Journal of Environmental Economics & Chemical Processes (JEECP)

https://doi.org/10.22034/jeecp.2026.735221

Journal Homepage: *WWW.JEECPJournal.com*

Journal of Environmental Economics & Chemical Processes (JEECP)

ORIGINAL RESEARCH PAPER

Trade Openness and Carbon Dioxide Emissions: The Threshold Effect of Political Stability in Developing Countries

Hamed Mokhtari Torshizi; Mahdi Zandi Dashtbayaz; Farzaneh Ahmadian-Yazdi *

Department of Economics , Faculty of Economics and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran..

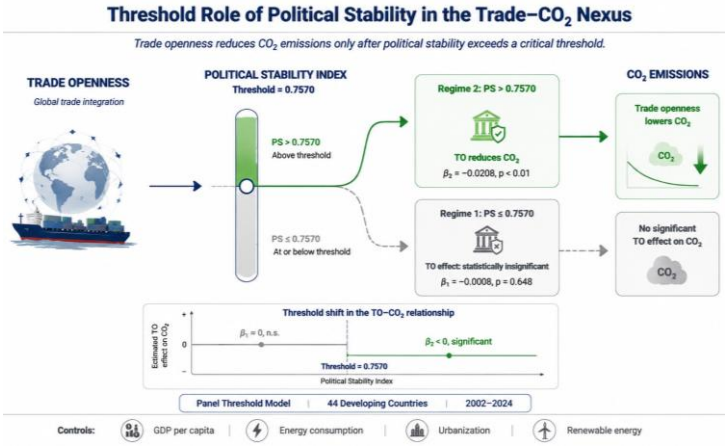
P A P E R I N F O

Paper history:
Received: 05/19/2026
Revised: 06/10/2026
Accepted in revised form: 06/12/2026
Published: 06/30/2026

***Keywords*:**
Carbon Dioxide Emissions;
Trade Openness;
Political Stability;
Panel Threshold.

A B S T R A C T

This study examines the effect of trade openness on carbon dioxide emissions, with an emphasis on the threshold role of political stability, in selected developing countries over the period 2002–2024. To identify nonlinear and regime-dependent relationships, Hansen's panel threshold econometric approach is employed. Preliminary analyses, including the Lin and Levin–Chu unit root tests, confirmed the stationarity of all variables, and based on diagnostic tests, the fixed-effects panel data model was selected for the final estimation. The results indicate the presence of a significant threshold for political stability, which separates the relationships among the variables into two distinct regimes. The findings show that in the low-political-stability regime, trade openness has no significant effect on carbon emissions; however, once the threshold is crossed and the high-political-stability regime is reached, this variable exerts a statistically significant reducing effect on carbon dioxide emissions. Regarding the control variables, per capita gross domestic product, energy consumption, and renewable energy exhibited positive effects, whereas urbanization had a negative effect on pollutant emissions. Based on the findings of this study, the realization of environmental benefits arising from integration into global trade is heavily contingent on enhancing institutional and political stability, improving the quality of environmental governance, and implementing structural reforms in the energy sector of developing countries.



1. Introduction

Climate change, as one of the most significant environmental challenges of the 21st century, has garnered extensive attention from policymakers, economists, and researchers. The continuous increase in greenhouse gas concentrations in the atmosphere, particularly carbon dioxide, plays a decisive role in intensifying global warming and climatic instability. Reports by the Intergovernmental Panel on Climate Change indicate that carbon dioxide emissions resulting from economic activities and fossil fuel consumption are the most critical factors in contemporary climate change, with consequences including rising global temperatures, the occurrence of extreme climate events, ecosystem degradation, and threats to food security [1]. In this context, identifying the economic and institutional factors affecting carbon emissions has become a central focus of research in environmental economics. In recent decades, developing countries have played an increasing role in global carbon emission trends. Rapid economic growth, the expansion of industrialization, rising energy demand, and growing urbanization have significantly increased these countries' share of global greenhouse gas emissions [2]. Simultaneously, many of these countries face institutional challenges, technological constraints, and weaknesses in environmental policy implementation, which can exacerbate the environmental consequences of economic growth. International trade and trade openness are recognized as some of the most vital drivers of economic

* Corresponding Author: Farzaneh Ahmadian-Yazdi
E-mail address: f.ahmadian@um.ac.ir
ISSN: 3116-0050
URL: https://www.jeecpjournal.com/article_735221.html

Please cite this article as: H.M. Torshizi, M.Z. Dashtbayaz, F. Ahmadian-Yazdi , *Journal of Enviromental Economics & Chemical Processes (JEECP)*, 2026, *3*(2), 95-100. https://doi.org/10.22034/jeecp.2026.735221

/© 2026 The Author(s). Published by Power of New Vision Movement Institute.

