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Does the Government Influence the Relationship Between the Globalization of the Digital Economy and Environmental Quality?

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ABSTRACT

The digital economy has become one of the most important drivers of economic growth, innovation, and technological transformation in recent decades, yet its environmental impacts continue to be the subject of much attention and debate in the economic literature. This study investigates the impact of the digital economy on environmental quality and analyzes the moderating role of institutional quality in selected Middle East and North Africa countries from 2005 to 2023. In this regard, the Panel Smooth Transition Regression (PSTR) model was used to identify nonlinear relationships and threshold effects. The study's dependent variable is the environmental quality index, and the model includes the digital economy development index, institutional quality, gross domestic product, government effectiveness, corruption control, and regulatory quality as explanatory variables. The research findings show that institutional quality plays a decisive role in the direction and intensity of the impact of the digital economy on environmental quality; in such a way that improving the quality of institutions moderates the impact of the digital economy on environmental quality and can affect the path of its impact in different directions (improving or weakening environmental quality). Accordingly, strengthening institutional reforms and improving the quality of governance should be the focus of policymakers' attention simultaneously with the development of the digital economy in the countries under study. ©authors

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Introduction

In recent decades, the expansion of the digital economy has become one of the most important structural developments in the global economy, the environmental consequences of which have sparked extensive debate among researchers. On the one hand, the digital economy can play an effective role in improving environmental quality by developing smart technologies, optimizing resource consumption, and improving energy efficiency (Lanre Ibrahim et al., 2022). On the other hand, the expansion of digital infrastructure, increasing energy consumption of data centers, and the growth of e-waste have intensified the pressure on environmental resources, especially in developing countries that face challenges such as the digital divide and weak governance (Raghutla & Chittedi, 2021).

Along with digital developments, economic globalization also affects environmental quality as a determining factor. Several studies have shown that globalization through trade openness, technological diffusion, and movement of goods and services can simultaneously lead to economic growth and increased energy demand, and ultimately environmental pollution (Eregba & Nwokoma, 2014; Isola & Mesagan, 2014; Shahbaz et al., 2017; You & Lv, 2018; Jafar et al., 2019; Zhang & Ozturk, 2022). Meanwhile, environmental quality, which requires minimal pollution, is highly dependent on institutional structures and regional economic activities (Efobi et al., 2019; Lyu et al., 2022).

One of the key topics in the sustainability literature is the role of institutions in moderating environmental impacts. While the “race to the bottom” theory warns that countries may lower their environmental standards to attract foreign investment (Dasgupta et al., 2002; Grecker, 2007; Adebayo et al., 2021), the “race to the top” theory argues that strengthening institutions and regulations attracts clean and competitive industries, leading to improved environmental quality (Hunjra & Hassan, 2023). This contrast in findings emphasizes that the environmental impacts of emerging technologies and the digital economy depend largely on the level of institutional maturity and governance capacity of countries (Sattar & Tolassa, 2022).

Institutional quality and digital governance are key factors in explaining countries’ environmental performance (Elfaki & Khan, 2022). Effective institutions enable the optimal exploitation of digital capacities by creating transparency, controlling corruption, and effective regulation, while institutional weakness can reduce the effectiveness of digital policies and exacerbate environmental damage (Bennett et al., 2018). The Middle East and North Africa (MENA) region is an ideal setting to explore this relationship due to its extensive investments in digital infrastructure, but also heterogeneity in the quality of governance and digital readiness (Mehmood & Tariq, 2021).

Given the research gap in simultaneously analyzing the moderating role of institutional quality on the relationship between the digital economy and environmental quality, this study uses a nonlinear econometric approach to answer the question, “Do institutional quality and government governance moderate the effect of the digital economy on environmental quality in selected MENA countries over the period 2005–2023?” The innovation of this study is the use of a comprehensive digital development index and a panel smooth transition regression (PSTR) model that allows for the identification of threshold effects. The results of this study, by explaining the effective institutional mechanisms, provide valuable policy solutions for policymakers to align digital transformation with sustainable development goals.

