Contents list available at IJRED website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.undip.ac.id

Research Article

Economic growth and renewable energy consumption in Asia: Does good governance moderate the trade-off?

Quyen Le Hoang Thuy To Nguyen* and Thu Quang Anh Pham

School of Government (SOG), College of Economics, Law and Government (CELG), University of Economics Ho Chi Minh City (UEH), Viet Nam

Abstract. This study examines the trade-off between economic growth and renewable energy consumption in 31 Asian economies over the period 1996-2023, with a focus on the moderating role of governance quality. Using fixed-effects panel estimation, with country-clustered standard errors, we construct a multi-dimensional governance quality index based on Principal Component Analysis (PCA). The findings suggest that economic growth is associated with a statistically significant decline in the share of renewable energy consumption (β=-13.59, $p<0.01$). In semi-log terms, a 1% increase in GDP per capita is associated with a 0.136 percentage-point reduction in renewable energy consumption share, implying the presence of growth-induced fossil fuel dependence. However, the interaction term between growth and governance is positive and significant (β=1.73, $p<0.05$), indicating that stronger governance quality mitigates this adverse effect. Further analysis using an environmental Kuznets curve (EKC) specification reveals a U-shaped relationship between income and renewable energy consumption. Sensitivity analysis using disaggregated governance indicators shows that government effectiveness and regulatory quality are the key institutional dimensions driving this moderating effect. Subsample analysis further uncovers significant heterogeneity across income groups. While the trade-off is prominent in lower-middle and upper-middle income economies, high-income countries exhibit a positive growth-renewable energy consumption nexus. The results remain robust when using lagged explanatory variables. This study contributes to the literature by providing cross-country evidence of a fossil lock-in effect in Asia and by identifying governance quality as a moderating institutional mechanism shaping the energy transition. The findings underscore the importance of strengthening institutional quality to align economic growth with renewable energy development in heterogeneous Asian contexts.

Keywords: SDG 7; SDG 13; Economic growth; Renewable energy consumption; Good governance; Moderating role; Asian economies, Fixed-effect panel estimation.

Received: 2nd March 2026; Revised: 17th April1 2026; Accepted: 14th May 2026; Available online: 22nd May 2026

1. Introduction

Advanced technology and economic growth have driven the electricity demand in modern economies (Javaid *et al.*, 2021; Gershon *et al.*, 2025). This demand has exponentially expanded with the population growth (Nepal and Paija, 2019; Mohamad and Ab-Rahim, 2025). However, the energy sector heavily relies on fossil fuels (Overland *et al.*, 2022; IPCC,2022), the largest source of greenhouse gas (GHG) emission with the share of 75% (Mentel *et al.*, 2023), which primarily contributes to climate change, environmental degradation and public health risks (Haines *et al.*, 2006; Mahalik *et al.*, 2023; Yildirim *et al.*, 2025). In this context, the global energy transition has become a central pillar of sustainable development, with renewable energy playing a critical role in decarbonizing energy systems and achieving net-zero emissions targets by the second half of this century, as committed at COP 26 (Wise,2021).

The economic growth and renewable energy consumption nexus remains ambiguous (Doğan *et al.*, 2020). Renewable energy consumption refers to the consumption of energy derived from naturally replenishable sources (Shukla *et al.*, 2017). Higher income levels enhance purchasing power, technology adoption capacity and environmental awareness, thereby fostering renewable energy uptake (Bakirtas and Akpolat, 2018; Rahman and Sultana, 2022). From a structural transformation perspective, rising income levels could shift energy demand toward cleaner sources, supporting decarbonization and sustainable development.

However, the magnitude and direction of this relationship may vary across different stages of economic development. This complexity has been explained in the environmental Kuznets curve (EKC) (Grossman and Krueger, 1995). The EKC has been extended to energy composition with the argument of prioritizing rapid industrialization and economic growth in the early stages of economic development at the expense of renewable energy adoption. This process can reinforce carbon reliance, whereby economic growth disproportionately favours conventional energy sources. In such contexts, economic growth may reduce the share of renewable energy consumption (Uzar, 2020), creating a structural trade-off between growth and clean energy transition. This trade-off is particularly relevant in Asia, a region that accounts for the highest GDP per capita growth (IMF, 2025), with predominantly fossil-fuel driven energy demand expansion. In fact, fossil fuel consumption per capita in Asia has increased 558% between 1965 (2,612 kWh) and 2024 (17,191 kWh), nearly thirteen times higher than the world average level (44%) (Energy Institute - Statistical Review of World Energy, 2025).

