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Examining the Threshold Effects of Government Governance on the Relationship Between Globalization, Government Effectiveness, and Environmental Pollutant Quality in Selected Developing Countries

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A B S T R A C T

Given the significance of the topic and the undeniable role of the environment in human life, this study seeks to examine the threshold effects of government governance on the relationship between globalization, government effectiveness, and the quality of environmental pollutants in selected developing countries during the period 2005 to 2023, using the Panel Smooth Transition Regression (PSTR) model. The research sample includes selected MENA and Middle Eastern countries, namely Saudi Arabia, Qatar, Pakistan, the United Arab Emirates, Algeria, Kuwait, Iran, Egypt, Oman, Morocco, Libya, Yemen, and Sudan. The findings reveal that by employing a PSTR model in which the transition variable is trade volume (EG) in the first model and government governance (INST) in the second model, the functional relationship between economic globalization and environmental quality can be modeled. The estimated results for the linear part of the first and second models (Regime 1) indicate that trade volume (EG) and gross domestic product (GDP) have a positive relationship with nitrogen dioxide (NO_2) emissions. Specifically, a one-unit increase in trade volume and GDP leads to an increase of 0.21 and 0.22 units in greenhouse gas emissions, respectively, in the first model. Furthermore, the variable of governance quality (INST) in the second model results in a reduction of 0.12 units in nitrogen dioxide (NO_2) emissions, and the interaction term of government governance with trade volume (INST × EG) reduces NO_2 emissions by 0.11 units. Additionally, the estimated results for the nonlinear part of the first and second models (Regime 2) confirm the presence of a positive relationship between trade volume (EG) and gross domestic product (GDP) with nitrogen dioxide (NO_2) emissions.

Keywords: *Government governance; globalization; government effectiveness; environmental pollutants; selected developing countries*

1. Introduction

In recent decades, rapid globalization and dynamic economic integration have reshaped trade flows, production networks, and resource allocation patterns worldwide, while simultaneously placing unprecedented pressure on environmental systems (Lu et al., 2024; Udemba et al., 2024). Global value chains, technological diffusion, and capital mobility have accelerated economic growth and improved living standards; however, these processes have also intensified greenhouse gas emissions, biodiversity loss, and natural resource depletion (Ahmad et al., 2023; Awosusi et al., 2023). Developing countries in particular face a dual challenge: capturing the benefits of global markets to fuel economic progress while mitigating the environmental externalities that threaten sustainable development (Azimi et al., 2023; Yasmeen et al., 2023).

Among the critical factors mediating the globalization–environment nexus is the quality of governance. Governance frameworks, including regulatory quality, institutional capacity, and the rule of law, fundamentally determine whether economic openness leads to environmental upgrading or degradation (Azimi et al., 2023; Nemati et al., 2023). Strong institutions can enforce environmental regulations, incentivize green innovation, and channel foreign direct investment toward cleaner technologies (Lu et al., 2024; Wan et al., 2022). Conversely, weak governance may allow regulatory capture, unsustainable resource exploitation, and pollution-intensive industrial expansion (Abbas et al., 2022; Baqerian Kasgari, 2023).

Economic globalization itself is multifaceted, encompassing trade openness, foreign investment flows, and technology transfers. Trade can enhance environmental outcomes when it facilitates the diffusion of cleaner technologies, environmental goods, and sustainability-oriented standards (Bacchetta et al., 2022; Doan & Ha, 2022). However, trade liberalization can also increase emissions if comparative advantages are linked to pollution-intensive industries or if regulatory frameworks are too weak to internalize environmental costs (Balogh & Borges Aguiar, 2022; Kohli, 2022). This "pollution haven" dynamic remains a concern for many emerging economies seeking export competitiveness without sufficient environmental safeguards (Baqerian Kasgari, 2023).