Against this backdrop, examining the environmental implications of the digital economy requires moving beyond the direct effects of digitalization and considering the institutional and policy conditions under which digital transformation takes place. Although the globalization of the digital economy can facilitate technological innovation, resource efficiency, digital connectivity, and more sustainable production processes, it may also intensify energy consumption, electronic waste, and environmental pressures through

expanding digital infrastructure and global economic integration. In this context, the role of government becomes particularly important, as regulatory quality, environmental policies, digital governance, and institutional capacity may determine whether the benefits of digital globalization are translated into improved environmental outcomes or, conversely, contribute to environmental degradation. Therefore, identifying the extent to which government intervention shapes this relationship is essential for developing effective policies that reconcile digital economic globalization with environmental sustainability. Accordingly, the present study seeks to answer the following fundamental research question: Does the government influence the relationship between the globalization of the digital economy and environmental quality?

Literature Review

1. The evolution of globalization, the digital economy and its environmental impacts

The digitalization of the economy, which began with the development of communication infrastructure, has now gained unprecedented momentum with the emergence of new technologies such as cloud computing, artificial intelligence, big data and the Internet of Things, making data flows and innovation the core of global growth and competitiveness (Wu et al., 2017; Asongu & Nting, 2019; Hasanov et al., 2023). Along with this evolution, globalization has also moved beyond the stages focused on countries and companies and reached the level of “individual globalization” (Salman & Long, 2019; Zafar & Saud, 2019; Zhang & Ozturk, 2022). This pervasive process has affected all living and non-living components of the ecosystem (Acheampong & Opoku, 2023). Although the initial goal of globalization and trade liberalization was to expand economic exchanges, in practice the dramatic growth of international trade has been accompanied by increased energy consumption and emissions of pollutants such as carbon dioxide, and has brought about dire environmental challenges (Rahman & Alam, 2022).

2. Empirical evidence of drivers and restraints of environmental degradation

Empirical analyses at the country level show that the interaction between economic growth, industrialization, and the environment is complex and multidimensional. For example, studies in Indonesia show that economic growth, industrialization, and government spending play a significant role in determining environmental quality (Amar & Satrianto, 2024). In Australia, trade liberalization, financial development, and energy consumption have also had long-term negative effects on the environment, and the Environmental Kuznets Curve (EKC) hypothesis has not been confirmed (AliNasir et al., 2021). In contrast, China’s experience shows that technological innovation, green finance, and renewable energy development can align economic growth with sustainability goals (Lanre Ibrahim et al., 2022). In the Iranian economy and other developing countries, studies also show that although the expansion of the shadow economy or operational sectors of globalization can increase pressure on the environment, the legal dimensions of globalization, smart governance, and the structure of a smart green government play a deterrent role in the emission of pollutants, in some cases confirming the EKC hypothesis (Abassian et al., 2022; Imani et al., 2022; Zeruki et al., 2022; Martin et al., 2015).

3. The Determinative and Moderating Role of Institutional Quality and Governance

A significant body of recent literature is based on the assumption that the environmental consequences of globalization and economic growth are a direct consequence of “institutional quality” and “governance.” Research in various country groups, including the E7 and OECD, confirms that although economic growth and urbanization exacerbate environmental pressures, strong institutions and smart economic liberalization prevent environmental degradation (Oyang Junyan et al., 2024; Simic et al., 2025). Also, in Asian economies and sub-Saharan Africa (SSA), the positive interaction between institutional

quality and economic globalization has led to improved environmental performance and pollution control (Yameogo et al., 2021; Latif et al., 2023). In this regard, global studies, by introducing Composite Governance Indicators (CGI) and assessing the MENA region, have shown that good governance and institutional quality have both short- and long-term mitigating effects on CO2 emissions, although the intensity of this effect varies depending on the income level and infrastructure of each country (Naim Azimi et al., 2023; Abbas et al., 2025).

4. Importance of Research and Knowledge Gap

Despite the development of the empirical background, a review of the existing literature indicates several fundamental knowledge gaps that explain the importance and necessity of conducting the present study:

Ignoring nonlinear and threshold effects: Most previous studies have only included institutional quality as a linear control variable in the model and have neglected to examine the "moderating" role and threshold effects of government governance on the relationship between the digital economy/globalization and the environment.

Limited focus on structural features of the MENA region: Despite heavy investment in emerging technologies and globalization, countries in the Middle East and North Africa region face severe heterogeneity in institutional quality and high energy dependence, an issue that has received less attention in comprehensive research.

Methodological limitations: The use of traditional linear models is unable to uncover complex behaviors and institutional turning points.

