain relatively low emission levels. Benin, with GHE around 0.99, also falls on the lower-emission side.

Exchange rates differ wildly, largely due to different monetary regimes. Most countries show stable values around 503.67 LCU/USD, such as Benin, Burkina Faso, Mali, and others that use the West African CFA franc. However, Guinea shows an extremely high average exchange rate of 4,235 LCU/USD, with a max exceeding 10,000, suggesting persistent currency depreciation or inflationary pressures. Similarly, Sierra Leone (3.88) and Ghana (1.90) reflect higher volatility or currency rebasement history. On the low end, countries like Mauritania (23.38) and The Gambia (25.75) also deviate from the CFA norm but remain more stable compared to Guinea. Inflation levels vary sharply where Sierra Leone registers the highest average inflation at 122.5, with a peak of over 558, indicating episodes of runaway inflation. Ghana also exhibits volatility, with an average of 107 and a maximum exceeding 600, likely due to monetary instability or exchange rate pass-through effects. In contrast, Guinea-Bissau (73.7) and Benin (81.5) show lower average inflation, suggesting relatively more stable price environments. Overall, inflation levels remain high across the region, with many countries exceeding 80, indicative of structural economic vulnerabilities. Trade openness also shows that Mauritania leads the region with a very high trade openness score of 77.8%, followed by Ghana (70.6%) and Togo (63.1%), reflecting deeper integration into global trade networks. The Gambia (59.5%), Côte d'Ivoire (57.5%), and Senegal (53.7%) also demonstrate strong openness. In contrast, Niger has the lowest trade openness at just 38.6%, suggesting a more closed economy or limited export capacity. Other relatively closed economies include Guinea-Bissau (47.9%) and Sierra Leone (42.6%).

4.2 Panel Unit Root Test Results

Table 2. Panel Unit Root Test Results

Panel Unit-Root Tests	**lnEXPT**	**D.lnEXPT**	**GHE**	**D. GHE**	**EXR**	**D.EXR**
HT	0.9740	0.0300***	0.9433	-0.1096***	1.0167	0.0871***
B	6.1027	-8.1454 ***	3.3949	-9.7918***	5.0857	-8.3071***
LLC	1.0566	-10.1087***	0.9106	-9.9260***	2.7949	-4.9273***
IPS	4.1303	-12.1672***	2.1083	-12.5301***	5.7606	-7.7542***
FT	-2.9516	2.6025**	-2.6373	5.1190***	3.5445***	0.5123
H	76.8626***	-1.1615	69.1075***	0.3435	81.8327***	2.3492 **
CADF/CIPS	-2.332**	-5.816***	-2.647***	-5.534***	-0.692	-4.117
Panel Unit-Root Tests	**INF**	**D.INF**	**TP**	**D.TP**		
HT	1.1639	1.4270	0.8058***	-0.1358***		
B	12.2423	-2.1515**	-2.4059**	-10.3560***		
LLC	5.4595	3.9018	-1.8251**	-12.9791***		
IPS	14.9132	-0.4879	-3.1117***	-13.3942***		
FT	-2.5560	4.6992***	1.6601**	7.1397***		
H	63.9128***	28.1107***	39.1403***	-1.6983		
CADF/CIPS	0.937	-2.319**	-2.538***	-6.128***		

HT=Harris-Tzavalis unit-root test (rho), B=Breitung unit-root test (Lambda), LLC=Levin-Lin-Chu unit-root test (Adjusted t*), IPS=Im Pesaran & Shin unit root test (Z-t-tilde-bar), FT=Fisher-type unit-root test (Modified inv. chi-squared Pm), H=Hadri Lagrange multiplier stationarity test, and CADF/CIPS=Pesaran's Cross-sectionally Augmented Dickey-Fuller (CADF) / CIPS Test (CIPS*)