growth in developing economies. Integration into the global economy through increased exports and imports can facilitate access to new markets, foreign investment, advanced technologies, and technical expertise [3]. However, the environmental impacts of expanding international trade remain a controversial topic in the economic literature. Some studies argue that free trade can lead to increased pollutant emissions by expanding industrial activities and energy consumption, while others contend that trade can contribute to improving environmental quality through the transfer of clean technologies and the elevation of environmental standards [4]. Two primary theoretical perspectives regarding the relationship between trade and pollution have emerged in the environmental economics literature. First, the "Pollution Haven Hypothesis" suggests that polluting industries tend to relocate to countries with laxer environmental regulations; consequently, trade openness may lead to increased pollution in developing countries [5]. Conversely, the "Pollution Halo Hypothesis" argues that foreign investment and international trade can bring about the transfer of clean technologies and efficient management practices, thereby enhancing environmental quality [6]. Despite the extensive development of this literature, empirical findings regarding the effect of trade openness on carbon dioxide emissions remain contradictory and heterogeneous. Some studies have reported a positive effect of trade on carbon emissions, whereas others have identified negative effects or even nonlinear relationships dependent on economic and institutional conditions [7–9]. This heterogeneity in results suggests that the relationship between trade and the environment is likely influenced by contextual and institutional factors. One important institutional factor that has received relatively limited attention in many studies is political stability. Political stability can influence the environmental outcomes of economic activities through various mechanisms. In countries with higher levels of political stability, there is a greater likelihood of effective enforcement of environmental regulations, the formulation of sustainable and long-term policies, and effective monitoring of industrial activities [10]. Moreover, political stability can create favorable conditions for attracting green foreign investment and facilitating the transfer of low-carbon technologies. In contrast, political instability may be associated with increased investment risk, weak enforcement of environmental regulations, and a prioritization of short-term economic objectives, which can intensify environmental degradation [11]. Accordingly, the effect of trade openness on carbon emissions may not be uniform across different levels of political stability. In other words, there may exist a level of political stability beyond which the environmental consequences of trade change. At low levels of political stability, trade may lead to higher pollutant emissions, whereas at higher levels of institutional stability, the same trade may contribute to reducing carbon emissions through the transfer of clean technologies and improvements in energy efficiency. In light of these considerations, the primary objective of this study is to examine the threshold role of political stability in the relationship between trade openness and carbon dioxide emissions in developing countries. Specifically, this study seeks to answer the question of whether there exists a level of political stability beyond which the effect of trade openness on carbon emissions changes. To achieve this objective, the panel threshold model proposed by Hansen [12] is employed. The data used consist of a balanced panel of 44 developing countries over the period 2002–2024. Carbon dioxide emissions are considered the dependent variable, while trade openness, per capita gross domestic product, energy consumption, urbanization, and renewable energy are included as explanatory and control variables in the model. In addition, the “Political Stability and Absence of Violence/Terrorism” index from the Worldwide Governance Indicators is used as the threshold variable. This study contributes to the existing literature in several ways. First, from a theoretical perspective, it provides an analytical framework for understanding the role of institutional quality particularly political stability in determining the environmental consequences of international trade. Second, from an empirical perspective, by employing the panel threshold model, it enables the identification of nonlinear relationships and regime shifts in the effect of trade on carbon emissions. Third, the findings of this study may have important policy implications for developing countries, as they indicate that improvements in political stability and institutional quality can help alter the environmental impacts of trade. The structure of the article is as follows: Section 2 reviews the literature, Section 3 describes the methodology and data, Section 4 presents and analyzes the empirical results, and finally, Section 5 is dedicated to the conclusion and policy recommendations.

1.1. Theoretical Foundations

The relationship among economic growth, international trade, and environmental quality is a key topic in environmental economics literature. One of the prominent theoretical frameworks in this field is the Environmental Kuznets Curve (EKC) hypothesis. According to this hypothesis, the relationship between per capita income and environmental degradation takes an inverted U-shape; that is, in the early stages of economic development, economic growth is associated with increased pollution, but after reaching a certain income level, rising income leads to environmental improvement [13]. The seminal study by Grossman and Krueger [14], which examined the environmental effects of the North American Free Trade Agreement, was one of the first to provide evidence supporting this relationship. The economic literature has identified three main channels through which trade affects the environment: the scale effect, the composition effect, and the technique effect [4]. The scale effect posits that trade expansion increases overall economic production, consequently leading to higher pollution levels if technology and production structure remain unchanged. The composition effect refers to the changes in production structure and specialization of countries resulting from trade; countries may specialize in producing goods in which they have a comparative advantage. If this comparative advantage lies in polluting industries, trade can lead to increased pollution. Conversely, the technique effect suggests that trade can improve production technology and reduce pollution intensity through the transfer of more advanced and efficient technologies. Within this analytical framework, two important hypotheses have been proposed in the trade and environment literature. First, the Pollution Haven Hypothesis suggests that multinational corporations may relocate their polluting activities to countries with weaker environmental regulations [5]. In such a scenario, trade openness could lead to increased pollution in developing countries. Conversely, the Pollution Halo Hypothesis argues that foreign investment and trade can bring cleaner technologies and more advanced management standards, ultimately leading to improved environmental quality [6]. However, many researchers emphasize that the ultimate effect of trade on the environment depends on countries’ institutional conditions. Institutional quality, the level of institutional development, the rule of law, and political stability can determine whether trade leads to an increase or a decrease in pollution [15]. Therefore, understanding the role of institutional factors is essential for accurately analyzing the relationship between trade and the environment.

1.2. Trade Openness and Carbon Emissions

Empirical studies on the relationship between trade openness and carbon dioxide emissions have produced diverse results. Some studies indicate that trade openness leads to increased carbon emissions. For example, Cole [5], examining data from developing countries, found that trade expansion can result in the relocation of polluting industries to these countries. Similarly, Lee and Rooney [16] showed that international trade in many countries has been associated with increased environmental degradation. In contrast, other studies suggest that trade can have positive environmental effects. Frankel and Rose [6], using international data, argued that free trade can contribute to environmental improvement through the transfer of clean technologies and increases in per capita income. More recent studies, such as Destek and Ozsoy [8] and Nathaniel and Khan [9], also indicate that trade can help reduce carbon emissions in certain countries. Moreover, a number of studies have reported nonlinear or threshold-dependent relationships between trade and pollution. For instance, Shahbaz et al. [7] demonstrated that the effect of trade on carbon emissions may vary across different levels of economic development. Ahmad et al. [17] and Khan et al. [18] also provided evidence of nonlinear relationships among trade, energy, and the environment. More recent studies have further emphasized the importance of institutional factors in this relationship. Recent research indicates that institutional quality, governance, and political stability can determine the direction and magnitude of the effect of trade on the environment [19–22]. Nevertheless, there is still no clear consensus in this area, and the findings of different studies remain heterogeneous. This suggests that institutional and structural variables play an important role in shaping the relationship between trade and carbon emissions.