By filling these knowledge gaps and using the Panel Smooth Transition Regression (PSTR) model, this study shows how and at what levels of institutional quality (threshold) the impact of the digital economy on environmental quality changes behavior; which provides practical guidance for policymakers to adopt smart regulatory strategies and environmental sustainability.

Method

The aim of this study, following the studies of Yameogo et al. (2021), AliNasir et al. (2021), and Hunjra 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 PSTR model, given that the dependent variable is environmental quality and the explanatory variables are globalization and government governance, is as follows:

(1)

$$AQI_{it} = \alpha_0 + \beta_1 KOF_t + \beta_2 INST_t + \beta_3 KOF * INST_t + \beta_4 GDP_t + \beta_5 GE_t + \beta_6 CC_t + \beta_7 RQ_t (\theta_1 KOF_t + \theta_2 INST_t + \theta_3 KOF * INST_t + \theta_4 GDP_t + \theta_5 GE_t + \theta_6 CC_t + \theta_7 RQ_t) F(S_t, \gamma, c) + u_t$$

Where the transition function F is equal to:

(2)

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

$AQI_{i,t}$: Environmental quality (air quality index) of country i in year t

RQ : Regulatory quality, an index between 0 and 100, the closer to 100, the more countries have been able to improve the quality of regulations in the country.

$INST$: The weighted average of five sub-categories is used to measure the quality of governance: (1) size of government (2) legal system and property rights (3) sound money (4) international free trade (5) credit, labor and business regulations. There are main components in these five areas, and these components include sub-components that lead to an overall index of independent variables. The Fraser Institute uses a scale for each category that calculates the average of these five indicators to obtain a complete index for each country. In this index,

zero represents the smallest value of governance quality and ten represents the highest governance quality.

GE: Government effectiveness, an index between 0 and 100, the closer it is to 100, the more effective the government is.

CC: Control of corruption, an index between 0 and 100, the closer it is to 100, the more countries have been able to control corruption in the country.

KOF: Globalization (includes real economic flows, namely trade, foreign direct investment and portfolio investment, and trade and capital restrictions, which include average tariff rates and taxes on international trade, as well as an index of capital controls.).

GDP: Gross domestic product per capita in dollars at constant prices in the base year 2010, an index to show economic growth. In order to examine the characteristics of the PSTR model with a logistic transfer function based on the Van Dijk model (1999), it is assumed that the dependent variable *AQI* is only a function of its own intervening values. In this case, assuming a two-regime transfer function, the following relationship is obtained:

$$AQI_t = (\theta_0 + \theta_1 AQI_{t-1} + \dots + \theta_p AQI_{t-p}) + (\phi_0 + \phi_1 AQI_{t-1} + \dots + \phi_p AQI_{t-p}) G(INST_t, \gamma, c) + u_t$$

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

The results of this model are called a two-regime PSTR model, where the location parameter *c* represents a point of transition between two extreme regimes $G(INST_t, \gamma, c) = 0$ and $G(INST_t, \gamma, c) = 1$, where $G(INST_t, \gamma, c) = 0.5$. γ indicates the speed of transition between regimes, and higher values of γ indicate faster regime change. The statistical population of the present study is the selected countries of MENA and the North of the Middle East, including; Saudi Arabia, Qatar, Pakistan, United Arab Emirates, Algeria, Kuwait, Iran, Egypt, Oman, Morocco, Libya, Yemen and Sudan, during the period 2005 to 2023, using the Panel Smooth Transition Regression (PSTR) model.

Institutional Quality (INST)

Institutional quality (INST) is conceptually defined in this study as the extent to which the institutional environment provides a predictable, market-supportive, and rules-based framework for economic activities, private-sector decision-making, and resource allocation. Rather than referring narrowly to the quality of government administration or the effectiveness of public-sector institutions, institutional quality captures the broader institutional and economic framework within which individuals, firms, and markets operate. Accordingly, the study operationalizes institutional quality using the Economic Freedom Index developed by the Fraser Institute. This index incorporates five major dimensions: (i) size of government, (ii) legal system and property rights, (iii) sound money, (iv) freedom to trade internationally, and (v) regulation. These dimensions collectively reflect the extent to which the institutional environment protects property rights, supports the rule of law, ensures monetary stability, facilitates international economic exchange, and provides a predictable regulatory framework. Therefore, the INST variable should be interpreted as a broad measure of the institutional environment and economic freedom rather than as a direct measure of government performance or administrative governance.

