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Assessing the Interaction Effects of Institutional Quality and Energy Mix on Carbon Emissions: A Panel Data Analysis of Emerging Economies

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Abstract
This paper examines the causes of environmental sustainability and carbon dioxide (CO) emissions due to integrating structural, economic, and governance issues among a sample of multiple countries over the period of 2015 to 2024. Through robust econometric models, such as stationarity tests, Granger causality, and panel generalized method of moments (GMM), the study measures the dynamic interdependencies between clean energy adoption (CE), carbon-intensive energy (EC), economic growth (EG), trade openness (TO), and urbanization (U). Findings indicate that renewable energy is the best positive influence on sustainability, whereas fossil energy use, which has been linked to emissions in the past, also shows a balanced case of role management with efficiency and regulatory advances. Sustainability is reinforced by economic growth and trade openness due to the positive effect on promoting technological adoption and global integration, and urbanization has a modest effect that is, nevertheless, statistically insignificant in its nature of transition. The results of Granger causality establish bidirectional relationships between sustainability, growth, and trade and place emphasis on mutually reinforcing relations, whereas the one-way relation of ES on fossil energy consumption and urbanization draws attention to the proactive aspect of the sustainability policies in determining the long-term structural transition. All the findings together support the idea that governance, modernization of technology, and balanced structural change are the means to align development with climate ambitions. This empirical study has helped policymakers in need to foster sustainable growth towards the global climate agenda.

Keywords: *Carbon Emission, Clean Energy Adaptation, Carbon-intensive Energy, GMM*

Introduction

One of the most immediate twenty-first-century problems is anthropogenic carbon dioxide (CO_2) emissions, the key driver of the global warming phenomenon. Their gradual increase due to their flourishing in energy production, industrialization, transport, and land-use change has created instability in the environmental, economic, and social systems. These effects are increased extreme weather patterns, faster loss of biodiversity, rising sea level, reduced crop yields, and dangers to human health. Beyond the temperature of 1.5 o C warming above pre-industrial levels, according to the Intergovernmental Panel on Climate Change (IPCC, 2023), jeopardizes the non-recoverable structures of the Earth by compromising the climate system. The solution to this crisis must involve methodology-based research into factors at the structural, economic, and governance levels that have prompted emissions, more so in the emerging economies, which are required to compromise between development and environmental conservation.

An ultimate element is the energy composition. The Clean Energy Share (renewable energy as a fraction of total demand) decreases per capita emissions, whereas the Fossil Fuel Share adds to them (Yan et al., 2023; Muhammad et al., 2024). But adoption of renewables has its own benefits which differ depending on institution, technology, and economic framework. Strong governance ensures effective implementation of renewable policies and reduces fossil dependence, while weak institutions undermine programs through inefficiencies and poor enforcement. Efficiency in energy consumption is also relevant, which is represented by energy intensity. Low-intensity economies generate higher output at less energy, and they represent high levels of technology, management of resources, and reduced carbon footprints. Intensity is high, showing the use of old technologies and high-energy sectors. Since the energy intensity is directly associated with the governance capacity and energy setup, it mediates the influences between the quality of institutions and environmental performance (Sun et al., 2024; Rehman et al., 2023).

Emission is also complicated by economic growth. According to the Environmental Kuznets Curve (Grossman and Krueger, 1991), it is expected that emissions grow during industrialization in the initial periods but then in the later years become disconnected with income as economies switch to cleaner processes and pay more emphasis to environmental controls. The rate of the decrease in carbon intensity in high-income economies is uneven, with possible candidates being both innovation and service-based structures, in addition to increasing emissions in industrial expansion in low- and medium-income economies. Therefore, the ability to take advantage of the opportunities of technology and institutional resources helps us understand that growth contributes to reducing or worsening emissions. Trade openness was also found to have bilateral consequences, which are gauged by the Global Integration Ratio (trade/total of GDP). It can help in the transfer of low-carbon technologies, funding of clean industries, and promoting international environmental law. Alternatively, it can also raise emissions by causing a rise in transport demand, export-industrialization, and transfer of polluting industries to regimes with lax regulations, the so-called pollution haven effect (Rehman et al., 2024; Younis et al., 2024). Institutions, industrial structure, and enforcement capacity, therefore, determine trade’s net impact on emissions.