Extensive literature has identified various determinants of renewable energy consumption, yet the empirical link between

* Corresponding author:
Email: quyennlhtt@ueh.edu.vn (Q.L.H.T.T.Nguyen)

https://doi.org/10.61435/ijred.2026.62444
ISSN: 2252-4940/© 2026.The Author(s). Published by CBIORE

economic growth and clean energy transition remains inconclusive (Bakirtas and Akpolat, 2018; Dogan *et al.*, 2020; Sarkodie *et al.*, 2020; Uzar, 2020; Rahman and Sultana, 2022; Mahalik *et al.*, 2023; Eyuboglu and Uzar, 2025). While existing studies treat governance as a standard control variable (Uzar, 2020; Rahman and Sultana,2022; Evensen and Sovacool, 2024), they overlook the possibility that this relationship may be conditional on institutional quality, limiting the insight into why some economies successfully decouple growth from carbon emissions while others remain locked into fossil fuel dependence.

Moreover, prior studies often rely on fragmented governance indicators or a simple average, which may fail to capture its multi-dimensional nature and lead to inconsistent findings (Asongu and Odhiambo, 2022; Mahalik *et al.*, 2023; Nguyen and Pham, 2025). We employed a fixed-effects panel model to control for unobserved country-specific heterogeneity that may bias the estimated relationship. This study makes three key contributions. First, it systematically documents this trade-off across Asian economies, highlighting how growth dynamics can hinder the transition toward renewable energy. Second, it departs from prior literature by explicitly modelling governance quality as a moderator rather than a standard control variable. Third, it constructs a governance index using PCA to capture its multi-dimensional nature and provide parametrically estimated weighted index (Heshmati and Rashidghalam, 2020) for cross-country analysis.

2. Literature review

2.1 Economic growth and renewable energy consumption

The relationship between economic growth and renewable energy consumption has been widely researched in the literature. A complementary approach suggests that economic expansion and renewable energy transition reinforce one another (Doğan *et al.*, 2020; Rahman and Sultana, 2022). According to Rahman and Sultana (2022), economic growth acts as a significant driver for renewable energy in emerging economies. As GDP increases, nations gain the financial resource to invest in capital-intensive green technologies and infrastructure (Marques *et al.*, 2010). This aligns with the growth hypothesis, where energy consumption is viewed as a vital input for production; thus, a shift toward renewables ensures long-term energy security without the environmental volatility of fossil fuels (Doğan *et al.*, 2020).

Furthermore, Bakirtas and Akpolat (2018) utilized Granger causality tests to demonstrate that in several emerging markets, a bi-directional causality (the feedback hypothesis) exists. This implies a reciprocal relationship: while economic growth provides the R&D funding necessary for renewable innovation, the subsequent increase in renewable energy consumption supports sustainable industrialization by reducing energy dependency and mitigating the external costs of carbon emissions. Mohamad and Ab-Rahim (2025) confirm this in bibliometric analysis, noting that "energy market" and "economic development" are increasingly researched as integrated components of a circular economy.

Conversely, a trade-off relationship also emerges, particularly in the early stages of development or within transition economies. This is often framed within the conservation hypothesis or the initial phase of the EKC. Uzar (2020) argues that while renewable energy is crucial for climate mitigation, it requires substantial upfront investment which may compete with other immediate developmental priorities, such as poverty reduction or basic infrastructure. In this scenario, a "trade-off" occurs where rapid economic growth is prioritized through cheaper, more accessible fossil fuels, potentially stagnating the transition to renewables. Bakirtas and Akpolat (2018) also highlight that the reliance on traditional energy sources in emerging countries remains deeply structural that a sudden shift to renewables could pose a risk to short-term economic growth. Therefore, economic growth increases total energy demand while disproportionately favours conventional energy sources, reducing the relative share of renewable energy consumption. The coexistence of these complementary and trade-off perspectives indicates that the economic growth and renewable energy consumption nexus is context dependent, which motivates further empirical evidence, particularly in heterogeneous region.