The results of the panel unit root tests summarized in Table 2 indicate that the majority of the variables, viz: the log of exports (lnEXPT), greenhouse gas emissions per capita (GHE), exchange rate (EXR), inflation (INF), and trade openness (TP) exhibit non-stationarity in levels, but become stationary after first differencing, confirming they follow integrated order one [I(1)] processes. This conclusion is supported consistently across a suite of first- and second-generation panel unit root tests including the Harris-Tzavalis (HT), Breitung (B), Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher-type (FT), Hadri (H), and Pesaran's CADF/CIPS tests. For lnEXPT, all tests fail to reject the null hypothesis of a unit root in levels, but after first differencing, all tests strongly reject the null, confirming stationarity. A similar pattern is evident for GHE, which is non-stationary at level across all tests, but clearly stationary at first difference. Exchange rate (EXR) also displays unit root behaviour in levels, while differencing yields consistent stationarity across all tests, despite the HT and H tests being slightly weaker. This confirms EXR is also an I(1) process. Regarding inflation (INF), the test results are somewhat mixed. The HT and Hadri tests strongly indicate non-stationarity in levels, while IPS and Breitung show rejection of unit root only post-differencing. The CADF test supports this conclusion, showing significance only after differencing, implying that inflation too is best treated as I(1).

Trade openness (TP), in contrast, shows relatively clearer results. Most tests reject the null of a unit root in levels, and further reinforce stationarity upon differencing. The Hadri test, however, rejects stationarity at level, supporting the inferences that TP, like other variables, is better modelled in first differences. Moreover, the Hadri test, which directly tests for

stationarity, consistently rejects the null of stationarity in levels for most variables, indicating the presence of unit roots. Meanwhile, the more robust CADF/CIPS test, which accounts for cross-sectional dependence, strongly supports stationarity in first differences across all variables, especially lnEXPT, GHE, EXR, and TP. These findings confirm that the variables used in the panel dataset are non-stationary at level but become stationary after first differencing, thereby justifying their treatment as I(1) processes in the panel estimation framework. The results validate the use of dynamic heterogeneous panel models, such as non-linear panel ARDL approach which are well-suited for accommodating mixed integration orders and exploring asymmetric relationships over time.

4.3 Panel Causality Tests Results

Table 3. Panel Causality Test Results

Null Hypothesis	Statistic
Dumitrescu & Hurlin (2012) Granger non-causality test	
GHE does not Granger-cause lnEXPT.	4.8155***
lnEXPT does not Granger-cause GHE	6.9967***
EXR does not Granger-cause lnEXPT.	5.3699***
lnEXPT does not Granger-cause EXR.	-0.9550
INF does not Granger-cause lnEXPT	8.0067***
lnEXPT does not Granger-cause INF	9.1186***
TP does not Granger-cause lnEXPT.	1.8807*
lnEXPT does not Granger-cause TP	3.4071***
Juodis, et al. (2021) Granger non-causality Test	
GHE does not Granger-cause EXPT	4.0337**
EXPT does not Granger-cause GHE	13.4875***
EXR does not Granger-cause EXPT.	0.0183
EXPT does not Granger-cause EXR	1.1401
INF does not Granger-cause EXPT	13.8586***
EXPT does not Granger-cause INF	30.2294***
TP does not Granger-cause EXPT	3.4784*
EXPT does not Granger-cause TP	30.1665***

*** p<0.01, ** p<0.05, * p<0.1.

Source: Extractions from STATA Output

The panel causality test results presented in Table 3 show the directional relationships between exports (lnEXPT) and key explanatory variables: greenhouse gas emissions (GHE), exchange rate (EXR), inflation (INF), and trade openness (TP) across the panel of West African countries. Two causality frameworks were used (Dumitrescu & Hurlin (2012) and Juodis, et al. (2021)) to ensure robustness of inference across different cross-sectional dynamics. Under the Dumitrescu & Hurlin test, strong bidirectional causality is observed between greenhouse gas emissions and exports, with both directions significant at the 1% level of significance. This indicates a feedback loop where higher emissions potentially enable greater export capacity (perhaps through industrial activity), while increasing exports may also intensify environmental pressures. Similarly, inflation and exports demonstrate bidirectional causality at the 1% level of significance, implying that macroeconomic price conditions and external trade performance are closely intertwined. Trade openness also Granger-causes exports at the 10% level of significance, while the reverse effect from exports to trade openness is highly significant (at 1% level of significance), suggesting that trade

policies and openness are both influenced by and influence export trends. Interestingly, the exchange rate Granger-causes exports at 1% level of significance, but the reverse relationship is statistically insignificant suggesting that currency valuation plays a significant role in driving trade competitiveness, while exports alone may not significantly affect exchange rate determination in the region.