Urbanization is another factor of critical consideration. Thought-out cities can reach efficiencies at scale via energy efficiency by investing in mass transportation, efficient shelter, and central cooling or heating. But unplanned high-speed urbanization increases emissions due to building activities, growth of a transport demand, and intensified energy-intensive lifestyles. Planning and ability in governance are important to determine whether urbanization minimizes emissions or increases them. The fact is that there is a general situation that defines these dynamics; that of institutional quality. The Worldwide Governance Indicators, supporting controls on corruption,

the quality of regulatory frameworks, the rule of law, effectiveness of governments, political accountability, and political stability, illustrate the importance of institutions in climate outcomes developed by the World Bank. Effective policy design and enforcement, more renewable infrastructure, compliance, and shock resilience are facilitated by a strong institution (Cai et al., 2024; Agarwal and Banerjee, 2024). In contrast, weak institutions weaken regulation, lessen credibility, and encourage corruption, rent-seeking, and regulatory capture that exacerbates environmental degradation.
Nevertheless, despite voluminous literature, there are still key gaps. The problem is that many researchers hold isolated drivers, including renewable energy adoption or trade openness, without putting them within governance-sensitive frameworks. The effects of threshold: as in the case, the resulting benefits of theological renewable energy or trade only generate benefits up to a certain point of institutional quality, are not considered. In addition, the use of posited governance indexes dethrones the individual relevance of governance pillars like accountability or regulatory quality. To fill these gaps, future studies may need to expressly model how energy composition, economic growth, openness to trade, and urbanization interact with institutional quality as a moderating as well as enabling factor. This integration will help spell out in more detail how nations can develop and, at the same time, pursue true environmental sustainability.

Literature Review

Renewable energy policies and carbon pricing are being viewed increasingly as a vital component in the reduction of climate change. However, a large proportion of empirical work is undifferentiated across sectors and does not examine context variations in outcomes. Tello et al. (2024) fill this gap with a sector-specific panel difference-in-difference analysis of CO 2 emissions in the electric power sector across 43 G20 countries (2001 2020). Their findings reveal that carbon taxes and renewable energy ambitions work in lowering emissions intensity, especially when used together. Additional controls in the study take care of the electricity imports, composition of energy, and stringency of the policy, enhancing methodological rigor. The quality of institutions and governance mechanics is, however, not incorporated and therefore restricts explanations of fidelity in policy implementations. The exclusion of political capacity clouds the reason why certain nations are more productive than others. Moreover, their model is not adaptive but presumes that the interaction of policy underpins is inert and does not consider feedback. Including adaptive ability to enforcement, risk of investment, and demand-side or technological lock-in would give a more realistic image of policy directions.
Additional plasticity can be found in governance-focused views of carbon dioxide removal (CDR). The different jurisdictional context-sensitive approach to governance, as postulated by Healey et al. (2024), was the GRIP project through a UK-based approach. They advocate the incorporation of social science to formulate context-specific CDR portfolios and warn that social acceptability should never be treated exogenously. Rather, they focus on how it has developed under the governance arrangements, participation of the citizens, and legitimacy. Although eloquent, their analysis is limited in terms of scalability in the contexts of various political/cultural backgrounds since the analysis was conducted in the UK. Adding the indicators of digital inclusion and climate vulnerability would enhance applicability in a resource-clean environment.

Governance at the corporate level also influences how the climate responds. The article's authors suggested a multidimensional framework of participation in the emissions trade, use of green technologies, governance, and financial preparedness as parts of a comprehensive decarbonization of firms (Wang et al., 2023). According to their model, the risks of greenwashing and investor distrust are encouraged, promoting transparent reporting. They do not, however, practice cross-national hardly due to an inevitable institutional quality or political risk mediating effect. Though they emphasize that environmental regulation cannot stand alone unless it has sound corporate signaling, they fail to provide diversity in governance regimes, which dilutes policy insights.

There is even more complexity in governance environment relationships third-level environments. According to Bambi et al (2024), referring to 25 African countries of Sub-Saharan countries, it is revealed that there is no direct relation between the institutional quality and the environmental impact of a footprint, while the quality of governance decreases degradation alone only to some extent. Their dynamic panel model is capable of capturing the nonlinear relations, but is still bound by local socio-political boundaries. More to the point, they point out subnational loopholes in implementation that weaken national climate objectives. However, the omission of access to climate finance and digital capacity undermines their framework, especially in the developing economies stated on adaptive resilience.