1.3. Political Stability and Environmental Quality

Political stability is an important dimension of institutional quality that can have a significant impact on countries’ environmental performance. Under conditions of political stability, governments are better able to design and implement long-term environmental policies and effectively monitor economic activities [23]. In contrast, political instability may lead to weak enforcement of environmental regulations and increased degradation of natural resources. Numerous studies have shown that political stability is associated with improvements in environmental quality. For example, Kaufmann et al. [10], by introducing the Worldwide Governance Indicators, demonstrated that institutional quality plays a crucial role in countries’ economic and environmental performance. More recent research also indicates that reducing political risk can facilitate investment in clean technologies and renewable energy projects [24,25].

1.4. The Interaction between Political Stability and Trade Openness

The interaction between political stability and trade openness can play a significant role in determining the environmental consequences of trade. First, through the institutional channel, political stability can facilitate the effective enforcement of environmental regulations and prevent countries from becoming pollution havens. Second, through the foreign investment channel, political stability can enhance the attraction of foreign direct investment in clean and low-carbon sectors. Third, through the technology transfer channel, countries with greater institutional stability typically possess a higher capacity to absorb and localize advanced technologies. Despite the importance of this interaction, limited empirical studies have examined the role of political stability as a moderating or threshold variable in the relationship between trade and the environment. Some recent studies have employed threshold models to investigate the role of institutional quality in carbon emissions [26,27], yet a direct focus on political stability remains limited.

1.5. The Role of Other Determinants of CO_2

In addition to trade and political stability, numerous economic and structural factors affect carbon dioxide emissions, and understanding them is essential for a comprehensive analysis of pollution in developing countries. The first and most important of these factors is economic growth. According to the Environmental Kuznets Curve (EKC) hypothesis, the relationship between per capita income and environmental degradation follows an inverted U-shape; that is, in the early stages of development, an increase in gross domestic product is accompanied by greater fossil fuel consumption and the expansion of polluting industries, thereby increasing carbon emissions [13]. Empirical evidence from developing countries has largely confirmed this pattern, showing that prior to reaching a certain income level, economic growth exerts increasing pressure on the environment [7, 8]. The second key factor is energy consumption, which is directly linked to carbon dioxide emissions. Since the energy mix in these countries still relies heavily on fossil fuels—oil, coal, and natural gas—increases in energy consumption almost invariably imply a simultaneous increase in pollutant emissions [4, 3]. Numerous studies have shown that the elasticity of carbon emissions with respect to energy consumption is positive and statistically significant in developing countries; moreover, rapid industrialization and rising transport demand further intensify this dependence [16,18].On the other hand, urbanization, as a demographic-economic phenomenon, exerts a dual effect on carbon emissions. On the one hand, population concentration in urban areas places direct pressure on resources and the environment through increased demand for housing, private and public transportation, energy-intensive infrastructure, and waste generation [9]. On the other hand, well-planned urbanization can help reduce per capita emissions by creating economies of scale in the provision of public services—such as rail transport and centralized heating and cooling—increasing density and reducing the need for long-distance travel, and improving energy-use efficiency [17]. Studies of urbanization in developing countries show that the direction and magnitude of this effect depend on the quality of urban management, the level of infrastructure, and the nature of transport policies. Finally, the development of renewable energy sources—such as solar, wind, biomass, and hydropower—is regarded as a key strategy for the transition to a low-carbon economy. Increasing the share of these energy sources in the energy mix can reduce carbon emissions by substituting for fossil fuels [28]. However, in many developing countries, due to the initially very low share of renewable energy, the rapid growth of total energy demand, and the presence of fossil fuel subsidies, the expansion of clean energy has often failed to generate effective substitution and therefore has sometimes not exhibited an immediate and significant mitigating effect on carbon emissions [24, 25]. This issue highlights the need to design complementary policies, such as the gradual removal of fossil fuel subsidies and investment in smart distribution grids.

1.6. Research Gap and Study Innovation

Despite considerable advances in the trade and environment literature, several research gaps still remain. First, many studies have examined the relationship between trade and carbon emissions within the framework of linear models and have paid less attention to nonlinear or threshold relationships. Second, the role of institutional factors, particularly political stability, in determining the environmental consequences of trade has received limited attention. The present study seeks to fill this research gap by examining the threshold role of political stability in the relationship between trade openness and carbon dioxide emissions in developing countries. The use of Hansen's panel threshold model makes it possible to identify critical levels of political stability at which the effect of trade on the environment changes. The findings of this study can provide new insights into the interaction among trade, institutions, and the environment and offer important guidance for policymakers in developing countries.

2. Methods

2.1. Methodology

This study investigates the relationship between trade openness and carbon dioxide emissions, with an emphasis on the threshold role of political stability, in selected developing countries over the period 2002 to 2024. To this end, an annual panel dataset is employed for a sample of developing countries selected based on the availability and consistency of data for all variables used in the model. The empirical framework of the study is based on the panel threshold model, which makes it possible to examine the effect of trade openness on environmental quality across different regimes according to the level of political stability. Given the main objective of this study—namely, to examine the effect of trade openness on carbon dioxide emissions with emphasis on the threshold role of political stability in developing countries over the period 2002–2024—a panel threshold regression model is employed. This model, first introduced by Hansen (1999) [29] within the framework of panel data, is regarded as one of the appropriate approaches for analyzing nonlinear and regime-dependent relationships among variables. Panel threshold regression models make it possible, instead of assuming coefficient homogeneity across the entire sample, to estimate the relationship between explanatory variables and the dependent variable across different regimes according to the value of an observable threshold variable. In other words, in this class of models, the structure of the relationship among variables may change when the threshold variable crosses a critical level. In the present study, political stability is considered the threshold variable; therefore, it is expected that the effect of trade openness on carbon dioxide emissions will not be identical at different levels of political stability and may vary depending on the regime in which countries are located.