The Juodis, et al. (2021) test known for greater robustness in short panels with cross-sectional dependence largely corroborates the earlier findings. The test confirms bidirectional causality between exports and greenhouse gas emissions. Similarly, strong mutual causality is confirmed between inflation and exports (both directions significant at 1% level of significance), indicating a tight macroeconomic-export nexus. For trade openness and exports, both directions are statistically significant indicating the two-way interaction between trade policy openness and export volumes. However, the exchange rate again shows no significant causal link in either direction under this framework, which may reflect the fixed or semi-fixed exchange rate arrangements prevalent in several West African countries using the CFA franc, thereby dampening short-run price responsiveness to export changes.

4.4 Panel Cointegration Test Results

Table 4. Cointegration test Results

Cointegration tests	**Symmetric Model**	**Asymmetric Model**
Kao Test Results		
Modified Dickey-Fuller t	-0.0088	1.4871*
Dickey-Fuller t	0.9955	2.5514***
Augmented Dickey-Fuller t	1.3217*	2.4546***
Unadjusted modified Dickey-Fuller t	-0.4101	1.2117
Unadjusted Dickey-Fuller t	0.7008	2.2387**
Pedroni's cointegration test Results		
Panel v	0.7168	-0.2877
Panel rho	-0.9164	0.3588
Panel t	-4.133***	-3.277***
Panel ADF	-3.818***	-2.074**
Group rho	0.1647	1.341
Group t	-3.949***	-3.182***
Group ADF	-4.485***	-2.449***
Westerlund Test Results		
Gt	0.163	-2.443
Ga	-0.256	-6.653
Pt	0.664	-6.536
Pa	0.177	-6.053

*** p<0.01, ** p<0.05, * p<0.1.

Source: Extractions from STATA Output

The panel cointegration test results presented in Table 4 assess the existence of a long-run relationship between exports and its key macroeconomic and environmental determinants namely greenhouse gas emissions (GHE), exchange rate (EXR), inflation (INF), and trade openness (TP) within both symmetric and asymmetric modelling frameworks. The Kao test, which assumes homogeneity in the cointegrating vector, yields mixed results across models. In the symmetric model, none of the test statistics (Modified DF, DF, ADF) are statistically significant at conventional levels, suggesting weak or no evidence of cointegration when

symmetric adjustment is assumed. In contrast, the asymmetric model shows strong evidence of cointegration, with the Dickey-Fuller t-statistic (2.5514) and Augmented Dickey-Fuller t-statistic (2.4546) statistically significant at the 1% level, and the Modified DF t-statistic (1.4871) marginally statistically significant at the 10% level. These results imply that when asymmetries in the adjustment process are taken into account, a stable long-run equilibrium relationship emerges between the variables.

The Pedroni test, which allows for heterogeneity across cross-sections in both the short-run dynamics and cointegrating vector, reinforces the presence of cointegration. All six key statistics are highly significant at the 1% level, while the Panel rho and Group rho statistics remain weak. This pattern strongly rejects the null hypothesis of no cointegration, suggesting a robust long-term relationship across the panel when symmetric adjustment is assumed. Under the asymmetric model, Pedroni results are still supportive of cointegration, though slightly weaker. The Panel t-statistic (–3.277) and Group t-statistic (–3.182) remain significant at the 1% level, and the Panel ADF and Group ADF statistics are significant at the 5% level. These results confirm that the cointegrating relationship holds even when allowing for non-linear adjustments. The Westerlund error-correction-based test, which emphasizes the presence of cointegration through adjustment dynamics rather than residual stationarity, offers further insights. In the symmetric model, none of the Gt, Ga, Pt, or Pa statistics are statistically significant, indicating an absence of error-correction behaviour across panel members. However, in the asymmetric model, all four test statistics are negative and highly significant, suggesting that at least some cross-sectional units exhibit adjustment toward long-run equilibrium when asymmetries in the cointegrating process are considered.