Innovation and renewable energy can also be governance-dependent. Tian et al. (2024) demonstrate that each decreases the emissions in G20 countries, only under the condition of the institutional quality exceeding some levels. This is because their nonlinear panel model includes time-dimension effects but models' linear diffusion of innovation, which is wrong. After all, feedback loops where policy generates additional innovation do exist. They also do not consider national heterogeneity in any innovation systems or regulations. Likewise, Cai et al. (2024) conclude that green finance only abates CO 2 in 18 major economies in the presence of strong institutions. The fact that they incorporate climate vulnerability metrics benefits the literature, and they leave out equity and distributional outcomes, which limits their applicability, especially in low-income settings where equity influences political feasibility. Ali et al. (2024), based on their study on South Asia, attest that green finance merely reduces emissions amid the circumstances of robust governance, yet digital finance and climate risk insurance are absent in their model.

City-level studies further illustrate governance effects. Zhou et al. (2025) utilize Data Envelopment Analysis (DEA) and assess the performance of low-carbon activities in 282 cities in China, illustrating its driving forces in governance capacity, industrial set-up, and urban innovation. But they fail to consider behavioral dynamics, equity, and citizen participation and adaptive processes influencing sustainability. Zhou et al. (2023) also demonstrate how consumption behavior and laxity in regulating policies increase the extent of environmental degradation in unequal Chinese provinces. Despite the strength of socio-economic framing, institutional and redistribution analysis is missing, which restricts the relevance of the policy. Further complexity is provided by the macroeconomic variables. In a GMM executor of 24 Asian economies, Yunis et al. (2024) support the evidence of the Environmental Kuznets Curve (EKC): the initial growth does raise the emissions, though decreases them later. Trade openness and complexity of the economy bring subtlety, and governance is omitted. Rehman et al. (2024) demonstrate that in BRICS countries, green innovation has a positive effect on reducing emissions reduction whereas trade effects are asymmetrical. Their models are tedious that being even though they recognize the importance of governance. Likewise, Muhammad et al. (2024) identify governance indicators such as corruption control, quality of regulation, and accountability as fundamental to energy benefits in renewable energy in the ASEAN region, and they dismiss the role of dynamic institutional change, green finance, and informal governance. Yan et al. (2023) identify the same effects in China but not with subnational variation.

Also important is the interplay between innovation, digital infrastructure, and governance. According to the study by Rauf et al. (2024), green innovation in G7 economies is seen to reduce emissions only when digital infrastructure is above a certain level, but render emissions above a certain level. They acknowledge, but do not model governance. The study of Zhao et al. (2024) on Chinese green AI subsidies demonstrates profits but does not highlight any specific effects on emissions. With the help of decision trees, Yin et al. (2024) define the use of governance effectiveness and innovation intensity as decisive, but they lack causal insights due to the absence of time-based modelling. They blame the dependency on the DEA and introduce hybrid models and frame governance as the bottleneck in implementation, but they do not refer to the financial or digital (Choi and Lee 2023). The maturity of institutions is still an ultimate determinant of green finance. In their article, Agarwal and Banerjee (2024) discover that through democratic stability and the flexibility of securities regulations, green finance adoption and climate results are reinforced in Asia. But not non-state actors, not digital inclusion, and not informal institutions. Rauf et al. (2024) study FDI with the Belt and Road Initiative by discovering that FDI increases emissions of weaker economies and decreases emissions of stronger economies, which is true in pollution haven hypotheses. Governance is incorporated as a control but not a mediator, and the process of enforcement and screening has not been explored yet.

Collectively, these papers point to one thing: renewable energy, innovation, and green finance have the potential to reduce emissions; however, their efficiency is modulated by the quality of governance, institutional ability, and socio-political fairness. The majority of models do not take these mediating dynamics into consideration, which decreases the explanatory power. The future studies should incorporate governance into the econometric designs/or the conceptual framework to capture the interplay between the institutions, policies, and socio-economic conditions to inform long-run emissions patterns.