Importantly, INST is conceptually distinct from the governance-related variables included separately in the empirical model. Government Effectiveness (GE) captures the quality of public services, the quality and independence of the civil service, and the credibility of government policy implementation. Control of Corruption (CC) reflects the extent to which public power is exercised without corruption, while Regulatory Quality (RQ) captures the government's capacity to formulate and implement policies and regulations that support private-sector development. In contrast, INST represents a broader institutional framework encompassing legal, economic, monetary, trade, and regulatory conditions. Consequently, the inclusion of INST alongside GE, CC, and RQ does not imply conceptual duplication;

rather, these variables capture different dimensions of the institutional environment and governance structure

Table1. Variable Definition and Measurement

Variable	Conceptual Meaning	Main Dimension Captured	Source
INST	Institutional quality / broader institutional environment	Government size, legal system and property rights, sound money, freedom to trade internationally, regulation	Fraser Institute
GE	Government effectiveness	Quality of public services, civil service and policy implementation	World Bank WGI
CC	Control of corruption	Extent to which public power is exercised for private gain	World Bank WGI
RQ	Regulatory quality	Capacity to formulate and implement effective regulations and market-supportive policies	World Bank WGI

The selection of the transition variable is a critical step in the PSTR framework because the transition variable determines the state-dependent mechanism through which the relationship between the explanatory variables and environmental quality changes across regimes. Therefore, the transition variable was not selected solely on the basis of the linearity test. Given the theoretical focus of this study on the institutional conditions under which the globalization of the digital economy affects environmental quality, several theoretically relevant candidates were considered, including the KOF Globalization Index (KOF), GDP, institutional quality (INST), government effectiveness (GE), control of corruption (CC), and regulatory quality (RQ). For each candidate variable, alternative PSTR specifications were estimated and their statistical performance was compared using the linearity test, information criteria, residual sum of squares, and the adequacy of the resulting regime specification. The transition variable that provided the strongest statistical evidence of regime-dependent nonlinearity and the most appropriate model fit was selected as the final transition variable. The results of this comparative procedure indicate that institutional quality (INST) provides the most appropriate transition mechanism for the relationship examined in this study. This finding is also theoretically consistent with the central argument of the study: the environmental consequences of digital-economic globalization may differ substantially depending on the quality of the institutional environment within which digital economic activities are developed, regulated, and implemented.

Measurement of Air Quality Index (AQI)

The dependent variable in this study is the Air Quality Index (AQI), which is used as an indicator of ambient air conditions rather than as a general measure of environmental quality. To avoid ambiguity, the term “AQI” is used consistently throughout the empirical analysis, while “environmental quality” is used only in the broader conceptual discussion. The AQI is an index-based measure and is therefore dimensionless; its interpretation depends on the underlying methodology used to construct the index. In the dataset employed in this study, the AQI ranges from 22.32310 to 370.3261 over the sample period. Importantly, higher AQI values indicate poorer air-quality conditions, whereas lower AQI values indicate better air-quality conditions. Therefore, an increase in AQI should be interpreted as a deterioration in air quality, while a decrease in AQI represents an improvement in air quality.

This direction of measurement is particularly important for interpreting the estimated coefficients in the PSTR model. Because AQI increases as air quality deteriorates, a positive coefficient on the globalization of the digital economy indicates that greater digital-economic globalization is associated with an increase in AQI and, consequently, a deterioration in air quality. Conversely, a negative coefficient indicates a reduction in AQI and therefore an improvement in air quality. The same interpretation applies to the coefficients of the other explanatory variables. Accordingly, the signs of the estimated coefficients are interpreted throughout the Results, Discussion, and Conclusion sections with reference to the inverse relationship between the AQI value and air-quality conditions.

The empirical analysis focuses on a set of countries located in the Middle East and North Africa (MENA) region and selected according to an explicit geographical and data-availability

criterion. To avoid ambiguity, the study does not use the expression “North of the Middle East”; instead, the geographical scope is consistently referred to as the selected MENA sample throughout the manuscript. The countries included in the analysis are Saudi Arabia, Qatar, the United Arab Emirates, Algeria, Kuwait, Iran, Egypt, Oman, Morocco, Libya, Yemen, and Sudan. These countries were selected because they fall within the geographical scope adopted for the study and provide sufficient annual observations for the variables required in the empirical analysis over the 2005–2023 period.