Governance quality strongly shapes these trade–environment interactions. High-quality governance enhances transparency, strengthens environmental regulations, and increases the capacity of states to implement climate commitments (Azimi et al., 2023; Yasmeen et al., 2023). For example, empirical evidence shows that countries with effective regulatory regimes are better able to attract green technology transfers and implement carbon taxation frameworks that discourage emissions (Abbas et al., 2022; Yasmeen et al., 2023). In contrast, low institutional capacity exacerbates resource misallocation and fosters unsustainable industrialization, often under foreign investment pressure (Nemati et al., 2023; Oteng et al., 2023).

A related body of work examines the role of government effectiveness and political stability in achieving long-term environmental objectives. Effective governments are better positioned to integrate sustainability into macroeconomic policies, align fiscal incentives with low-carbon transitions, and enforce environmental standards (Awosusi et al., 2023; Kirikkaleli & Osmanlı, 2023). Political instability, however, disrupts policy continuity, weakens enforcement, and creates uncertainty that deters sustainable investment (Kirikkaleli & Osmanlı, 2023; Rosser, 2022). These institutional characteristics determine whether globalization acts as a catalyst for environmental improvements or a driver of degradation (Lu et al., 2024; Sheikh, 2023).

Another crucial dimension concerns technological innovation and its interaction with governance structures. Technological advancement, particularly in renewable energy and clean production systems, has proven instrumental in reducing ecological footprints (Ahmad et al., 2023; Fuinhas et al., 2023). However, the diffusion of such innovations is highly dependent on governance quality; states with robust institutions and effective environmental policies are better able to support R&D, enforce intellectual property rights, and adopt green technologies (Tan et al., 2024; Wan et al., 2025). Conversely, in settings with weak oversight, technology adoption can be slow or uneven, limiting environmental progress despite economic integration (Udemba et al., 2024; Zhao et al., 2022).

Energy systems and resource dependency also intersect with globalization and governance quality. Overreliance on fossil fuels, especially in resource-rich developing countries, amplifies carbon emissions and weakens environmental sustainability (Li et al., 2023; K. Wang et al., 2023). Governance effectiveness is essential for diversifying energy portfolios, incentivizing renewable energy deployment, and implementing environmental taxes (Awosusi et al., 2023; Lu et al., 2024). Empirical studies demonstrate that economies that invest in renewable energy and maintain strong institutional oversight achieve both

economic growth and environmental protection (Fuinhas et al., 2023; G. Wang et al., 2023).

An emerging area of research emphasizes the importance of environmental audits, public procurement, and market-based instruments in aligning globalization with sustainability goals. Rigorous government-led environmental audits can improve corporate compliance and reduce emissions (Tan et al., 2024; Wan et al., 2025). Greening public procurement, through transparent and sustainability-oriented purchasing policies, can stimulate demand for low-carbon technologies and influence corporate environmental performance (Shahin et al., 2024). Such mechanisms depend critically on governance quality, as only capable and transparent institutions can implement complex monitoring and enforcement systems effectively (Luo et al., 2023; Rosser, 2022).

In addition, the demographic and social structures of countries mediate the environmental effects of globalization. Rapid urbanization and population aging, combined with technological progress, shape energy consumption patterns and carbon emissions (Udemba et al., 2024; Zheng et al., 2023). Countries with robust governance can better manage urban growth through sustainable infrastructure and transport policies (Zhao et al., 2022), while poorly governed systems often experience unplanned expansion, inefficient energy use, and high pollution levels (Oteng et al., 2023).

Trade liberalization in environmental goods offers another pathway to reconcile economic growth with environmental objectives. By reducing tariffs and non-tariff barriers on green technologies, governments can facilitate access to pollution-control equipment and renewable energy solutions (Bacchetta et al., 2022; Baqerian Kasgari, 2023). Yet the effectiveness of such trade policies relies on regulatory quality and institutional enforcement to ensure that imports genuinely support environmental upgrading rather than displacing domestic innovation (Doan & Ha, 2022; Huang & Wu, 2022).