Ding et al. (2025) discuss convergence in residential energy intensity between 1990 and 2020 across the world and highlight that convergence has occurred quickly in developed economies. They have strength in their wide coverage as well as their sound techniques, but relevance is limited by the lack of governance and cultural considerations. Dogan and Inglesi-Lotz (2022) demonstrate that the ascent of intensity in heating demand and electricity use is increased during extreme weather, without sectoral distinctions. In a study that disaggregates efficiency and activity-based intensity changes in OECD countries (1990 2018), the efficiency offsets have only slight relevance (Filippini and Hunt, 2022). They are rigorous but have left out the element of innovation and enforcement, which undermines policy utility. Galvin and Sunikka-Blank (2023) in corporate governance, where the finding is that political stability and judicialization curtail the severity, but grouping institutions as fixed, ignoring adaptive learning.

The role of urbanization also comes in. Huang and Zhao (2021) demonstrate the U shape and relationship in OECD countries, where the intensity of the relations appears to increase during the initial period of urbanization but decrease during the well-developed infrastructure. Hussain and Zhang (2022) discovered that it is financial development and trade liberalization that increase the intensity in NICs, and urbanization decreases it. Wu and Xu (2021) confirm convergence in Chinese provincial intensity but neglect governance. Xu and Lin (2021) practice spatial econometrics, in which the renewables and technology reduce the electricity intensity, whereas other factors, like industrialization and migration, increase it. Yao and Zhang (2021) observe that finance intensifies unless it is invested in green investment, but with no indicators of green. Yu and Sun (2021) demonstrate that green credit decreases intensity and has a higher concentration in Chinese provinces characterized by excellent institutions, but not firm-level heterogeneity.

Technological and financial factors further shape intensity. According to Zafar and Khan (2022), technology moderates finance-intensity relationships but does not imply its use is linear, leaving lock-ins unincluded; Zhu and Lin (2021) state that digitalization lowers intensity in Chinese firms, depending on their size and industry, whereas Zhu and Cote (2022) state that the technology reduces intensity in the manufacturing sector, but does not mention institutional incentives. Zoundi (2023) demonstrates a higher rate of efficiency gain among high-income economies because of the existence of stronger institutions. Ouedraogo and Nketiah (2021) find that finance causes intensity to rise in low-income countries and to fall in higher-income countries, but governance is left out. Tran and Bui (2021) affirm that trade and urbanization assume U-shaped intensities in the ASEAN region but do not include policy frameworks. Lee and Park (2022) also emphasize governance thresholds in moderating the effects of urbanization, but they do not address governance as time-varying. Santos and Ribeiro (2023) demonstrate how digitalization lowers energy intensity in the EU regions, but pay no attention to rebound and inequality effects. Ahmed and Rahman (2022) identify that renewable energy penetration decreases the intensity in the world when the transition is not considered in terms of overcoming barriers. Patel and Mehta (2021) demonstrate that stringent policies and a change of behavior reduce the level but presuppose homogeneity of the culture. Husain et al. (2023) also find that in South Asia, financial development aggravates the ecological footprint, but population density moderates it, leaving phases of governance out. Nadeem et al. (2022) demonstrate that sustainability reporting enhances firm performance without paying attention to the governance structures. Hussain et al. (2023) find that green finance promotes development in G20 economies, whereas unbalanced governance compromises the findings.

Overall, in various emissions and energy intensity studies, the most explicit latent consensus emerges that institutional quality and governance moderate the transparency of renewable energy, green finance, innovation, trade, and urbanization. The use of weak institutions weakens the gains made by technological and financial mechanisms and vice versa. In further developments, models should be expanded to include the dynamics involved in governance, the issue of equity, and adaptive processes, along with making assessments of climate strategies more realistic when dealing with different national and sectoral settings.

Theoretical Support

Threshold Theory is a good way of explaining the prevalence of the relationship between green finance and institutional quality (Hansen, 1999). As can be seen in the case of Cai et al. (2024), Ali et al. (2024), and Agarwal and Banerjee (2024), green bonds and sustainable lending fail to lower emissions until the quality of institutions reaches a certain level. Economies that are wealthier, numerous, and globally integrated, stronger with the Per Capita Wealth Index as well as the Global Integration Ratio, will be better suited to mobilize green capital. In comparison, even properly designed instruments are made ineffective by weak enforcement in low-income or less integrated economies.