The inclusion of each country was determined based on three criteria: (i) its geographical classification within the study's defined MENA scope, (ii) the availability of the required annual data for the study variables, and (iii) the comparability of the available observations across countries and over time. The final sample therefore reflects both the geographical scope of the research and the data requirements of the PSTR methodology.

Findings

Study of descriptive statistics of the study index

Based on the results of Table 1, the descriptive statistics for the average AQI variable are 152.3265, its maximum is 370.3261 for Iran and its minimum is 22.32310 for the United Arab Emirates. Also, looking at the graphical trend of the average of this variable for the study countries, it can be seen that since 2012, environmental pollution has had an upward trend. The descriptive statistics of other variables can be seen in Table 1.

Table 2. Descriptive statistics of the main study indicators

Country Group	INST	RQ	KOF	AQI
Average	3.533339	43.00709	55.32620	152.3265
Maximum	6.642805	75.33334	74.3265	370.3261
Minimum	1.064284	21.480769	22.3261	22.32310

Source: World Bank (2022) and World Governance Indicators website

Linearity test, selection of transition variable and model type

To check the existence of a linear or nonlinear relationship between the model variables, it should be checked whether (m is the number of regime parameters) is one or not. It should be noted that in the following tests, it is assumed that the model is linear and the counter-hypothesis will be 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 linearity of the model (null hypothesis) is rejected; therefore, there is a nonlinear relationship between the role of social cohesion and economic development with an emphasis on the distribution of opportunities in the countries under study and, as a rule, it is necessary to use the PSTR method to estimate the model parameters.

Table 3. Results of the linearity hypothesis test of the model (BBC test)

Null hypothesis	Statistics F	Significance level
Wald test	5.326	000.0
Fisher test	3.156	000.0
LRT test	2.582	000.0

As is evident from the results of the test in Table 2, the hypothesis of linearity between the variables is rejected, so the possibility of a linear relationship between the variables is rejected. It is also worth noting that the proposed (PSTR) model is selected as the optimal model for estimating the model in the selected countries by the selected transfer variable.

For this purpose, following Gonzalez et al. (2005) and Colletaz & Hurlin (2006), the null hypothesis of the existence of a PSTR model with one transfer function was tested against the hypothesis of the existence of a PSTR model with at least two transfer functions, the results of which are presented in Table 3.

The results show that the null hypothesis of the adequacy of considering a transfer function in both cases of one and two thresholds is not rejected. Therefore, a transfer function is able to

specify the nonlinear behavior between economic globalization and environmental quality with an emphasis on the threshold effects of government governance.

Table 4. Test of the existence of a residual nonlinear relationship

The state of existence of a threshold limit $M=1$			The state of existence of two thresholds $M=2$		
LMw	LM _t	LR	LMw	LM _t	LR
1.352 (0.743)	1.471 (0.630)	1.432 (0.654)	1.425 (0.675)	1.362 (0.751)	1.297 (0.802)

$H_0: r=1, H_1: r=2$

By confirming the existence of a nonlinear relationship between the variables and the adequacy of a transfer function to specify the nonlinear behavior, the optimal mode between the transfer function with one or two thresholds should be selected. For this purpose, the PSTR model corresponding to each of these modes will be estimated, and among them, based on the criteria of the sum of squared residuals, Schwartz and Akaike, the PSTR model with one threshold is the optimal model. Therefore, a PSTR model with one transfer function and one threshold is selected to examine the nonlinear behavior between the variables under study.