Hansen's (1999) [29] panel threshold model is estimated based on the least squares method while accounting for cross-sectional fixed effects. Within this framework, the threshold value and model coefficients are determined simultaneously, and observations are divided into two or more homogeneous regimes according to the value of the threshold variable. One of the most important advantages of this method is that it allows for the identification of endogenous structural heterogeneity without requiring prior specification of the breakpoint. However, since the classification of observations is based on a specific threshold value, observations close to the threshold may be assigned to different regimes despite only slight differences; consequently, coefficient changes around the threshold point appear discontinuously [30].In this study, carbon dioxide emissions are included as the dependent variable, political stability as the threshold variable, and trade openness as the main explanatory variable. In addition, to control for other factors affecting carbon dioxide emissions, the logarithm of per capita gross domestic product, the logarithm of energy consumption, urbanization, and renewable energy are also incorporated into the model as control variables. The selection of these variables is based on theoretical foundations and existing empirical evidence in the literature on environmental determinants in developing countries.

In general, if the balanced panel data are expressed as follows:

$$\{yit\ ,\ qit\ ,\ xit : 1 \le i < n\ ,\ 1 \le t < T\} \qquad (1)$$

where i denotes the cross-sectional units and t indicates the time period. In this structure, yit is the dependent variable, qit is the threshold variable, and xit is the vector of explanatory and control variables. The general form of the two-regime threshold panel model can be expressed as follows:

$$Y_{it} = \mu_i + \beta_1' x_{it} I(q_{it} \le \gamma) + \beta_2' x_{it} I(q_{it} > \gamma) + e_{it} \qquad (2)$$

where μi denotes the unit-specific fixed effects, γ is the estimable threshold value, I(.) is the indicator function, and εit is the disturbance term. In addition, β1 and β2 represent the vectors of coefficients in the first and second regimes, respectively. Accordingly, if the value of the threshold variable for an observation is less than or equal to the threshold value, the coefficients of the first regime prevail; otherwise, the coefficients of the second regime apply [31,32]. In the context of the present study, this model makes it possible to test the hypothesis that the effect of trade openness on carbon dioxide emissions in developing countries is a function of the level of political stability. In other words, in countries with a low level of political stability, the expansion of foreign trade may lead to an intensification of environmental pollution, whereas in countries with higher political stability, the same variable may exert a different effect on carbon emissions through improvements in institutional quality, facilitation of clean technology transfer, and enhancement of regulatory efficiency. From this perspective, the panel threshold model constitutes an appropriate tool for identifying and analyzing such heterogeneous and nonlinear relationships.

2.2. Data

The study covers the period 2002–2024. Official observations were available up to 2024 for most variables, including CO_2 emissions, trade openness, political stability, GDP per capita, and urbanization. However, due to publication lags in energy-related databases, two control variables required limited forecasting at the end of the sample period. Energy consumption was available up to 2023, and only its 2024 value was forecasted. Clean/renewable energy was available up to 2022, and its values for 2023 and 2024 were forecasted. The forecasted values were obtained using a country-specific log-linear trend extrapolation based on the most recent five available observations. This procedure was applied only to the final missing observations of the two energy-related control variables. No forecasting or imputation was applied to CO_2 emissions, trade openness, or political stability.

Given the characteristics of developing economies, there is substantial heterogeneity across countries in terms of economic structure, institutional capacity, degree of integration into global trade, and environmental policy quality. Accordingly, the use of panel data in this study offers two main advantages. First, by combining the time and cross-sectional dimensions, it increases the number of observations and improves estimation efficiency. Second, it makes it possible to control for unobserved country-specific heterogeneity, which may influence countries' environmental performance.
In this study, a panel threshold approach is employed to investigate whether the effect of trade openness on carbon dioxide emissions changes when political stability crosses a critical level. This methodology is particularly relevant to the present topic because the impact of trade on environmental degradation is not necessarily uniform across countries or across different levels of political stability. In politically unstable environments, trade expansion may increase emissions through weak oversight, institutional inefficiency, misallocation of resources, and the intensification of polluting activities. By contrast, in countries with greater political stability, trade openness may have a different effect on carbon emissions through technology transfer, improved governance quality, and the diffusion of cleaner production methods.

2.3 Definition and Measurement of Variables

In order to examine the effect of trade openness on carbon dioxide emissions with emphasis on the threshold role of political stability, a set of dependent, threshold, independent, and control variables is employed. The dependent variable of the study is carbon dioxide (CO_2) emissions, which is considered an indicator of environmental pressure. Political stability is included in the model as the threshold variable in order to examine whether the effect of trade openness changes across different levels of political and institutional quality. Trade openness is used as the main explanatory variable. In addition, several control variables are incorporated into the model, including the logarithm of GDP per capita, the logarithm of energy consumption, urbanization, and renewable energy. These variables are selected based on theoretical considerations and previous empirical studies addressing the determinants of environmental degradation.

The data for these variables are obtained from reputable international databases, including the World Bank's World Development Indicators (WDI), the Worldwide Governance Indicators (WGI) for political stability, and the International Energy Agency (IEA) for energy-related indicators.