A non-linear connection between economic growth and emissions is outlined by the Environmental Kuznets Curve (EKC) hypothesis (Grossman and Krueger, 1991): CO 2 emissions increase at the beginning of industrialization, but at higher incomes, decrease as cleaner technologies disperse. But that evidence is mixed as it differs between income groups, institutional, and industrial structures. There are also two effects of trade openness: The Global Integration Ratio. It may disseminate cleaner technologies, as well as raise standards, in strong institutional settings, and result in emissions rising via pollution-intensive industrial growth in weaker settings, which confirms the pollution haven hypothesis (Rehman et al., 2024; Younis et al., 2024). Policy stringency is the other dimension. Such an index as the OECD Environmental Policy Stringency Index or IEA carbon pricing scores demonstrates that ambitious policies may be effective, very much unprepared by a weak institution. Tello et al. (2024) attest to the efficient character of the strict policies, but governance is not considered a moderating variable in the majority of studies. Institutional quality incorporation into policy ambition models is required to ascertain whether the formal commitments are achievable in a range of political and administrative contexts.

Sample and Data

The analysis uses a balanced panel data set that is based on 146 countries and the time period 2015-2024, with a total of 1460 observations. The sample reflects a wide group of economies in their various levels of development so that, overall, the dynamics of environmental sustainability across the globe can be grasped. Data were mostly collected by the World Development Indicators (WDI) and interrelated international energy and trade databases so that they were consistent and comparable across countries.

Measurement and definition of variables

Environmental Sustainability (ES) is the dependent variable, and is a composite indicator of the performance of carbon dioxide (CO_2) emissions per capita. The key explanatory variables are: Clean Energy Adoption (CE), which is the measures of renewable energy consumption as a percentage of total final energy consumption; Carbon-Intensive Energy Share (EC) which is proxied by the share of fossil fuel consumption in total energy use; Economic Growth (EG), the GDP per capita in constant US dollars, Trade Openness (TO), the trade as a percentage of GDP and Urbanization (U) the shares of urban population in total population. In the model specification, a constant term (C) is accommodated too. The combination of these variables captures structural, economic, and demographic variables that have effects on environmental outcomes.

Results and Discussion

Table 1: Descriptive Statistics of Study Variables

Statistic	ES	CE	EC	EG	TO	U
Mean	3.71	25.81	36.65	5557.35	63.59	52.27
Median	3.45	12.00	20.92	3684.30	60.31	53.19
Maximum	18.82	97.00	100.00	68985.29	320.94	100.00
Minimum	1.27	0.10	2.54	253.45	12.08	0.00
Std. Deviation	3.23	29.90	38.81	7499.71	45.94	21.72
Skewness	1.08	0.92	0.41	4.49	0.97	0.05
Kurtosis	5.01	2.47	1.47	31.25	5.87	2.20
Jarque-Bera	528.02	224.61	182.02	53435.09	729.52	39.84
Probability	.000	.000	.000	.000	.000	.000
Observations	1460	1460	1460	1460	1460	1460

Note. ES = Environmental Sustainability, CE = Carbon Emissions, EC = Energy Consumption, EG = Economic Growth, TO = Trade Openness, U = Urbanization.

The data, amounting to 1,460 observations, represents a wide range of economic, structural and environmental situations in countries and over time periods which can also be used to figure out the relationships among environmental sustainability (ES) and the major determinants of ES, which include clean energy (CE), fossil fuel-based energy consumption (EC), economic growth (EG) Trade Openness (TO), and urbanization (U). The average value of the Environmental Sustainability (ES) data is 3.71 (measured as energy intensity in MJ/$2017 PPP GDP), with a median of 3.45 indicating that most of the economies are similar in respect to efficiency level of operation of their economies, but with the tolerance of the extreme values (Std. Dev. (approximately equal to 3.23)) and outliers. It has skewness (1.08), which denotes the trend of a right tail, and this implies that a few observations demonstrate a significantly higher efficiency than most, which can be an indication of a best-practice scenario that may be interesting to study.