Model Estimation Results

Using a PSTR model in which the transfer variable is government sovereignty (INST), the function of economic globalization and environmental quality analysis is modeled. The estimation results of the nonlinear part of the model (second regime) show that the globalization variables (KOF) and gross domestic product (GDP) have a positive relationship with the air quality index. Also, the variables of government governance (INST), government effectiveness (GE) and corruption control (CC) lead to a reduction in the emission of environmental pollutants and an improvement in the air quality index. The variable of government governance (INST) and the multiplicative mode of government governance in the globalization index (KOF*INST) also reduce the emission of environmental pollutants and improve the air quality index in selected countries. During the process of trade and production growth due to the use of fossil fuels, we witness air pollution and subsequent greenhouse gas emissions that lead to environmental degradation. The environment and natural resources provide many production inputs, and the production process, as well as having desirable outputs (consumer goods), also brings undesirable outputs (environmental pollutants and global warming). The damage to the environment may have irreparable costs if the amount of these outputs is not controlled, and this, with the heavy costs it creates, causes the losses from undesirable outputs to exceed the benefits of desirable products, and as a result, poses serious risks to sustainable development, so the need to pay attention to environmental consumption becomes more apparent than ever. Although the composition of developing countries in this study consists of countries that are mostly on the path to development, paying attention to the issue of production stability and also institutional stability in these countries should be among the issues that are of more concern to government officials and officials than any other issue. Of course, some researchers such as Morrow (1995) and Knack & Keefer (1995) consider governance quality as the oil in the wheels of heavy administrative bureaucracy and believe that the quality of governance and administrative laws cause a decrease in the speed of production, because the existence of various administrative and economic controls acts as a kind of stick in the wheel and slows down growth. Considering the structure of most developing countries in MENA, most of which are oil-based, the existence of various types of rents and economic and administrative corruption, the low coefficients of governance variables, and also a look at the average of the variables in Table 4, this theory can be considered acceptable to some extent for MENA countries.

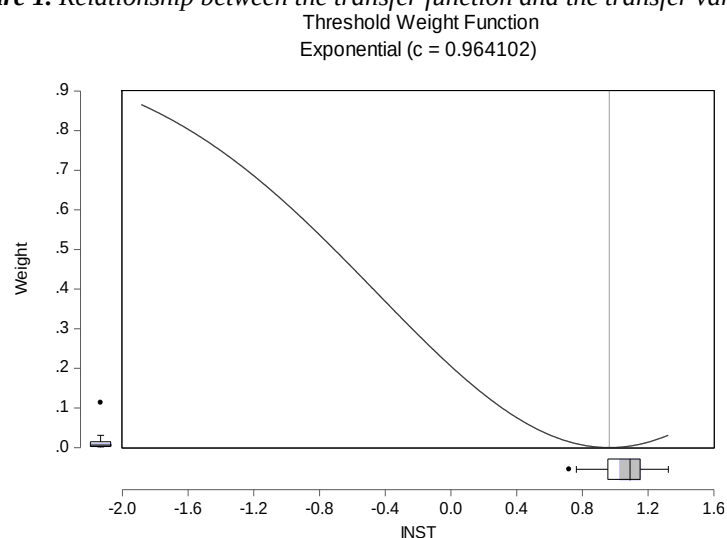
Table 5. Model estimation using the PSTR model

Model (Air Quality Index AQI)				
Linear Price Estimation Model				
Variable	Probability	t-statistic	Standard deviation	Coefficient
CONSTANT	0.0823	1.737401	0.300193	0.521556

Economy				
KOF	0.0147	2.453674	0.029185	0.071610
INST	0.0000	5.319560-	0.025286	0.134509-
KOF*INST	0.0126	2.516070-	0.070478	0.177326-
GDP	0.0757	1.786497	0.202713	0.362146
GE	0.0038	2.892296-	0.048299	-0.139694
CC	0.0829	1.733825-	0.307849	-0.533757
RQ	0.1664	1.390754-	0.208206	-0.289564
Estimation of the nonlinear part of the model				
CONSTANT	0.0937	1.748721	0.260162	0.454951
KOF	0.0000	12.20875	0.021786	0.265979
INST	0.0001	4.651335-	0.114026	0.530375-
KOF*INST	0.0092	2.649681-	0.061974	0.164212-
GDP	0.0248	2.400855	0.086277	0.207139
GE	0.0000	11.57561-	0.064482	0.746418-
CC	0.0098	2.611624-	0.111290	0.290648-
RQ	0.0042	2.856400-	0.096685	0.276170-
(C)Threshold	0.0000	6.077495	0.158623	0.964102
Slope parameter(γ)	0.0284	2.274678	2.934622	6.675325
Adjusted coefficient (R^2) = 0.95				
Source: Research findings				

The comparison of coefficients in two different regimes is based on the transfer variable and its values, and the value of the transfer variable can determine the transfer function and, consequently, the governing regime. In the above estimation, the transfer variable is government governance (institutional quality), and the estimated threshold value for this variable was equal to 0.964102. Based on the distance of the air quality index from this threshold value, the model follows two different limit regimes. By comparing the model coefficients in two different regimes, it is observed that when the institutional quality crosses the threshold (0.964102) (transition from the linear to the nonlinear part), the response of the air quality index to changes in this variable has increased sharply, so that environmental policymakers have tried to control the air quality index with a more appropriate response and prevent its increase.