2.2 Good governance and renewable energy consumption

The role of public governance in shaping the renewable energy consumption is theoretically anchored in the institutional theory. North (1990) defines institutions as the "rules of the game" which initiate economic incentives and reduce transaction costs. In the context of energy transition, Uzar (2020) argues that the shift toward renewable energy consumption is not merely a technical choice but a response to the institutional environment. Since adopting renewable energy often requires consumers and firms to face high switching costs and long-term investment risks, "good governance" acts as a mechanism to lower these barriers. Stable property rights, effective legal frameworks, and reduced bureaucratic red tape provide the necessary security for private and industrial actors to shift their energy demand from fossil fuels to cleaner alternatives (Bertoldi, 2022).

Empirical evidence from emerging and developing economies suggests that institutional quality is a vital determinant of renewable energy demand patterns (Asongu and Odhiambo, 2022; Mahalik *et al.*, 2023; Evensen and Sovacool, 2024). Rahman and Sultana (2022) find that strong institutional quality (measured by control of corruption and government effectiveness) significantly boosts renewable energy consumption in the long run by ensuring the effective implementation of green subsidies and environmental mandates. Without a functional government, price signals intended to encourage renewable uptake are often muffled by corruption or administrative inefficiency. Similarly, Mahalik *et al.* (2023) demonstrate that government effectiveness is a critical factor for renewable energy demand in South Asia, as it facilitates the complex regulatory reforms needed to integrate decentralized renewable sources into the national grid, thereby making it easier for end-users to consume green electricity.

Despite these theoretical advantages, the direct impact of good governance on renewable consumption remains a debatable subject. While Rahman and Sultana (2022) confirm the governance role (corruption control and government effectiveness) in boosting renewable energy consumption in emerging countries, Asongu and Odhiambo (2021) report the negative and Mahalik *et al.* (2023) conclude the insignificant impact. One primary argument for this debate is the concept of institutional lock-in emphasized by Uzar (2020). In many nations, even those with relatively high governance scores, the "rules of the game" may be historically biased toward fossil fuel consumption due to the influence of powerful energy lobbies or rich natural resources (Evensen and Sovacool, 2024). In such cases, a "stable" and "effective" government might inadvertently maintain the status quo, subsidizing coal or oil to ensure short-term economic stability, thus hindering the growth of renewable energy consumption.

Furthermore, Evensen and Sovacool (2024) suggest that different dimensions of governance may have conflicting effects on energy transitions. While regulatory quality might promote renewable adoption, high levels of political stability in resource-

rich nations can sometimes correlate with a slower transition if the regime relies on fossil fuel rents. Additionally, Nguyen and Pham (2025) suggest that governance may not always exert a direct push on consumption but rather acts as a moderator that determines how effectively other factors, such as economic growth or trade openness, translate into actual increases in renewable energy utilization. This complexity justifies a more nuanced investigation into whether good governance directly drives consumption or if it simply creates the frontier within which other economic drivers operate.

2.3 Good governance as a moderator in the economic growth and renewable energy consumption nexus

Despite extensive research on economic growth and governance separately, limited attention has been given to their joint interaction in shaping renewable energy consumption. The divergent findings in Sections 2.1 and 2.2 suggest that the growth-renewable relationship may be conditional on institutional quality. From an institutional economics perspective, economic growth generates financial capacity, but governance determines how effectively those resources are allocated (North, 1990; Acemoglu *et al.*, 2001). In weak institutional environments, growth may amplify fossil-fuel expansion, as regulatory enforcement is limited and short-term economic priorities dominate (Uzar,2020; Sarkodie *et al.*, 2020). Conversely, in strong institutional settings, governance can redirect economic gains toward renewable investment and consumption behaviours by enforcing environmental regulations, ensuring policy consistency, and providing credible long-term incentives (Rahman and Sultana, 2022; Bertoldi, 2022; Shao *et al.*, 2024).