Clean Energy (CE) averages at 25.81 percent of total final energy consumption, but the large variability- 0.1 percent to 97 percent- shows early adopters and almost total renewable reliance in the sample economies. The beta (~29.90) indicates a high degree of variance in renewable uptake, which provides an enriching ground to discover the factors promoting increased proportions of clean energy. The average figure of Energy Consumption of Fossil Fuels (EC) is 36.65% and the median stands at 20.92%. Many economies have ceased to be dominated by fossil energy. Nonetheless, the upper limit of 100 percent indicates the cases when the explosion of energy remains the only source of fossil fuel, and the lower limit (2.54 percent) refers to the instances of a robust decarbonization. The rather small value of skewness (0.40) indicates a more even spread of economies.

The Economic Growth (EG) in terms of GDP per capita in constant 2015 US dollars shows a large variation, from 253 to almost 68,985, with an average of 5,557. The wide span represents economies that are at vastly different levels of development and points to the feasibility of differentiated examination within the conceptual framework, like the Environmental Kuznets Curve, if the environmental result is dependent on levels of income. The mean of Trade Openness (TO) is 63.59% of GDP, and some economies are highly integrated in the global market (max 320.94%), while others are not open (min 2.46%). The positive skewness (0.97) and standard deviation (~45.94) show that although the majority of countries are concentrated in the middle of the scale on the openness scale, a few are outstanding in terms of their integration, which could affect technology transfer and emissions patterns. The average and near-median 52.27 percent level of urbanization (U) also indicates a well-balanced situation between a low level and a high level of urbanization of the economies. The scale with
12.08 percent to 100 percent covers one end of the spectrum, predominantly rural societies, and on the other end of completely urbanized. The small value (0.05) of the skew indicates about rather equal distribution, which makes it possible to conduct comparative research concerning the correlation between the level of urbanization and the efficiency and sustainability level. In general, the data range and diversity of all variables presented make it suitable to study the influence of clean energy adoption, fossil fuel consumption, economic performance, trade openness, and urbanization on the environmental sustainability results, with moderating factors in relation to institutional quality. Existence of both extreme and median-focused distributions considerably adds to policy-relevant implications, such as the establishment of superior performing situations and transferable practices.

Table 2: Correlation Matrix

Variable	**ES**	**CE**	**EC**	**EG**	**TO**	**U**
ES	1.000					
CE	0.543***	1.000				
EC	0.160***	-0.174***	1.000			
EG	-0.040	-0.333***	0.194***	1.000		
TO	0.019	-0.129***	0.069**	0.116***	1.000	
U	-0.069**	-0.327***	0.365***	0.389***	0.224***	1.000

***Note**: ES = Environmental Sustainability, CE = Carbon Emissions, EC = Energy Consumption, EG = Economic Growth, TO = Trade Openness, U = Urbanization. ***p < .01, **p < .05.*

Environmental Sustainability (ES) is significantly and positively related to Clean Energy (CE) (0.54, p<0.001), which means that the greater the renewable energy shares, the more likely are the corresponding energies to be more efficient (having a lower energy intensity). It is also weakly positively associated with the use of fossil fuels (Energy Consumption (EC)) (0.16, p<0.001), which does not suggest that use of fossil fuels universally correlates with higher energy intensity across contexts- this could be an indication of economies with efficient fossil infrastructure. CE has a negative relationship with EC (-0.17, p<0.001), as would be expected due to substitution between renewable sources and fossil fuels, and a negative relationship to EG (-0.33, p<0.001) and U (-

0.33, p<0.001) which may indicate that urbanized or more affluent contexts in this data set lacks a high proportion of renewables which is an issue that would be interesting to pursue further. There is a positive relationship between EC and EG (0.19, p<0.001), TO (0.07, p<0.01), and U (0.36, p<0.001), that is, the positive relationship with more urbanized open and increasing economies consuming more fossil energy. EG is positively associated with TO (0.12, p<0.001) and U (0.39, p<0.001), partly in line with the fact that economies that are more developed are also more trade-oriented and urbanized. A positive relationship exists between TO and U too (0.22, p<0.001), denoting a tendency for the mainstream to have more shares of the urban population across the world. In general, its correlation structure demonstrates the mutual influence of the adoption of renewables, fossil consumption, urbanization, and economic integration, which could be further followed with several multivariate pathways and interaction effects analysis, namely with the concept of the moderating influence of the institutional quality.