Table 1. Definition of Variables

Source	Measurement	Variable	Symbol
WDI	CO_2 emissions (metric tons per capita)	Carbon dioxide emissions	CO_2
WGI	Political Stability and Absence of Violence/Terrorism index	Political stability	PS
WDI	Trade openness	Trade openness	TO
WDI	Natural logarithm of GDP per capita	Logarithm of GDP per capita	LnGDP
IEA	Natural logarithm of energy consumption per capita	Logarithm of energy consumption	LnEC
WDI	Urban population as a percentage of total population	Urbanization	URB
IEA	Renewable energy consumption as a percentage of final energy consumption	Renewable energy	RE

Source: Research Calculations

3. Results and Discussion

In order to examine the effect of trade openness on carbon dioxide emissions with emphasis on the threshold role of political stability in selected developing countries, a panel threshold regression model is employed. This model makes it possible to investigate nonlinear and regime-dependent relationships among the variables and shows that the effect of the main explanatory variable may vary depending on the level of the threshold variable. Accordingly, the empirical model of the study is specified as follows:

$$CO2it = \alpha_{it} + \beta_1 TO_{it} I(PS_{it} \leq \Upsilon) + \beta_2 TO_{it} I(PS_{it} > \gamma) + \beta_3 LnGDP_{it} + \beta_4 LnEC_{it} + \beta_5 URB_{it} + \beta_6 RE_{it} + \varepsilon_{it} \quad (3)$$

where the subscript i denotes cross-sections and the subscript t represents time, γ is the numerical threshold value, and qit is the threshold variable. In the above model and relationships, the threshold variable is represented by the function I (0), and the observations are divided into two or more regimes depending on whether the threshold variable qit is below or above the threshold γ. Before estimating the panel threshold model, it is necessary to test the stationarity of the variables used in the analysis, since the presence of non-stationary variables may lead to spurious regression and consequently to misleading inferences. Therefore, in this study, the Levin, Lin, and Chu (LLC) panel unit root test is employed to examine the stationarity properties of the variables [33]. This test is one of the commonly used methods in the panel data literature and has been widely applied in empirical analyses based on pooled cross-sectional and time-series data. The results of the stationarity tests for the variables are reported in Table 2.

Table 2. Stationarity Test Based on the LLC Statistic

Variable	Probability	Statistic
CO_2	0.0310	-1.8664
PS	0.0000	-5.8472
TO	0.0000	-4.8746
LnGDP	0.0000	-5.2288
LnEC	0.0072	-2.4489
URB	0.0000	-7.3278
RE	0.0285	-2.0285

Source: Research Calculations

Since the results of the LLC panel unit root test indicate that all variables are stationary at level, the variables are integrated of order zero, I(0). Therefore, the empirical model is not estimated using non-stationary variables. Panel cointegration tests such as Pedroni or Kao are mainly applicable when the variables are non-stationary at level and integrated of order one, I(1), in order to examine whether a long-run equilibrium relationship exists among them. Given that none of the variables in the present study follows an I(1) process, the application of panel cointegration tests is not econometrically required. Consequently, the risk of spurious regression due to non-stationarity is minimized, and the fixed-effects panel threshold model can be estimated using the level form of the variables. The examination of variable stationarity is one of the fundamental prerequisites for estimating panel data models, particularly nonlinear models such as the panel threshold model. In this regard, the Levin, Lin, and Chu (LLC) test was employed to assess the stationarity properties of the study variables. The results presented in Table 1 show that the test statistics for all variables are statistically significant. Moreover, the probability values associated with all variables are below the 5 percent significance level, indicating rejection of the null hypothesis of a unit root. Therefore, it can be concluded that carbon dioxide emissions, political stability, trade openness, the logarithm of GDP per capita, the logarithm of energy consumption, urbanization, and renewable energy are all stationary at level. Accordingly, the use of these variables in the estimation of the panel threshold model is statistically appropriate, and the resulting estimates can be considered reliable.

In estimating models based on pooled cross-sectional and time-series data, it is first necessary to determine whether a pooled model or a panel data model is more appropriate. For this purpose, the F-Limer test is applied. In the next step, to choose between the fixed-effects model and the random-effects model, the Hausman test is employed. The results of these tests are presented in Table 3.

Table 3. Testing for Panel Structure and Fixed Effects

Probability	Statistic	Test
0.0000	94.3582	F-Limer
0.0000	44.2581	F Hausman

Source: Research Calculations

After confirming the stationarity of the variables, the appropriate model specification for estimation was determined. To this end, the F-Limer test was first conducted in order to choose between the pooled model and the panel data model. The results of this test, with a statistic of 94.3582 and a probability value of 0.0000, indicate that the null hypothesis regarding the adequacy of the pooled model is rejected. Therefore, the panel data model is more appropriate than the pooled specification. In the next step, the Hausman test was employed to choose between the fixed-effects and random-effects models. The test statistic was found to be 44.2581, with a probability value of 0.0000, implying rejection of the null hypothesis and preference for the fixed-effects model. Accordingly, the appropriate specification for estimating the relationship between trade openness and carbon dioxide emissions, while accounting for the threshold role of political stability, is a fixed-effects panel model.

In this section, the threshold determination test for the estimated model is conducted. As noted earlier, political stability is considered as the threshold variable. To examine whether a statistically significant threshold effect exists in the model, Hansen's panel threshold test is applied. Since the threshold parameter is not identified under the null hypothesis of no threshold effect, the likelihood ratio statistic does not follow a standard asymptotic distribution. Therefore, following Hansen's methodology, the statistical significance of the threshold effect is evaluated using bootstrap inference. In this study, the bootstrap p-value is obtained based on 400 bootstrap replications. The results of the threshold test are reported in Table 4.