Figure 1. Relationship between the transfer function and the transfer variable



Diagnostic tests

In the present study, the Durbin-Watson test is used to examine autocorrelation.

Table 6. Results of the autocorrelation test

Durbin-Watson	Prob	Statistics F
2.398	0.48	1.458

As can be seen in the table above, the results of the Durbin-Watson autocorrelation test show that there is no correlation between the disturbance components, so the third assumption of the classical standard that there is no autocorrelation between the error terms is not violated.

Therefore, the estimators have the necessary properties (minimum variance and efficiency). Another assumption of the classical standard is the assumption of homogeneity of variance, in the present study, the Brosch-Pagan-Godfrey test is used.

Table 7. Results of the heterogeneity of variance test

Breusch-Pagan test	Prob	F
0.129	0.812	0.698

As can be seen in the table, the test results indicate the absence of variance heterogeneity.

Discussion

The results of this study show that the relationship between economic globalization and environmental quality in selected countries in the Middle East and North Africa (MENA) region is not linear and uniform; rather, with the intensification of digital transformation and the move towards platform economies and emerging spaces such as the metaverse, this relationship takes on a nonlinear nature and depends on institutional quality. The estimation of the Panel Smooth Transition Regression (PSTR) model showed that institutional quality, in addition to its direct effect on environmental performance, acts as a transition variable and changes the direction and size of the effect of economic globalization at different levels of governance. Therefore, analyzing the consequences of globalization in the era of digital transformation—especially with the emergence of virtual ecosystems, data-driven economies, digital assets, and platform value chains—without taking into account institutional heterogeneity leads to incomplete and sometimes contradictory results.

From a theoretical perspective, the findings are consistent with the institutional economics approach and the digital governance literature; Because institutions create the framework within which digital technologies (from cloud services and AI to metaverse infrastructure) are regulated, investments are made, and environmental spillovers occur. In countries with transparent laws, effective government, quality of regulation, and efficient accountability and oversight mechanisms, economic globalization can help improve environmental quality by facilitating access to clean technologies, the transfer of low-carbon production standards, energy efficiency through digitalization, and even the development of metaverse applications (such as virtual education/meetings and “digital twins” for energy management and traffic reduction) (Raghutla & Chittedi, 2021).

In contrast, in weak institutional environments, the potential benefits of globalization and digital transformation are not fully realized, and the digital/metaverse economy may exacerbate environmental pressures, primarily through increased energy consumption in data centers, growing electricity demand, intensified resource extraction, and an increased carbon footprint of computing and network infrastructure (Efobi et al., 2019; Lyu et al., 2022).

One of the key findings of the study is the significant interaction effect of economic globalization and institutional quality, which suggests that institutional quality plays a moderating role: by improving governance, globalization (and by extension, digitalization and the spread of virtual economies) can transform from a potentially disruptive factor to a driver for the digital green transition (Wu et al., 2017; Asongu & Nting, 2019; Hasanov et al., 2023). This also explains why previous studies on the environmental impacts of globalization/digitalization have sometimes reported inconsistent results, as institutional capacity and the quality of digital governance vary across countries, which alters the path of impact.

From a policy perspective and in line with the agenda of digital transformation and metaverse journals, the message of the study for MENA countries is clear: the success of economic liberalization policies, attracting foreign investment, and expanding trade in improving environmental quality depends significantly on institutional reforms, and in particular on the regulation of the data economy and digital infrastructure. In the absence of effective institutions, globalization can lead to the expansion of polluting economic activities, while the transfer of clean technologies, ESG standards, and energy efficiency resulting from the digital transformation cannot be achieved. In this context, improving indicators such as

government effectiveness, corruption control, and regulatory quality not only strengthens the implementation of environmental policies, but is also crucial for the sustainable governance of the metaverse, as the metaverse without clear rules in areas such as energy, data centers, technical standards, data protection, and accountability mechanisms can lead to increased environmental costs

Finally, the findings of this study show that economic globalization—especially in conjunction with the new wave of digital transformation and the metaverse—is neither a definitive threat to the environment nor a guaranteed prescription for its protection. The quality of institutions and digital governance determines whether the opportunities of globalization and emerging technologies are placed on the path of sustainable development and low-carbon transition or lead to increased energy consumption and pollution. Therefore, institutional reforms should be focused on as a complement to economic development policies and as a prerequisite for national metaverse/digital transformation strategies in countries in the region.