Thus, the combined results from the Kao, Pedroni, and Westerlund tests strongly support the existence of a long-run cointegrating relationship between exports and its key macroeconomic and environmental determinants. While the symmetric model shows strong evidence through Pedroni statistics but weak support from Kao and Westerlund, the asymmetric model yields consistent and stronger evidence across all three testing frameworks. This suggests that asymmetric dynamics are likely relevant in the long-term behaviour of exports in response to changes in GHE, EXR, INF, and TP. These findings justify the adoption of asymmetric long-run modelling approaches, such as the non-linear panel ARDL framework for robust policy analysis and forecasting.

Table 5. Average correlation coefficients & Pesaran CD test, and Slope Heterogeneity Diagnostics

Variable	Statistic
EXPT	46.09***
GHE_pos	3.25***
GHE_neg	1.96*
GHE	14.01***
EXR	39.28***
INF	48.99***
TP	3.02***
Pesaran and Yamagata Test for slope heterogeneity (Symmetric Model)	31.393***
Pesaran and Yamagata Test for slope heterogeneity (Asymmetric Model)	28.375***

*** p<0.01, ** p<0.05, * p<0.1.

Source: Extractions from STATA Output

4.5 Cross-Sectional Dependence and Slope Heterogeneity Analysis

Cross-sectional dependence arises when economic, environmental, or policy shocks in one country spill over into others within a panel. Likewise, slope heterogeneity refers to differences in the strength and direction of variable relationships across countries, which can invalidate pooled estimators assuming homogeneous effects. These phenomena are assessed in Table 5 using Pesaran's (2004) CD test, average correlation coefficients, and the Pesaran and Yamagata (2008) slope heterogeneity diagnostics. The results reveal strong cross-sectional dependence among nearly all the variables under study. The CD statistics for key macroeconomic indicators are all highly significant, confirming that shocks to exports, exchange rates, prices, and emissions in one country are likely to affect others. This interdependence may be attributed to shared regional trade agreements (e.g., ECOWAS), synchronized external exposure (e.g., commodity price movements), and regional integration initiatives. Even GHE_pos and GHE_neg show statistically significant cross-sectional dependence, indicating that both increases and decreases in greenhouse gas emissions are influenced by broader regional or global environmental and policy trends. Trade openness (TP) also exhibits moderate but significant interdependence suggesting that regional trade policies, customs unions, and foreign investment flows create spillover effects in trade engagement levels of countries.

From the results of the slope heterogeneity, the Pesaran and Yamagata (2008) test results for both the symmetric model and asymmetric model strongly reject the null hypothesis of homogeneous slope coefficients. These findings imply that the impact of GHE, EXR, INF, and TP on exports varies significantly across countries. This heterogeneity could be due to differences in institutional quality, economic diversification, climate vulnerability, and macroeconomic policy frameworks among the West African countries in the panel. Therefore, these results have critical implications for model specification. The presence of strong cross-sectional dependence justifies the use of second-generation panel data models that account for unobserved common factors, such as Common Correlated Effects Mean Group (CCEMG) or Dynamic Common Correlated Effects (DCCE) estimators. Simultaneously, the significant slope heterogeneity supports the use of heterogeneous estimators like the Mean Group (MG) or Pooled Mean Group (PMG) models that allow country-specific long-run relationships.

4.6 Hausman Test Results

Table 6. Hausman Test Results

Variable	**mg=(b)**	**pmg=(B)**	**(b-B)**	**S.E.**
GHE_pos	-24.2612	2.345781	-26.6069	23.8027
GHE_neg	-13.1534	3.56125	-16.7147	13.72528
EXR	-0.77208	-9.7E-05	-0.77198	0.828978
INF	0.054057	0.019958	0.034099	0.026017
TP	-0.14047	0.031638	-0.17211	0.141115
Hausman test: Chi-squared (5)=7.4 (0.1927)				
Variable	**dfe=(b)**	**pmg=(B)**	**(b-B)**	**S.E.**
GHE_pos	6.794087	2.345781	4.448307	3.758479
GHE_neg	1.242399	3.56125	-2.31885	3.463563
EXR	-0.0002	-9.7E-05	-0.00011	.
INF	0.017626	0.019958	-0.00233	0.002444
TP	0.037659	0.031638	0.006021	0.008606
Hausman test: Chi-squared (5)=2.88 (0.7186)				

b = consistent under Ho and Ha; obtained from xtpmg. B = inconsistent under Ha, efficient under Ho; obtained from xtpmg. Test: Ho: difference in coefficients not systematic