Table 4. Bootstrap Inference for the Single Threshold Effect of Political Stability

Test	Statistic	Bootstrap p-value	Lower Threshold Value	Threshold Value	Upper Threshold Value
LR	78.89	0.04	0.7488	0.7570	0.7789

Source: Research Calculations

Based on the bootstrap results reported in Table 3, the likelihood ratio (LR) statistic is 78.89, and the corresponding bootstrap p-value is 0.04. Since the bootstrap p-value is below the 5 percent significance level, the null hypothesis of no threshold effect is rejected. This re sult confirms the existence of a statistically significant threshold effect of political stability in the relationship between trade openness and carbon dioxide emissions. This result indicates that political stability exerts a statistically significant threshold effect on the relationship between trade openness and carbon dioxide emissions. In other words, the impact of trade openness on CO_2 emissions in the selected developing countries is not uniform across all observations, but rather can be analyzed within two distinct regimes depending on the level of political stability.

Moreover, the estimated threshold value is found to be 0.7570, with the lower and upper bounds reported as 0.7488 and 0.7789, respectively. This finding suggests that 0.7570 serves as the critical value of political stability that divides the sample into two different regimes. Accordingly, countries whose political stability index is less than or equal to this threshold fall into the first regime, whereas countries with political stability values above this threshold are classified in the second regime.

From an analytical perspective, the significance of the political stability threshold implies that the quality of the political and institutional environment can play a decisive role in shaping the way trade openness affects environmental outcomes. Put differently, trade openness does not necessarily have the same effect on carbon dioxide emissions in countries with different levels of political stability, and this relationship may change once political stability surpasses a certain critical level. Therefore, the application of the panel threshold model to analyze the relationship under investigation is both statistically justified and analytically appropriate.

Therefore, the research sample, which consists of 44 developing countries, is divided into two groups based on the estimated threshold value. Each of these groups exhibits greater homogeneity with respect to the threshold variable compared with the full sample.

Subsequently, for both the low-threshold regime and the high-threshold regime, the specified equation (3) is estimated using the panel data approach with fixed effects. The estimated coefficients of the variables for the two regimes are reported in Table 5.

Table 5. Estimation Results of the Panel Threshold Model

Probability	t-Statistic	Coefficient	Variable
0.000	5.28	1.2511	LnGDP
0.000	8.86	2.1363	LnEC
0.003	-2.92	-0.0277	URB
0.002	3.18	0.0175	RE
0.648	-0.46	-0.0008	TO < 0.7570
0.000	-7.09	-0.0208	TO > 0.7570

Source: Research Calculations.

The estimation results of the effect of trade openness and the control variables on carbon dioxide emissions within the fixed-effects framework are reported in Table 5. The findings indicate that a considerable share of the variation in carbon emissions in the studied sample can be explained by economic and structural factors, and the estimated coefficients are statistically significant.

According to the results, the logarithm of GDP per capita has a positive and statistically significant effect on carbon dioxide emissions. The estimated coefficient of this variable is 1.2511, which is significant at the 1 percent level. This result suggests that economic growth in the countries under study is associated with an increase in carbon emissions, indicating that the development process in these economies still relies heavily on carbon-intensive activities and polluting energy sources. This result is in line with previous research [34-36].

The logarithm of energy consumption also exhibits a positive and strong effect on CO_2 emissions, with a coefficient of 2.1363. The relatively large magnitude of this coefficient, together with its statistical significance at the 1 percent level, indicates that energy consumption represents one of the key and decisive factors driving the increase in emissions in developing countries. The results related to urban population show that this variable has a negative and statistically significant coefficient of −0.0277. This finding, which is significant at the 1 percent level, may suggest that urbanization processes in developing countries are gradually associated with improvements in energy efficiency, the expansion of public transportation systems, or changes in energy consumption patterns, all of which may contribute to a reduction in per capita carbon emissions. Regarding renewable energy consumption, a positive and statistically significant coefficient of 0.0175 is observed. Although this finding may initially appear unexpected, it is relatively common in the literature on developing countries. This outcome can be attributed to the very small share of renewable energy in the total energy mix, alongside the simultaneous growth in overall energy demand. As a result, the increase in renewable energy consumption has not yet led to a real substitution for fossil fuels; instead, it has expanded alongside the continued use of polluting energy sources, rather than replacing them.

3.1. Results Concerning Trade Openness and Threshold Regimes

In the current model, the trade openness variable is divided into two regimes based on the threshold value of political stability. The reported coefficients indicate:

In the first regime (values of political stability less than or equal to the threshold), the coefficient of trade openness is −0.0008, which is not statistically significant. Therefore, at low levels of political stability, trade openness has no discernible effect on carbon emissions.

In the second regime (values of political stability above the threshold), the coefficient of trade openness is −0.0208 and is statistically significant at the 1% level. This result indicates that as political stability increases, trade openness leads to a reduction in carbon emissions. In other words, under more stable conditions, countries are able to benefit from the environmental advantages of trade, including the transfer of cleaner technologies and the implementation of more effective environmental regulations.

This significant difference between the two regimes confirms the presence of a threshold effect of political stability, such that the impact of trade openness on environmental quality varies across different levels of political stability.

4. Conclusions

This study aimed to examine the effect of trade openness on carbon dioxide emissions, with particular emphasis on the threshold role of political stability, in 44 selected developing countries over the period 2002–2024. To achieve this objective, a panel threshold model was employed, which allows the identification of nonlinear and regime-dependent relationships among variables. Within this framework, carbon dioxide emissions were considered the dependent variable, trade openness was the main explanatory variable, political stability served as the threshold variable, and the logarithm of GDP per capita, the logarithm of energy consumption, urbanization, and renewable energy were included in the model as control variables. Prior to model estimation, the Levin, Lin, and Chu unit root test was applied to examine the stationarity of the variables. The results indicated that all research variables are stationary at level; therefore, the risk of spurious regression is reduced and reliable model estimation is possible. Moreover, the results of the F-Limer test and the Hausman test indicated the superiority of the panel data model over the pooled model and the preference for the fixed-effects model over the random-effects model, respectively. These findings suggest that unobserved heterogeneities and country-specific characteristics play a significant role in explaining variations in carbon dioxide emissions and should therefore be controlled for in the estimation process.