Conclusion

The main objective of this study was to investigate the impact of economic globalization on environmental quality, focusing on the moderating role of “institutional quality” in selected MENA countries during the period 2005-2023. With the emergence of new paradigms such as digital transformation and metaverse economics, the need to examine the nonlinearity of these relationships has become more apparent than ever. The results of the Panel Smooth Transition Regression (PSTR) model showed that the relationship between globalization, institutional quality and the environment is nonlinear and threshold in nature. This finding confirms that in the era of digital transformation, classical linear models are unable to explain the complexities arising from data flows, global platforms and the interaction effects of governance on the ecosystem. Diagnostic tests confirmed the existence of a threshold value of 0.964102 in the institutional quality index. This critical point shows that before reaching this level of institutional maturity, economic globalization (which is now inextricably linked to digitalization) cannot unleash its potential for environmental improvement. But after crossing this threshold, institutional quality becomes an active driver for controlling environmental consequences. From the perspective of institutional economics theory, this finding indicates that institutions determine the “rules of the game” in physical and virtual space; countries that have crossed this threshold have been able to guide globalization in a direction that leads to the transfer of clean technologies and energy optimization through smart governance.

The estimation of coefficients in two different regimes showed that although globalization affects air quality in both regimes, the intensity and efficiency of this effect are much greater in the second regime (above the threshold). This result means that economic globalization in itself is neither a threat nor an opportunity; Rather, institutional capacity and maturity of digital governance determine whether capital and technology flows are directed towards “green industries and digital twins” or simply lead to the expansion of polluting activities and energy consumption in computing infrastructure.

The research findings also showed that improving government effectiveness indicators and controlling corruption play a direct and key role in reducing pollution. By strictly enforcing regulations and reducing rents, efficient governments provide an environment in which digital innovations become a tool for monitoring and reducing pollution, rather than exacerbating the carbon footprint. The fact that the quality of regulation variable becomes significant only in the second regime reflects the fact that regulation is only successful in protecting the environment when governance infrastructures have reached the necessary level of stability and efficiency. In contrast, gross domestic product (GDP) growth will continue to put increasing pressure on resources unless this link is broken through institutional reforms and the transition to a low-carbon digital economy.

Overall, the results show that for MENA countries, globalization in the context of digital transformation contributes to environmental sustainability when accompanied by strengthening governance and institutional transparency. Otherwise, the development of virtual economies and international platforms may only lead to increased energy consumption and resource destruction.

Research Recommendations

1. Enhancing digital and institutional governance: Governments in the region should make institutional reforms a prerequisite for entering the metaverse and digital transformation era. Transparency in resource allocation and strengthening the rule of law are essential to guide digital investments towards sustainable projects.
2. Smart and green regulation: It is recommended that regulatory bodies set strict standards for industries and data centers, using new generation tools (such as blockchain to track emissions and artificial intelligence to monitor energy consumption), to align digital transformation with the “green transition”.
3. Financial incentives for green platform economies: Directing international trade flows and foreign investment towards low-carbon technologies, energy-efficient metaverse industries, and supporting Clean-Tech startups through tax breaks and institutional incentives.
4. Policymaking tailored to institutional capacity: Given the threshold behavior of the model, MENA countries should formulate their digitalization strategies in line with their level of institutional maturity. For countries below the threshold, priority should be given to structural and administrative reforms to provide the necessary platform for the positive impact of globalization.
5. Future research horizons: Researchers are suggested to examine the role of variables such as “Digital Readiness”, “Development of Metaverse Technologies”, and “Digital Human Capital” on environmental quality in the form of nonlinear models in future studies to make the new dimensions of governance in the era of digital transformation clearer.

Declaration of Competing Interest

The author declares that he has no competing financial interests or known personal relationships that would influence the report presented in this article.

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