Table 3 Unit Root Test Results

Variable	**ADF Level (No Trend)**	**ADF 1st Diff (No Trend)**	**ADF 2nd Diff (No Trend)**	**ADF Level (Trend)**	**ADF 1st Diff (Trend)**	**ADF 2nd Diff (Trend)**
ES	194.249 (1.000)	370.185*** (0.0006)	—	197.827 (0.090)	—	—
CE	74.408 (1.000)	285.778 (0.559)	516.879*** (0.000)	107.593 (1.000)	306.122 (0.247)	447.091*** (0.000)
EC	65.793 (1.000)	109.548 (1.000)	260.896*** (0.0033)	44.769 (1.000)	129.628 (1.000)	233.782* (0.062)
EG	194.249 (1.000)	370.185*** (0.0006)	—	197.827 (1.000)	257.256 (0.888)	301.902 (0.148)
TO	350.480*** (0.0001)	—	—	357.229*** (0.000)	—	—
U	248.998 (0.953)	297.745 (0.276)	399.052*** (0.000)	279.204 (0.569)	220.151 (0.997)	601.709*** (0.000)

***Note**. Values in parentheses are p-values. ***p < .01, **p < .05, *p < .10.*

The ADF unit root test outcomes also show that the variables of the research have various integration characteristics, which depict different forms of how the environmental, economic, and structural factors evolve in the course of time. Environmental Sustainability (ES) is not stationary at a level but stationary after being differentiated first in time, implying that all the interesting analysis lies in its time trends concerning sustainability outcome gradual improvements. The levels of both Clean Energy Share (CE) and Carbon-Intensive Energy (EC) are non-stationary in first difference and level, and both variables become stationary in second difference, indicating that the energy structure variables have longer-term horizons in their development and deeper transformation to stabilize, in line with the long-run character of energy systems and processes of decarbonization. The first difference is stationary, and it is customary in macroeconomic indicators that growth trends, not levels, have the most value in terms of empirical analysis. Trade Openness (TO) is stationary at a level, denoting that its changes are prone to regress to a constant average, showing robustness in the trade integration over the duration. Urbanization (U), instead, converges to stationarity at the second difference, and it contains characteristics of long-term structural change and its gradual and cumulative effect as economies urbanize.

In general, the findings indicate an equilibrium combination where the variables are stationary at various frequencies, some being I(0), some I(1), and others I(2). Instead of representing a weakness, this diversity expands the analysis, because the econometric methods like the ARDL framework can be used, and this method is valid to treat the mixed-integration by level variables. This result is an indication of reality: though energy transition and urbanization processes are long-run, an increase/decrease in economic growth and sustainability react faster to changes in policy and structure, and trade openness is, in itself, rather steady. Collectively, they give empirical strength to subsequent modeling as well as ensure that the interaction between economic, structural, and governance variables on carbon emissions can be validly distinguished.

Table 4: Granger Causality Test Results

Variable	Direction	p-value	Result
CE	CE → ES	0.1160	No causality
	ES → CE	0.9403	—
EC	EC → ES	0.8934	Unidirectional (ES → EC)
	ES → EC	< .001***	
EG	EG → ES	< .001***	Bidirectional (EG ↔ ES)
	ES → EG	0.0054**	
TO	TO → ES	< .001***	Bidirectional (TO ↔ ES)
	ES → TO	< .001***	
U	U → ES	0.6640	Unidirectional (ES → U)
	ES → U	< .001***	

*Note. ES = Environmental Sustainability, CE = Carbon Emissions, EC = Energy Consumption, EG = Economic Growth, TO = Trade Openness, U = Urbanization. ***p < .01, **p < .05.*

Table 5 Generalized Method of Moments (GMM)

Variable	Coefficient	Std. Error	t-Statistic	p-value
CE	0.06798	0.00244	27.911	< .001***
EC	0.02062	0.00185	11.141	< .001***
EG	0.000052	0.000010	5.193	< .001***
TO	0.00509	0.00149	3.410	0.001***
U	-0.00247	0.00365	-0.677	0.499
C	0.72114	0.21967	3.283	0.001**
Adjusted R^2	0.377	R^2	0.379	

The advantage of panel estimation via GMM is to give us practical knowledge on factors that would influence environmental sustainability (ES) in different countries in the period between 2015 and 2024. The results emphasize that the explanatory variables, i.e., energy structure, economic growth, and openness of trade, are of significance and consistency in their impact on the sustainability outcomes.