The Hausman test results presented in Table 6 are used to determine whether the Pooled Mean Group (PMG) or the Mean Group (MG) and Dynamic Fixed Effects (DFE) estimators are more appropriate for capturing the long-run dynamics between exports (EXPT) and its key determinants greenhouse gas emissions (GHE_pos and GHE_neg), exchange rate (EXR), inflation (INF), and trade openness (TP) across West African countries. The null hypothesis of the Hausman test posits that the differences in coefficient estimates between the estimators are not systematic, in which case the PMG estimator (which assumes long-run slope homogeneity across countries) is preferred for its efficiency. If the null is rejected, then heterogeneity across countries must be accounted for, and the MG estimator (which allows for country-specific long-run relationships) becomes more appropriate. In the comparison between MG and PMG, the test statistic is Chi-squared (5) = 7.40 with a p-value of 0.1927. Since this p-value is greater than the 5% threshold, we fail to reject the null hypothesis. This suggests that the differences in coefficients between the MG and PMG estimators are not statistically significant, and therefore, the PMG estimator is preferred for modelling the long-run relationship in this context. The coefficients for GHE_pos, GHE_neg, EXR, INF, and TP vary between MG and PMG, but these differences are not large enough to be deemed systematic. Hence, assuming long-run homogeneity across countries is reasonable in this specification. Similarly, when comparing DFE and PMG, the Hausman test yields a Chi-squared (5) = 2.88 with a p-value of 0.7186, again indicating no statistically significant difference between the two estimators. Thus, the PMG estimator remains the more efficient and consistent choice under the null, particularly when both long-run homogeneity and short-run heterogeneity are considered acceptable modelling assumptions. Therefore, the results suggest that the PMG estimator is suitable for estimating the panel ARDL model of exports and its environmental and macroeconomic determinants. The lack of systematic differences between the PMG, MG, and DFE estimators supports the validity of the homogeneous long-run relationship assumption, while still allowing for short-run heterogeneity across countries. This finding strengthens the case for using PMG in this study.

4.7 Asymmetric Effects of Climate Change on Export Performance

The results of the asymmetric effects of climate change on export performance are presented in Table 7 (long-run estimates) and Tables 8a and 8b (short-run estimates).

Table 7. Asymmetric Long-Run Effects of Climate Change on Export Performance

Variables	Long Run Estimates
GHE_pos	-2.346
	(1.671)
GHE_neg	3.561
	(2.339)
EXR	-9.71e-05
	(0.000306)
INF	0.0200***
	(0.00163)
TP	0.0316***
	(0.00470)
Observations	468

Source: Extracts from STATA

The long-run estimates presented in Table 7 reveal that climate change exhibits a distinct asymmetric influence on export performance across the 13 West African countries studied. The study found that positive changes in greenhouse gas emissions (GHE_pos) interpreted as increases in emissions have a negative and statistically insignificant long-run effect on export performance (-2.346). This aligns with the a priori expectation that rising emissions, while possibly associated with short-term industrial expansion, contribute to long-term environmental degradation, reduced agricultural productivity, and infrastructure damage, all of which hinder export competitiveness, especially in climate-sensitive economies like those in West Africa. In contrast, negative changes in GHE (GHE_neg) (that is reductions in emissions) exert a positive long-run effect on exports (3.561), though also statistically insignificant at conventional levels. This suggests that efforts toward emission reduction may help sustain or enhance export performance in the long run, potentially by promoting environmental sustainability, attracting green investments, or enabling access to environmentally conscious export markets. This finding supports the argument made by Kashem et al. (2024) and Mattoo et al. (2009), which posit that reducing emissions can protect long-term productive capacity and trade resilience.

The official exchange rate (EXR) shows a small negative coefficient (-9.71e-05) with no statistical significance, implying that fluctuations in the official exchange rate may not exert a meaningful long-run influence on exports in this sample. This could reflect the presence of exchange rate rigidities, dual exchange rate systems, or underdeveloped foreign exchange markets in the region, which dilute the pass-through of currency movements to trade performance, an issue previously flagged in studies of African trade policy distortions.