Moreover, global experiences demonstrate that governance interacts with fiscal and financial instruments to support environmental sustainability. The availability of green financing mechanisms, when combined with institutional capacity, accelerates investments in renewable energy and energy-efficient infrastructure (Lu et al., 2024; Wan et al., 2022). Financial globalization can also encourage or undermine sustainability depending on the domestic regulatory environment; countries with strong institutions attract environmentally conscious capital, while weak governance may facilitate unsustainable lending and speculative activities (Li et al., 2023; Tan et al., 2024).

From a methodological perspective, recent studies advocate for advanced econometric approaches to better capture the non-linear and threshold dynamics inherent in the globalization–environment–governance nexus. Traditional linear models often fail to detect regime shifts triggered by institutional changes or trade intensity (Azimi et al., 2023; Lu et al., 2024). Panel Smooth Transition Regression (PSTR) models, for instance, have been successfully applied to detect how environmental outcomes change once governance quality surpasses certain critical levels (Kirikkaleli & Osmanlı, 2023; Nemati et al., 2023). Such approaches are crucial for informing policymakers on when and how globalization becomes either environmentally beneficial or harmful.

Despite the growing empirical evidence, significant gaps remain in understanding how governance thresholds alter the trade–environment relationship, especially in developing and resource-dependent economies. Many studies have focused on advanced economies or have treated governance as a linear moderator, overlooking the possibility that its influence may intensify beyond specific institutional quality levels (Doan & Ha, 2022; Nikkhah Serneghi & Karim, 2022). Additionally, research integrating multiple governance dimensions—such as regulatory quality, political stability, and corruption control—with trade and globalization measures remains limited (Oteng et al., 2023; Sheikh, 2023).

The present study contributes to this literature by examining the threshold effects of government governance on the relationship between economic globalization and environmental quality in selected developing countries.

2. Methods and Materials

The purpose of this study, following the works of Yamgo et al. (2021), Ali Nasir et al. (2021), and Imran Hanif Hanjra et al. (2020), is to analyze the relationship between economic globalization and environmental quality, with an emphasis on the threshold effects of government governance. The general form of the Panel Smooth Transition Regression (PSTR) model, considering that the dependent variable is environmental quality and the explanatory variables are globalization and government governance, is as follows:

(1)

$$NO_{2t} = \alpha_0 + \beta_1 EG_t + \beta_2 RQ_t + \beta_3 CC_t + \beta_4 GDP_t + \beta_5 GE_t + (\theta_1 EG_t + \theta_2 RQ_t + \theta_3 CC_t + \theta_4 GDP_t + \theta_5 GE_t) F(S_t, \gamma, c) + u_t$$

(2)

$$NO_{2t} = \alpha_0 + \beta_1 EG_t + \beta_2 INST_t + \beta_3 EG \times INST_t + \beta_4 GDP_t + \beta_5 GE_t + (\theta_1 EG_t + \theta_2 INST_t + \theta_3 EG \times INST_t + \theta_4 GDP_t + \theta_5 GE_t) F(S_t, \gamma, c) + u_t$$

where the transition function F is defined as:

(3)

$$F(\gamma, s_t, c) = (1 + \exp\{-\gamma (s_t - c)\})^{-1}, \gamma > 0$$

Variable definitions:

- $NO_{2i,t}$: Environmental quality measured by the nitrogen dioxide (NO_2) greenhouse gas emissions index of country *i* in year *t*. Consistent with Ali Nasir et al. (2021), NO_2 is used as the indicator for greenhouse gas emissions.
- RQ: Regulatory Quality, an index ranging from 0 to 100, where higher values indicate improved quality of regulations.
- INST: Governance Quality Index. This is constructed using a weighted average of five subcomponents: (1) size of government, (2) legal system and property rights, (3) sound money, (4) freedom to trade internationally, and (5) regulation of credit, labor, and business. The Fraser Institute provides the underlying measures, averaging the five subindices to yield a comprehensive governance quality indicator for each country, where 0 represents the lowest and 10 represents the highest governance quality.
- GE: Government Effectiveness, an index ranging from 0 to 100, with higher values representing stronger governmental effectiveness.
- CC: Control of Corruption, an index ranging from 0 to 100, with higher values indicating greater corruption control.
- EG: Trade volume as a percentage of gross domestic product (GDP), used as the indicator of economic globalization.
- GDP: Real gross domestic product per capita in U.S. dollars at constant 2010 prices, representing economic growth.