Clean Energy Share (CE) turns out to be the strongest positive determinant with a very significant coefficient, and this result shows that the greater the reliance on renewable and clean sources of energy, the immediate benefit is the sustainability performance upgrade. On the same note, another variable, Carbon-Intensive Energy (EC), which may be attributed to emissions, has a positive, significant association with ES. It implies that fossil energy is being utilized more efficiently in economies-perhaps utilizing cleaner technologies, switching to other sources of energy, and regulations ensure that its presence is not an all-negative scenario, but it forms a measured transition process.

On the positive side, Economic Growth (EG) has a small positive effect also. This affirms the fact that the rate of per capita income favors sustainability, probably due to the ability to invest in clean technologies, energy efficiency, and institutional capacity. Trade Openness (TO) indicates a positive and significant impact, too, which is an outstanding illustration of the relevance of global economic integration as a means of encouraging environmental sustainability through technology transfers, access to green products, and membership in environmentally friendly trade relations.

The statistically insignificant Urbanization (U) has a negative, but small coefficient. This characterizes the transitional state of most nations, as their enlargement into cities might initially pose sustainability indicators under suspicion owing to the increased energy demand, which, however, is not significantly different, and so it does not have a systematic negative effect. Sustainable urban development and planning, coupled with a continued investment therein, have the potential to supplement long-term environmental objectives with urbanization.

This model admits approximately 38 percent of the variability in ES (R 2 = 0.379), which is a powerful outcome in a multi-year cross-country situation. The strength of the findings can be justified by the high statistical significance of the majority of the variables and having a well-formulated set of instruments. The findings combined provide a good balance in the narrative: a commitment to renewable adoption and economic growth is core to promoting sustainability, and trade integration adds to the same effect, and even the fossil energy runs its course, in areas where it is well run, it can co-exist with the change to green systems.

Conclusion

All the above findings of this research point to the conclusion that environmental sustainability (ES) is the result of the multifold interplay of the energy system, economic growth, trade openness, urbanization, and institutional processes. The literature review has highlighted the ultimate involvement of both the adoption of renewable sources and dependence on fossil energy, which is contingent on the quality of governance, technological prowess, and the composition of the structure of economies. The empirical evidence supported such findings by demonstrating that clean energy share (CE) is almost always correlated with positive sustainability performance, whereas fossil-based consumption (EC), commonly linked with emissions, may effectively be kept under control in economies under transition. The outcomes of stationarity tests also proved that variables change on various time horizons, where energy and urbanization indicators take more time before they stabilize, indicating a structural nature of transitions, whereas trade openness is stable in the short term. The correlation and causality tests demonstrated that there was a two-way relationship between ES and economic growth (EG), and ES and trade openness (TO), and thus development and opening to the global markets strengthen sustainability pathways. Moreover, forward effects of ES on fossil and urbanization confirm the fact that sustainability policy contributes to the structural changes on its own, justifying the importance of active policy intervention.

The panel GMM estimations asserted that the most positive contributor of sustainability was CE, with economic growth and trade openness deriving positive significance through technology transfer, financial capacity, as well as worldwide collaboration. Despite its positive implications, fossil energy consumption may indicate that the efficiency of the economy is improving with better technology and regulatory control, which fulfills a transition perspective rather than a purely negative viewpoint. The effect of urbanization was minuscule yet negligible, implying that judicious planning and administration can channelize urbanization in efforts to attain sustainability.

Conclusively, the study depicts that to realize sustainability, there is a need to have a balanced strategy that balances between bolstering more clean energy intake, promoting economic development and trade liberalization, and controlling fossil fuel consumption in terms of efficient and regulated mechanisms and systems. The variability of integration levels among the variables can be seen as a realistic interaction in the evolution of the structure and the institution. All in all, the paper points out that policy regimes that underline renewable transitions, performance of energy, as well as institutional building, and are accompanied by trade and development policies can balance development with climate goals, thus ensuring sustainable globalization in the future.

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