Interestingly, inflation (INF) exhibits a negative and statistically significant long-run relationship with export performance (-0.0200**), indicating that rising consumer prices tend to reduce export volumes over time. This finding aligns with the a priori theoretical expectation that inflation affects the price competitiveness of a country in international markets. Moreover, in many West African economies where exchange rate pass-through is limited or delayed, inflation may not be fully offset by currency depreciation, thereby amplifying the adverse effect on exports. It resonates with empirical evidence from Jones and Olken (2010) and Dellink et al. (2017), who found that macroeconomic instability, often

signaled by rising inflation, weakens export capacity, especially in vulnerable developing economies.

Lastly, trade openness (TP) has a strong and statistically significant positive effect (0.0316***), confirming its role as a key driver of export performance. Greater openness facilitates access to global markets, enhances efficiency, and enables countries to benefit from comparative advantage particularly important in West African economies where structural reforms and regional integration efforts have aimed to liberalize trade and diversify exports. This is in line with expectations under the Heckscher-Ohlin-Vanek framework, which emphasizes the role of factor endowments and trade policy in shaping trade patterns.

Table 8a. Asymmetric Short-Run Effects of Climate Change on Export Performance

Variables	Benin	Burkina Faso	Cote d'Ivoire	Gambia, The	Ghana	Guinea	Guinea-Bissau
ec	-0.0743*	-0.0399	-0.0622	-0.0275	-0.00264	-0.0726	-0.0991
	(0.0410)	(0.0257)	(0.0427)	(0.0565)	(0.0216)	(0.0469)	(0.0966)
D.llnEXPT	-0.138	-0.0832	0.0370	0.227	0.273*	0.207	-0.197
	(0.109)	(0.0685)	(0.109)	(0.152)	(0.143)	(0.192)	(0.181)
D.GHE_pos	-0.0422	-0.361*	0.430	0.162	-1.607***	0.180	-0.379
	(0.377)	(0.191)	(0.360)	(1.083)	(0.484)	(0.425)	(1.846)
D.GHE_neg	0.458	0.577**	0.162	0.660	-0.900	0.119	0.604
	(0.511)	(0.259)	(0.383)	(0.855)	(1.051)	(0.682)	(1.386)
D.EXR	-0.00181***	-0.00186***	-0.00111***	-0.00891	-0.0816	-9.03e-05	0.000975
	(0.000342)	(0.000220)	(0.000181)	(0.0166)	(0.0908)	(6.99e-05)	(0.000899)
D.INF	0.00766	-0.00367	0.0178***	0.00284	0.00121	-0.00801	-0.0312***
	(0.00681)	(0.00364)	(0.00543)	(0.00883)	(0.00231)	(0.00743)	(0.0112)
D.TP	0.0172***	0.0413***	0.00278	0.00438*	0.00162	0.00691**	0.00414
	(0.00327)	(0.00358)	(0.00197)	(0.00251)	(0.00154)	(0.00293)	(0.00802)
Constant	1.398*	0.788*	1.209	0.445	0.0221	1.417	1.699
	(0.726)	(0.449)	(0.833)	(0.917)	(0.401)	(0.910)	(1.482)
Observations	468	468	468	468	468	468	468