This conditional view reconciles the complementary and trade-off hypotheses. Growth may initially deepen fossil dependence in the absence of institutional reform (Mahalik *et al.*, 2025). However, once governance quality reaches a sufficient threshold, economic expansion can become a catalyst for renewable transition (Nguyen and Pham,2025). In this sense, governance acts not merely as a direct driver of renewable consumption but as a moderating mechanism that transforms the structural impact of economic growth. Despite these insights in the literature as mentioned in section 2.1, 2.2 and 2.3, several important gaps remain. First, existing studies provide mixed and inconclusive evidence on the growth-renewable energy nexus, particularly in the heterogeneous Asian economies, where structural conditions differ substantially. Second, governance has largely been treated as a control variable with direct effect, while its moderating role in shaping the impact of economic growth on renewable energy consumption remains underexplored. Third, prior studies often rely on fragmented indicators, which may not fully capture its multi-dimensional feature. To address these gaps, this study explicitly examines the moderating role of governance quality in the growth-renewable energy nexus and constructs a composite governance index using PCA to capture its multidimensional structure. By doing so, it provides new cross-country evidence on how institutional quality shapes the extent to which economic growth translates into renewable energy transition in Asia.

3. Research Methodology

3.1 Empirical model and estimation strategy

The baseline specification in equation (1) explicitly incorporates an interaction term between governance quality and economic growth to examine whether good governance moderates the economic growth and renewable energy consumption nexus in Asian economies.

$$re\_consumption_{it} = \beta_0 + \beta_1 lgdp\_percapita_{it} + \beta_2\, z\_GGI\_c1_{it} + \beta_3\, z\_GGI\_c1_{it}^{*}\, lgdp\_percapita_{it} + \beta_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

In equation (1), i denotes country, t represents the year, μ_i captures country-specific time-invariant heterogeneity, λ_t captures common time effects and ε_{it} is the idiosyncratic error term. The inclusion of country fixed effects controls for unobserved structural characteristics.

Dependent variable (re_consumption) is measured as the share of renewable energy in total final energy consumption (%). Using a share-based indicator allows us to capture structural energy transition rather than absolute scale effects (Rahman and Sultana, 2022). Core explanatory variables include *lgdp_percapita* (real GDP per capita, constant prices, expressed in logarithmic form to account for non-linearity and scale heterogeneity across countries), *z_GGI_c1* (constructed from the composite governance index, standardized to enhance comparability and interpretation). Control variables (X_{it}) include *lco2_gdpppp* (measured as CO_2 emissions per unit of GDP, reflects production structure and fossil-fuel dependence), and *urban_population* (measured as the percentage of the population residing in urban areas). These control variables are selected to capture key structural determinants of renewable energy consumption. Specifically, CO_2 emissions per unit of GDP is a proxy for carbon intensity and fossil-fuel dependence (Uzar, 2020; Mahalik *et al.*, 2023; Eyuboglu and Uzar, 2025), while urban population reflects demographic and infrastructural factors influencing energy demand patterns (Bakirtas and Akpolat, 2018; Liu, 2009).

An interaction term between GDP per capita and governance quality ($z\_GGI\_c1_{it}^{*}\, lgdp\_percapita_{it}$) is introduced to examine whether institutional quality conditions the growth-renewable energy nexus (Nguyen and Pham, 2025). The governance variable is mean-centered prior to constructing the interaction term to reduce non-essential multicollinearity and facilitate interpretation of marginal effects (Aiken et al., 1991). Centering does not alter coefficient estimates substantively but improves numerical stability in interaction models (Brambor et al., 2006). Equation (2) illustrates a partial derivative of equation (1) with respect to economic growth, which captures the marginal effect of economic growth on renewable energy consumption at a given level of good governance

$$\partial(re\_consumption_{it}) / \partial(lgdp\_percapita_{it}) = \beta_1 + \beta_3\, z\_GGI\_c1_{it} \quad (2)$$

The interaction term in equation (2) implies four possible outcomes depending on the signs of the estimated coefficients. First, when both β_1 and β_3 are positive, economic growth promotes renewable energy consumption, and stronger governance further amplifies this beneficial effect. Second, if both β_1 and β_3 are negative, economic growth diminishes the share of renewable energy, and this adverse relationship is intensified with poor governance. Third, when β_1 is positive but β_3 is negative, economic growth increases renewable energy consumption; however, higher governance quality weakens the strength of this positive association. Finally, if β_1 is negative while β_3 is positive, economic growth suppresses renewable energy consumption, yet stronger governance alleviates this negative impact, indicating a mitigating institutional effect.