The main finding of the study emerged from Hansen's threshold test. The results of the LR test showed that political stability has a significant threshold effect in the relationship between trade openness and carbon dioxide emissions. The estimated threshold value for political stability was 0.7570. This value divides the sample into two distinct regimes: the first regime includes observations in which the level of political stability is less than or equal to the threshold value, while the second regime includes observations in which the level of political stability exceeds the threshold value. Accordingly, the results confirm that the relationship between trade openness and carbon emissions in developing countries is not linear or uniform; rather, it depends on the level of political stability. The estimation results of the threshold model indicate that in the first regime, that is, at lower levels of political stability, the effect of trade openness on carbon dioxide emissions is negative but statistically insignificant. This result suggests that in environments lacking sufficient political stability, the expansion of trade alone cannot lead to improvements in environmental performance. Under such conditions, weak institutional capacity, policy instability, limited enforcement of environmental regulations, and the inability to absorb clean technologies may prevent the potential benefits of trade from being translated into environmental gains.In contrast, in the second regime—when the level of political stability exceeds the threshold value—trade openness has a negative and statistically significant effect on carbon dioxide emissions. This finding indicates that in countries with higher political stability, international trade can contribute to reducing carbon emissions. From an analytical perspective, this result implies that political stability plays a complementary role in activating the environmental benefits of trade. In more stable environments, the capacity to adopt low-carbon technologies, facilitate the transfer of technical knowledge, improve energy efficiency, enhance production standards, and implement environmental policies more effectively increases. Therefore, trade openness can lead to improvements in environmental quality only when it is accompanied by an adequate level of institutional and political stability. Regarding the control variables, the results show that GDP per capita and energy consumption have positive and statistically significant effects on carbon dioxide emissions. This finding indicates that the process of economic growth in the selected developing countries remains largely based on energy-intensive patterns and dependence on fossil fuels [37, 38]. In particular, the relatively large coefficient of energy consumption suggests that the energy structure in these countries is one of the most important factors contributing to increased carbon emissions. Therefore, without reforming the energy mix and improving energy-use efficiency, economic growth may exert greater pressure on the environment. Urbanization also exhibits a negative and statistically significant effect on carbon dioxide emissions. This result may indicate that the expansion of urbanization in the countries under study has, in some cases, been accompanied by improvements in infrastructure, greater energy-use efficiency, concentration of public services, development of urban transportation systems, and changes in consumption patterns. However, the interpretation of this finding should consider structural differences among countries, as the environmental impact of urbanization may vary depending on the quality of urban management, the infrastructure development, transportation policies and trade openness [39].

With regard to renewable energy, the positive and statistically significant coefficient of this variable indicates that increasing the share of renewable energy in the countries under study has not yet led to a reduction in carbon dioxide emissions. Although this result may appear unexpected at first glance, it may reflect the relatively small share of renewable energy in the overall energy mix, the rapid growth of total energy demand, and the lack of effective

substitution of clean energy sources for fossil fuels. In other words, in developing countries, the expansion of renewable energy may have functioned more as a complement to fossil fuel consumption rather than as a substitute for it.Based on the findings of the study, it can be concluded that political stability is not merely a contextual variable but rather a determining factor in shaping the environmental effects of international trade. This result carries substantial theoretical and empirical significance, as it indicates that evaluating the impact of trade openness on the environment without considering the quality of the institutional environment and the level of political stability may lead to incomplete or misleading conclusions. In fact, trade can simultaneously generate different outcomes: under weak institutional conditions, its effect on pollution reduction is uncertain or limited; however, in more stable environments, it can function as a channel for technology transfer, productivity improvement, and emission reduction. From a policy perspective, the results of this study carry several important implications. First, trade policies in developing countries should be coordinated with institutional and environmental policies. Merely increasing the degree of trade openness, without strengthening institutional capacity and ensuring policy stability, will not necessarily lead to improvements in environmental quality. Second, countries should utilize international trade as a mechanism for accessing clean technologies, low-carbon production standards, and green investments. Third, reducing carbon dioxide emissions requires reforming the energy structure and decreasing dependence on fossil fuels, as the results indicate that energy consumption is the most significant driver of increased emissions in the countries under study. Fourth, the development of renewable energy should be designed in such a way that it becomes a genuine substitute for fossil fuels rather than merely adding to total energy capacity.

Overall, the findings of this study indicate that the relationship between trade openness and carbon dioxide emissions in developing countries is conditional, nonlinear, and dependent on the level of political stability. At low levels of political stability, trade openness does not have a significant effect on emission reduction; however, once a certain threshold of political stability is surpassed, trade can play a significant mitigating role in carbon dioxide emissions. Therefore, achieving the environmental benefits associated with globalization and free trade requires the simultaneous integration of trade policies, institutional reforms, improvements in environmental governance, and a transition toward a low-carbon energy structure.

Author Contributions

Hamed Mokhtari Torshizi: Conceptualization, Methodology, Data Curation, Formal Analysis, Investigation, Writing – Original Draft. Mahdi Zandi Dashtbayaz: Methodology, Validation, Writing – Review & Editing. Farzaneh Ahmadian-Yazdi: Conceptualization, Supervision, Validation, Investigation, Writing – Review & Editing. All authors have read and approved the final version of the manuscript.

Conflict of Interest

The authors, while observing publication ethics in the referencing, declare the absence of interest of conflict.

Acknowledgement

The authors would like to thank the Editor and anonymous reviewers for their valuable comments and constructive suggestions, which helped improve the quality of this manuscript.