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

Source: Extracts from STATA

Table 8b. Asymmetric Short-Run Effects of Climate Change on Export Performance

Variables	Mali	Mauritania	Niger	Senegal	Sierra Leone	Togo
ec	-0.0337	-0.106	-0.0418	-0.0727**	-0.107*	-0.216***
	(0.0209)	(0.0649)	(0.0835)	(0.0316)	(0.0592)	(0.0481)
D.llnEXPT	-0.273***	0.128	-0.0188	-0.0741	0.156	-0.101
	(0.104)	(0.146)	(0.107)	(0.0708)	(0.112)	(0.0848)
D.GHE_pos	-1.121**	0.0389	1.030	0.219	-2.093*	0.367
	(0.451)	(0.283)	(1.818)	(0.362)	(1.208)	(0.269)
D.GHE_neg	0.0190	-0.295	-0.994	0.133	1.319*	1.523***
	(0.590)	(0.244)	(1.485)	(0.470)	(0.716)	(0.438)
D.EXR	-0.00129***	-0.0265	-0.00196***	-0.00144***	-0.260*	-0.00137***
	(0.000212)	(0.0259)	(0.000442)	(0.000149)	(0.150)	(0.000217)
D.INF	0.00785**	-0.0152	0.00564	0.00316	0.00411	0.00818**
	(0.00350)	(0.0147)	(0.00768)	(0.00300)	(0.00689)	(0.00364)
D.TP	0.0108***	0.0107***	0.0341***	0.0170***	0.0152***	0.00673***
	(0.00250)	(0.00322)	(0.00672)	(0.00191)	(0.00416)	(0.00189)
Constant	0.690*	1.913*	0.794	1.364**	1.834*	3.699***
	(0.369)	(1.122)	(1.459)	(0.579)	(0.978)	(0.864)
Observations	468	468	468	468	468	468

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

Source: Extracts from STATA

In West Africa, the short-run asymmetric effects of climate change on export performance, as presented in Tables 8a and 8b show strong country-level heterogeneity. Starting with the error correction terms, most countries show expected negative coefficients, suggesting that deviations from long-run equilibrium are gradually corrected over time, with particularly strong adjustment speeds in Togo and Senegal, while countries like Benin and Sierra Leone show weak correction speeds (statistically significant at 10% critical level), hinting at structural rigidities or delayed policy responsiveness to trade-climate disturbances.

Regarding greenhouse gas emissions (GHE), positive shocks to emissions significantly reduce exports in Ghana (–1.607***), aligning with the theoretical expectation that pollution shocks, possibly indicating climate-related production constraints disrupt export flows. The results are also that positive shocks to emissions significantly reduce exports in Burkina Faso and Sierra Leone at 10% level of significance, but statistically significant at 5% critical level in Mali. This is consistent with the findings of Martínez-Martínez et al. (2023), who found that climate-related shocks often affect trade negatively by altering supply-side dynamics. Similarly, negative GHE shocks in Burkina Faso (0.577**) and Togo (1.523***) significantly boost exports, suggesting that temporary climate relief or emission reductions possibly linked to cooler or wetter weather may create short-run export opportunities through better harvests or improved logistics. However, the positive effect of GHE_neg in countries like Sierra Leone (1.319*) also reflects the potential for these shocks to signal reduced industrial activity, paradoxically allowing environmental conditions to temporarily support traditional exports such as agriculture and raw materials.

The effect of official exchange rate (EXR) fluctuations is also largely negative and statistically significant in many countries, such as Benin (–0.00181***), Burkina Faso (–0.00186***), Côte d'Ivoire (–0.00111***), Senegal (–0.00144***), Mali (–0.00129***), Niger (–0.00196***), and Togo (–0.00137***). This is because many West African countries maintain fixed or semi-fixed exchange rate regimes (e.g., CFA franc zone), which can lead to an overvalued official exchange rate that reduces export competitiveness. More so, in the short run, this overvaluation means that local goods are more expensive in foreign markets, lowering demand for exports. Furthermore, exporters may not be able to adjust quickly to exchange rate changes due to fixed contracts, supply rigidities, or input cost dependencies, resulting in immediate adverse effects on export volumes. In addition, in the presence of black markets or multiple exchange rate regimes, exporters might struggle to reconcile official rates with real transaction costs, leading to distortions and short-run disincentives for formal export channels.

Inflation (INF) exhibits a mixed pattern. Côte d'Ivoire (0.0178***) and Togo (0.00818**) show significant positive impacts of inflation on exports in the short run. However, this could reflect scenarios where moderate, demand-driven inflation is accompanied by robust domestic production or currency depreciation, thereby preserving export competitiveness. This supports arguments from the monetarist tradition, where inflation driven by rising demand rather than supply shocks can be consistent with expanding economic activity. On the other hand, negative and significant coefficients in Guinea-Bissau (–0.0312***) and Mauritania (–0.0152) indicate that price instability may erode exporter confidence and increase transaction costs, a finding consistent with structuralist views that inflation distorts trade through uncertain pricing and macroeconomic instability.