To examine the characteristics of the PSTR model with a logistic transition function based on Van Dijk (1999), it is assumed that the dependent variable NO_2 is solely a function of its own lagged values. Under the assumption of a two-regime transition function, the relationship is as follows:

$$NO_{2t} = (\theta_0 + \theta_1 NO_{2t-1} + \cdots + \theta_p NO_{2t-p}) + (\varphi_0 + \varphi_1 NO_{2t-1} + \cdots + \varphi_p NO_{2t-p}) G(INST_t, \gamma, c) + u_t$$

$$G(INST_t, \gamma, c) = 1 / (1 + \exp\{-\gamma (INST_t - c)\})$$

The results of this model are referred to as a two-regime PSTR model. The location parameter *c* represents the transition point between the two extreme regimes, where $G(INST_t, \gamma, c) = 0$ and $G(INST_t, \gamma, c) = 1$, and the midpoint is $G(INST_t, \gamma, c) = 0.5$. The parameter γ indicates the speed of transition between regimes, with larger values of γ implying a faster regime shift.

The statistical population of the present study consists of selected MENA and Middle Eastern countries, including Saudi Arabia, Qatar, Pakistan, the United Arab Emirates, Algeria, Kuwait, Iran, Egypt, Oman, Morocco, Libya, Yemen, and Sudan, over the period from 2005 to 2023. The analysis is conducted using the Panel Smooth Transition Regression (PSTR) model.

3. Findings and Results

Based on the results in Table (1), the descriptive statistics show that the mean of the NO_2 total emission variable is 0.32444, with the maximum value of 1.22 belonging to Yemen and the minimum value of 0.17 belonging to the United Arab Emirates. Furthermore, by examining the graphical trend of the mean of this variable for the countries under study, it is observable that since 2012, environmental pollution has shown an upward trend.

The mean of the governance quality variable is 3.53, with the maximum value of 6.64 belonging to Qatar and the minimum value of 1.06 belonging to Yemen. The descriptive statistics of the other variables are presented in Table (1).

Table 1

Descriptive Statistics of the Main Study Indicators

Country Group	EG	RQ	INST	NO_2
Mean	69.01292	43.00709	3.533339	0.32444
Maximum	220.4068	75.33334	6.642805	1.223351
Minimum	21.85226	21.480769	1.064284	0.172473

To determine whether there is a linear or nonlinear relationship among the model's variables, it must be tested whether *m* (the number of regime parameters) equals one or not. It should be noted that in the following tests, the null hypothesis assumes a linear model, and the alternative hypothesis assumes either a logistic PSTR model (*m = 1*) or an exponential PSTR model (*m = 2*).

The results of the diagnostic test in Table (2) show that the null hypothesis of linearity is rejected; therefore, a nonlinear relationship exists regarding the role of social cohesion and economic development, with an emphasis on the distribution of opportunities in the countries studied. Accordingly, the PSTR method must be used to estimate the model parameters.

Table 2

Results of the Linearity Hypothesis Test (BBC Test)

Null Hypothesis	F-Statistic	Significance Level
Wald Test	5.825	0.000
Fisher Test	5.108	0.000
LRT Test	4.203	0.000

As shown in Table (2), the hypothesis of a linear relationship between the variables is rejected, indicating that a linear specification cannot adequately describe the relationships among the variables.

It should also be noted that the proposed PSTR model, with the selected transition variable, is chosen as the optimal model for estimation in the selected countries. To this end, following González et al. (2005) and Colletaz and Hurlin (2006), the null hypothesis of having a PSTR model with one transition function was tested against the alternative hypothesis of having a PSTR model with at least two transition functions. The results are presented in Table (3).