AI-Assisted

The authors retain full responsibility for the accuracy, originality, integrity, legality, and ethical compliance of all text, data, tables, figures, analyses, references, and conclusions, and have verified all AI-assisted outputs. Any fabrication, falsification, manipulation, plagiarism, copyright infringement, or other misuse of AI remains solely the responsibility of the authors and does not transfer or diminish their accountability for the published work.

References

[1] Intergovernmental Panel on Climate Change (IPCC) (Ed.). (2023). *Climate Change 2022 - Mitigation of Climate Change: Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

[2] Development Data Group. *World development indicators*. World Bank. 1978.

[3] B. R. Copeland, M. S. Taylor. *Journal of Economic Literature*, 2004, **42(1)**, 7-71.

[4] W. Antweiler, B. R. Copeland, M. S. Taylor. *American Economic Review*, 2001, **91(4)**, 877-908.

[5] M. A. Cole. *Ecological Economics*, 2004, **48(1)**, 71-81.

[6] J. A. Frankel, A. K. Rose. *Review of Economics and Statistics*, 2005, **87(1)**, 85-91.

[7] M. Shahbaz, S. Nasreen, K. Ahmed, S. Hammoudeh. *Energy Economics*, 2017, **61**, 221-232.

[8] M. A. Destek, F. N. Ozsoy. *International Journal of Energy and Statistics*, 2015, **3(4)**, 15500171-13.

[9] S. Nathaniel, S. A. R. Khan. *Energy, Ecology and Environment*, 2020, **5**, 265-278.

[10] D. Kaufmann, A. Kraay, M. Mastruzzi. *World Bank Policy Research Working Paper*, 2010, 54301-31.

[11] U. Farooq, S. Gillani, B. H. Subhani, M. N. Shafiq. *Environmental Science and Pollution Research*, 2023, **30**, 23479-23497.

[12] B. E. Hansen. *Journal of Econometrics*, 1999, **93(2)**, 345-368.

[13] S. Dinda. *Ecological Economics*, 2004, **49(4)**, 431-455.

[14] G. M. Grossman, A. B. Krueger. *National Bureau of Economic Research Working Paper*, 1991, 39141-15.

[15] M. A. Cole, R. J. R. Elliott, P. G. Fredriksson. *Scandinavian Journal of Economics*, 2006, **108(1)**, 157-178.

[16] Q. Li, R. Reuveny. *International Studies Quarterly*, 2006, **50(4)**, 935-956.

[17] M. Ahmad, Z. Ahmed, A. Majeed, B. Huang. *Environmental Impact Assessment Review*, 2021, **89**, 106603-13.

[18] I. Khan, F. Hou, H. P. Le. *Science of The Total Environment*, 2021, **754**, 142222-42.

[19] Y. Zhang, Y. Sun, J. Huo. *Energy Economics*, 2023, **125**, 106797-810.ssss

[20] L. Wang. *Sustainable Production and Consumption*, 2023, **38**, 201-215.

[21] S. Liu, H. Zhang. *Finance Research Letters*, 2024, **62**, 105198-18.

[22] M. M. Rahman, N. Sultana. *Sustainability*, 2024, **16(13)**, 5382-95.

[23] F. Farooq, M. Faheem, A. Nousheen. *Pakistan Journal of Humanities and Social Sciences*, 2023, **11(2)**, 1239-1253.

[24] S. F. Razmi, H. R. Ramezani, M. N. Asgari. *Energy Sources, Part B: Economics, Planning, and Policy*, 2021, **16(7)**, 672-686.

[25] S. Ali, T. S. Adebayo, et al. *Risk Analysis*, 2024, **44(8)**, 1874-1891.

[26] Y. Li. *Environmental Science and Pollution Research*, 2023, **30**, 29815-29835.

[27] Ahmed, Z., Rasheed, M. Q., & Pinzon, S. *International Journal of Sustainable Development & World Ecology*, ***32*(5)**,2025, 525-539.

[28] IRENA, R. E. C. H. *International Renewable Energy Agency, 2019*.

[29] B. E. Hansen. *Journal of Econometrics*, 1999, **93(2)**, 345-368.

[30] S. Chiou-Jer, S. Wu-Pei, Y. Huang-Bor. *Interdisciplinary Journal of Research in Business*, 2011, **1(4)**, 1-11.

[31] B. E. Hansen. *Econometrica*, 1996, **64(2)**, 413-430.

[32] B. E. Hansen. *Econometrica*, 2000, **68(3)**, 575-603.

[33] A. Levin, C. F. Lin, C. S. James Chu. *Journal of Econometrics*, 2002, **108(1)**, 1-24.

[34] F. Dashtroo, V. Varahrami. *Journal of Environmental Economics and Chemical Processes*, 2026, **3(2)**, e7351881-7.

[35] M. Nasr Esfahani, R. Motazer, E. Mehranpour. *Journal of Environmental Economics and Chemical Processes*, 2025, **2(4)**, 143-150.

[36] F. Ahmadian-Yazdi, W. Mensi, K. H. Al-Yahyaee, M. Ramsheh, S. Al-Kharusi. *Resources Policy*, 2025, **109**, 105728-40.

[37] Aboutorabi, M. A., Ahmadian Yazdi, F., & Parkam, S. In *Economic Growth and Financial Development: Effects of Capital Flight in Emerging Economies.* 2021.33-55.

[38] F. Ahmadian Yazdi, T. Ebrahimi Salari, F. Jandaghi, N. Rajab Zadeh Moghani. *Journal of Applied Economics Studies in Iran*, 2015, **4(15)**, 201-228.

[39] F. Ahmadian Yazdi, M. Salimifar, M. T. Ahmadi Shadmehri. *Economic Growth and Development Research*, 2015, **5(20)**, 11-30.