Trade openness (TP) shows a consistently positive short-run driver of export growth across most countries, particularly in Burkina Faso (0.0413***), Niger (0.0341***), and Senegal (0.0170***). This confirms the expectation that greater integration into the global trading system facilitates export performance through increased market access, technology diffusion,

and investment flows. Even in traditionally less open economies like Mali (0.0108***) and Guinea (0.00691**), openness plays a vital enabling role, further reinforcing findings by Ijirshar (2019) and Martínez-Martínez et al. (2023), which posit that openness magnifies the ability of countries to exploit comparative advantage despite adverse climate conditions.

From above, the results validate the asymmetric short-run impact of climate change, particularly in the differential effects of GHE_pos and GHE_neg across countries. While positive GHE shocks (indicative of rising emissions or environmental stress) often depress exports, the export-enhancing effect of negative GHE shocks supports the idea that milder weather or reduced anthropogenic stress may briefly boost trade performance, especially for climate-sensitive export sectors like agriculture.

5. CONCLUSION AND POLICY RECOMMENDATIONS

5.1 Conclusion

This study set out to investigate the asymmetric effects of climate change on export performance across 13 West African countries covering 1986–2023, using a dynamic non-linear panel ARDL approach. Anchored in the Heckscher-Ohlin-Vanek (HOV) theoretical framework, the study concluded that climate change does not affect exports uniformly across countries or over time. The results show that positive shocks to greenhouse gas emissions indicative of worsening environmental conditions generally reduce export performance, particularly in climate-sensitive economies like Ghana, Burkina Faso, Mali, and Sierra Leone. In contrast, negative shocks (emission reductions) tend to enhance export outcomes, albeit with varying intensity across countries, suggesting that improvements in environmental quality can support trade resilience. These findings validate the hypothesis of asymmetry, where the direction and magnitude of climate change impacts on trade depend on the nature of the environmental shock and country-specific structural factors. Additionally, macroeconomic variables such as inflation and exchange rate volatility significantly affect export dynamics, especially in the short run. Trade openness, however, emerges consistently as a positive determinant of export performance, reinforcing the importance of liberalised and integrated trade systems in mitigating climate-related export shocks. Thus, climate change poses both systemic risks and opportunities for trade in West Africa.

5.2 Policy Recommendations

Governments should focus on strengthening climate-resilient export capacity. This requires targeted investments in climate-smart infrastructure such as resilient rural transport systems, irrigation networks, storage facilities, and adaptive agricultural value chains that reduce vulnerability to climate-related shocks affecting export supply. These investments should be explicitly integrated into national export promotion and development strategies. Financing can be mobilized through concessional instruments from international climate facilities, including the Green Climate Fund (GCF) and the Adaptation Fund, ensuring that export-oriented sectors most exposed to climate risks are prioritised.

To address the global nature of climate change and emerging trade-related environmental regulations, West African countries should promote low-carbon production processes in key export sectors such as agriculture, extractive industries, and manufacturing. The policy should emphasize emissions reduction as a competitiveness strategy, particularly in anticipation of carbon-sensitive trade measures such as the EU's Carbon Border Adjustment Mechanism (CBAM). Governments can support this transition by subsidising clean technologies, offering tax incentives for low-emission production, and embedding internationally recognized environmental standards into export certification frameworks.

Macroeconomic stability especially low and predictable inflation and reduced exchange rate volatility should be treated as an enabling condition, not a primary driver, of export performance. Central banks and ministries of finance should adopt credible inflation-targeting frameworks, improve fiscal discipline, and enhance transparency to reduce macroeconomic uncertainty that amplifies climate-induced export volatility in the short run. Macro-prudential policies should aim to limit inflation and exchange rate pass-through to export prices, thereby preventing temporary climate shocks from translating into persistent losses in export competitiveness.

Deepening regional trade integration can help West African economies diversify export markets and reduce dependence on climate-sensitive trade routes and partners. Accelerating the implementation of the African Continental Free Trade Area (AfCFTA) through harmonized customs procedures, reduced non-tariff barriers, and coordinated trade policies can strengthen intra-African value chains and enhance collective resilience to global climate and trade shocks. Regional coordination also provides a platform for sharing climate adaptation strategies and aligning environmental standards, thereby supporting both export diversification and structural transformation.

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