The findings show that the null hypothesis, stating that one transition function is sufficient, is not rejected in both cases of one and two threshold levels. Therefore, a single transition function is adequate to describe the nonlinear behavior between economic globalization and environmental quality with an emphasis on the threshold effects of government governance.

Table 3

Test Results for the Existence of Nonlinear Relationship

Case	LR	LMf	LMw
M = 2	1.237 (0.512)	1.228 (0.548)	1.291 (0.552)
M = 1	1.396 (0.567)	1.222 (0.701)	1.415 (0.812)

H_0: r = 1, H_1: r = 2

With the confirmation of the nonlinear relationship among the variables and the adequacy of using a single transition function to describe the nonlinear behavior, the next step is to determine the optimal form of the transition function with one or two threshold levels. To this end, the PSTR model corresponding to each case is estimated, and based on criteria such as the sum of squared residuals, Schwarz, and Akaike information criteria, the PSTR model with one transition function and one threshold level is identified as the optimal model.

Accordingly, a PSTR model with a single transition function and one threshold level is selected to analyze the nonlinear relationship among the study variables.

Using a Panel Smooth Transition Regression (PSTR) model in which the transition variable in the first model is trade volume (EG) and in the second model is government governance (INST), the relationship between economic globalization and environmental quality is modeled.

The estimated results for the linear part of the first and second models (Regime 1) indicate that the variables of trade volume (EG) and gross domestic product (GDP) have a positive relationship with nitrogen dioxide (NO_2) emissions. Specifically, in the first model, a one-unit increase in trade volume and GDP leads to an increase of 0.21 and 0.22 units in greenhouse gas emissions, respectively.

The governance quality variable (INST) in the second model leads to a reduction of 0.12 units in nitrogen dioxide (NO_2) emissions, and the interaction term of government governance with trade volume (INST × EG) reduces NO_2 emissions by 0.11 units.

The estimated results for the nonlinear part of the first and second models (Regime 2) also show a positive relationship between trade volume (EG) and gross domestic product (GDP) with nitrogen dioxide (NO_2) emissions.

Additionally, the variables of government governance (RQ), government effectiveness (GE), and control of corruption (CC) in the first model reduce nitrogen dioxide (NO_2) emissions. In the second model, both the governance quality variable (INST) and the interaction term of governance with trade volume (INST × EG) reduce NO_2 emissions.

Table 4

Estimation of the Model Using PSTR

Variable	Model 1 (Environmental Quality)	Probability	Model 2 (Environmental Quality)	Probability
Linear Part				
CONSTANT	0.356321	0.0163	0.189653	0.0003
EG	0.156965	0.0111	0.126598	0.0094
GDP	0.196325	0.0334	0.256963	0.0422
RQ	-0.079653	0.0874	–	–
GE	-0.019632	0.2198	–	–
CC	-0.026564	0.2297	–	–
INST	–	–	-0.216593	0.0009
EG × INST	–	–	-0.226982	0.0285
Nonlinear Part				
CONSTANT	0.896596	0.0021	0.336964	0.0147
EG	0.213659	0.0039	0.250269	0.0249
GDP	0.223695	0.0018	0.296353	0.0000
RQ	-0.215987	0.0297	–	–
GE	-0.102365	0.0487	–	–
CC	-0.086532	0.0028	–	–
INST	–	–	-0.126985	0.0000
EG × INST	–	–	-0.118574	0.0787
Threshold (c)	-0.211146	0.0008	-0.459343	0.0017
Slope (γ)	2.32365	0.0198	2.69856	0.0016
Adjusted R^2	0.91		0.87	

Comparing the coefficients in the two regimes is based on the transition variable and its estimated values, which can determine the transition function and, consequently, the prevailing regime.

In the above estimations, the transition variable in the first model is trade volume (EG), and in the second model is government governance (INST). The estimated threshold values for these variables are -0.21 and -0.45, respectively.

Depending on the distance of trade volume and governance quality from these threshold values, the model follows two distinct regimes. Comparing the coefficients of the model in the two regimes shows that when the governance indicators cross the thresholds (-0.21 and -0.45) — transitioning from the linear to the nonlinear regime — the environmental indicators become more responsive to changes in these variables.

This implies that as trade volume and governance quality increase, policymakers attempt to react more strongly to control and limit the growth of environmental pollution.

Figure 1

Relationship Between the Transition Function and the Transition Variable

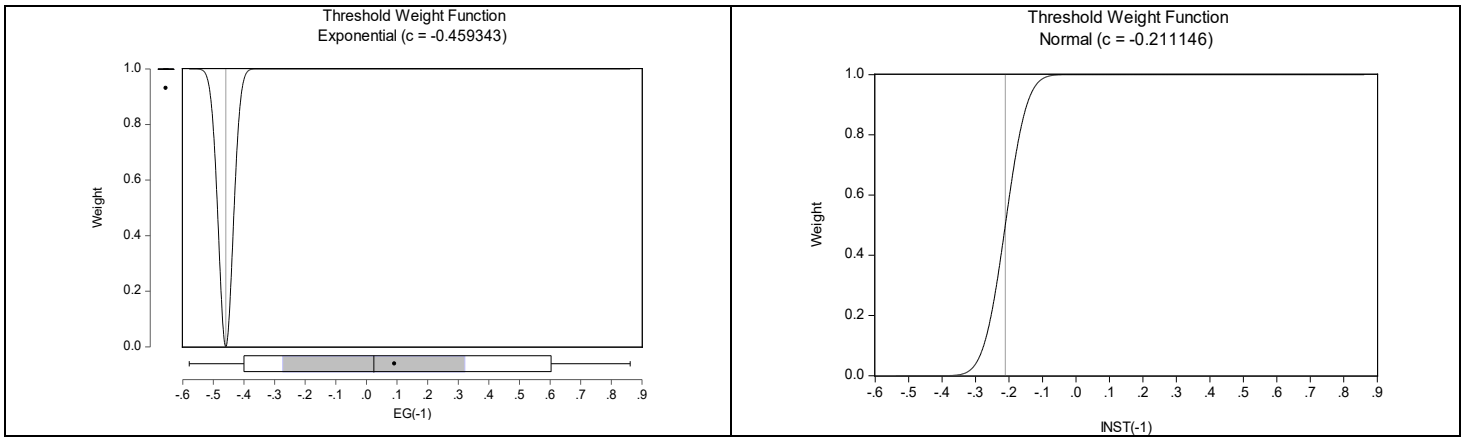

Table 5

Results of the Autocorrelation Test

F-Statistic	Prob	Durbin–Watson
1.502	0.59	2.102
1.412	0.31	1.997

As shown in the above table, the results of the Durbin–Watson test indicate no autocorrelation among the error terms. Therefore, the third classical assumption of no autocorrelation in the error terms is not violated. As a result, the estimators possess the required properties of minimum variance and efficiency.

Another standard classical assumption is homoscedasticity; in this study, the Breusch–Pagan–Godfrey test is used to examine heteroskedasticity.

Table 6

Results of the Heteroskedasticity Test

F-Statistic	Prob	Breusch–Pagan–Godfrey
1.319	0.219	1.415
1.207	0.308	1.396

As shown in the table, the results indicate no evidence of heteroskedasticity.

Another appropriate measure for evaluating the quality of the estimated model is to check whether the coefficients remain stable between the two regimes. If the estimated model is reliable, the coefficients are expected to remain unchanged when the regime changes.

Table 7

Results of the Smooth Transition Parameter Stability Test

Null Hypothesis	F-Statistic	Prob
$b_1 = b_2 = b_3 = b_4 = 0$	0.441	0.708
$b_1 = b_2 = b_3 = 0$	0.569	0.819
$b_1 = b_2 = 0$	0.789	0.714
$b_1 = 0$	0.925	0.710

As shown in the table, the stability test of the coefficients between the two regimes indicates that the coefficients do not significantly change when the regime shifts.

4. Discussion and Conclusion

The present study investigated the threshold effects of governance quality on the relationship between economic globalization and environmental quality in selected developing countries using the Panel Smooth Transition Regression (PSTR) model. The results provide nuanced evidence that the environmental consequences of globalization are not linear but shift depending on the level of governance performance. Specifically, the findings demonstrate that trade volume (EG) and gross domestic product (GDP) have a positive association with nitrogen dioxide (NO_2) emissions in the linear regime, confirming that globalization and economic expansion initially exert upward pressure on environmental degradation. However, the interaction between governance quality (INST) and trade significantly reduces NO_2 emissions once governance crosses critical threshold values, indicating that stronger institutional frameworks can mitigate the environmental costs of trade and economic growth.

These results are consistent with a growing body of evidence showing that globalization's environmental impact depends heavily on domestic governance structures. Countries with robust institutional capacity and effective regulatory systems can leverage economic integration to support cleaner technologies and reduce emissions (Azimi et al., 2023; Yasmeen et al., 2023). For instance, Lu et al. (Lu et al., 2024) demonstrated that good governance combined with renewable energy consumption significantly reduces pollution across BRICS-T economies, echoing the moderating role of governance found in this study. Similarly, Nemati et al. (Nemati et al., 2023) found that institutional constraints shape the environmental goods export structure, reinforcing that institutional robustness influences whether trade contributes to or undermines sustainability.

The positive and significant effect of trade and GDP on NO_2 emissions in the linear regime aligns with the early stages of the environmental Kuznets curve (EKC) hypothesis, where economic growth and trade liberalization initially increase pollution before institutional and technological adjustments take effect (Balogh & Borges Aguiar, 2022; Baqerian Kasgari, 2023). Bacchetta et al. (Bacchetta et al., 2022) similarly reported that liberalizing trade in environmental goods could reduce emissions only when coupled with domestic institutional readiness to adopt and enforce green standards. Without adequate governance, globalization often accelerates pollution-intensive industrialization, a dynamic also highlighted by Kohli (Kohli, 2022) in the context of intra-industry trade and environmental regulation.

Importantly, our results confirm that once governance quality surpasses certain thresholds, the environmental trajectory associated with globalization changes direction. Stronger governance enables the enforcement of environmental regulations, supports the diffusion of eco-innovations, and improves corporate environmental accountability (Tan et al., 2024; Wan et al., 2025). This is consistent with Shahin et al. (Shahin et al., 2024), who showed that government procurement policies grounded in environmental sustainability effectively incentivize firms to adopt cleaner practices. Likewise, Awosusi et al. (Awosusi et al., 2023) provided evidence that political stability and government capacity to manage income and energy policy are crucial to achieving carbon neutrality, reinforcing the pivotal role of governance thresholds identified here.

Another critical insight is the moderating influence of governance on the environmental outcomes of energy use and resource dependence. The finding that governance interacts with trade to reduce NO_2 emissions resonates with studies showing that natural resource reliance alone tends to increase emissions unless mitigated by strong environmental regulations (Li et al., 2023; K. Wang et al., 2023). Awosusi et al. (Awosusi et al., 2023) and Fuinhas et al. (Fuinhas et al., 2023) reported that renewable energy adoption and sustainability goals require political stability and regulatory efficiency—factors closely tied to governance performance. In weakly governed economies, trade-driven resource exploitation often worsens environmental degradation, while effective governance can redirect globalization's gains toward green transition investments.

The study also underscores the importance of environmental auditing and policy oversight in shaping the globalization–environment dynamic. The role of government environmental audits, as reflected in our results, parallels evidence from Tan et al. (Tan et al., 2024) and Wan et al. (Wan et al., 2025), who found that anticipated environmental audits improve corporate productivity and compliance with sustainability regulations. Such audits represent practical mechanisms through which states can enforce environmental accountability in open economies. Moreover, procurement systems designed to favor sustainable goods, as highlighted by Shahin et al. (Shahin et

al., 2024), can complement trade liberalization by stimulating demand for low-emission technologies.

Our results also confirm that corruption control and regulatory quality significantly affect pollution levels. This finding is reinforced by Azimi et al. (Azimi et al., 2023), who documented that high regulatory quality improves environmental outcomes globally, and Yasmeen et al. (Yasmeen et al., 2023), who emphasized governance's role in mobilizing environmental technology and taxation for renewable energy adoption. In contrast, weak institutional environments invite rent-seeking, reduce compliance with environmental standards, and perpetuate pollution havens (Oteng et al., 2023; Rosser, 2022).

In addition, the study contributes to understanding the importance of demographic and social dynamics when evaluating globalization's environmental effects. The evidence from Udemba et al. (Udemba et al., 2024) that demographic change and urbanization drive ecological footprints supports the notion that governance must adapt to emerging societal pressures associated with trade and growth. Zhao et al. (Zhao et al., 2022) further showed that smart transportation policies under effective governance can reduce emissions in urbanized economies, aligning with the adaptive governance perspective reflected in our threshold findings.

From a methodological standpoint, our use of the PSTR approach reinforces calls for more sophisticated econometric tools to capture non-linearities in the globalization–environment relationship. Traditional linear models obscure regime changes triggered by institutional improvements (Lu et al., 2024; Nemati et al., 2023). By identifying threshold levels where governance alters the sign and magnitude of globalization's environmental effects, this study responds to such methodological recommendations and provides actionable insights for policymakers in emerging markets.

Overall, the findings expand on existing theory by clarifying that governance does not merely moderate globalization's impact; it fundamentally conditions the environmental trajectory of open economies. Policymakers seeking to align economic integration with sustainability must therefore invest in institutional strengthening, including regulatory capacity, environmental auditing systems, and anti-corruption frameworks, to push their economies beyond harmful governance thresholds.

This study is not without limitations. First, while the PSTR approach effectively captures threshold effects and non-linearities, it is still reliant on the quality and consistency of secondary data, especially for governance indicators that may be subject to measurement error or reporting bias. Second, the analysis focuses on a selection of developing countries in the MENA and Middle Eastern region, limiting the generalizability of the findings to other emerging markets with different institutional configurations or trade structures. Third, the use of NO_2 emissions as the sole proxy for environmental quality, although widely recognized, may not fully capture multidimensional ecological degradation such as biodiversity loss, water pollution, or soil contamination. Finally, the model primarily emphasizes the moderating role of governance on trade and GDP but does not incorporate other potentially influential factors such as cultural norms, informal institutions, or geopolitical shocks that can influence environmental policy implementation.

Future studies should expand the geographic scope by including a more diverse set of developing and transitional economies to test the robustness and universality of governance thresholds in shaping globalization's environmental effects. Incorporating additional environmental quality indicators, such as carbon dioxide, particulate matter, or composite ecological footprint measures, would also provide a more comprehensive assessment of sustainability outcomes. Researchers could further explore the role of digital technologies and environmental innovation systems, particularly how digitalization and smart governance tools interact with trade to reduce emissions. Longitudinal case studies examining policy changes before and after surpassing governance thresholds could provide richer institutional insights beyond quantitative modeling. Moreover, mixed-methods approaches integrating econometric analysis with expert interviews or policy analysis may uncover qualitative dimensions of institutional reforms that influence sustainability under globalization.

For policymakers, the findings suggest that trade liberalization and economic expansion must be coupled with deliberate investments in governance capacity to avoid environmental harm. Strengthening regulatory quality, ensuring the independence and effectiveness of environmental oversight bodies, and implementing rigorous environmental audits are critical steps for countries aiming to transition globalization into a force for sustainable development. Governments should also promote transparency and anti-corruption measures to build institutional credibility and attract environmentally conscious investment. Developing targeted policies to

support renewable energy, sustainable transport, and green industrial innovation will allow nations to harness globalization's benefits while mitigating its ecological costs. Finally, aligning public procurement and fiscal incentives with environmental performance can accelerate private-sector compliance and foster a competitive green economy.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

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