A key econometric concern in this study is unobserved heterogeneity. If country-specific characteristics are correlated with economic growth or governance indicators, pooled OLS and random-effects estimators may produce biased estimates. We therefore estimate both fixed-effects (FE) and random-

effects (RE) models and conduct a Hausman specification test. The results indicate systematic differences between FE and RE estimates, supporting the consistency of the fixed-effects estimator. Consequently, all baseline estimations rely on the within-country FE estimator.

We estimate fixed-effects models incorporating interaction terms between economic growth and governance quality. Fixed effects are suitable because unobserved country-specific characteristics, such as historical energy endowments, institutional legacy, regulatory traditions, cultural factors and structural dependence on fossil fuels, are likely correlated with both economic growth and renewable consumption, which may lead to biased and inconsistent estimates due to omitted variables (Baltagi, 2008; Wooldridge,2010). The fixed-effects estimator addresses this concern by removing country-specific effects through within-transformation, thereby identifying the impact of changes in economic growth and governance within countries over time.

Moreover, institutional quality itself may be correlated with unobservable national traits such as political culture or administrative capacity. If these factors jointly influence renewable energy adoption and economic development, random-effects estimators would produce inconsistent estimates under the violation of the orthogonality assumption (Hausman, 1978). The fixed-effects framework relaxes this assumption by allowing the unobserved effects to correlate with explanatory variables, making it a more appropriate identification strategy in institutional-energy nexus studies (Marques *et al.*, 2010; Menegaki and Ozturk, 2013).

To further address potential endogeneity concerns, particularly reverse causality and dynamic adjustment effects, we re-estimate the baseline model using lagged explanatory variables with a one-period lag (Woolridge,2010). This approach helps mitigate simultaneous bias and ensures that the estimated effects reflect the impact of past economic and institutional conditions on current renewable energy consumption. The consistency of the results under this specification strengthens the robustness of the empirical findings.

Given the high degree of economic integration in Asia, policy diffusion, trade linkages, and regional energy markets may generate cross-sectional dependence. Pesaran's CD test is applied to examine residual cross-sectional dependence. Pairwise correlations and variance inflation factors (VIFs) are also examined to assess potential multicollinearity among explanatory variables. Conventionally, VIF values exceeding 10 are typically considered a serious problem (Gujarati, 2004). Hair *et al.*, (2010) suggest the thresholds of 5 in applied research.

3.2 Extended models: EKC and EKC with moderating role of governance

We first estimate a standard EKC specification without interaction terms before introducing governance-based moderation (Equation 4).

$$re\_consumption_{it} = \beta_0 + \beta_1 lgdp\_percapita_{it} + \beta_2 lgdp\_percapita^2_{it} + \beta_3 z\_GGI\_c1_{it} + \beta_4 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

The study then integrates the EKC framework with the moderating role of governance quality to further extend the analysis as shown in equation (5), which captures potential non-linear effects of economic growth on renewable energy consumption and allows governance quality to condition both the magnitude and the curvature of this relationship. However, given that higher order interaction terms involving quadratic transformation may introduce substantial multicollinearity (Aiken and West, 1991; Brambor *et al.*, 2006; Wooldridge,2010), equation (5) is treated as an extended specification rather than a primary empirical framework.

$$re\_consumption_{it} = \beta_0 + \beta_1 lgdp\_percapita_{it} + \beta_2 lgdp\_percapita^2_{it} + \beta_3 z\_GGI\_c1_{it} + \beta_4 z\_GGI\_c1_{it} * lgdp\_percapita_{it} + \beta_5 z\_GGI\_c1_{it} * lgdp\_percapita^2_{it} + \beta_6 X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

The marginal effect of economic growth is given by equation (6)

$$\partial(re\_consumption_{it}) / \partial(lgdp\_percapita_{it}) = \beta_1 + 2\beta_2 lgdp\_percapita_{it} + \beta_4 z\_GGI\_c1_{it} + 2\beta_5 lgdp\_percapita * z\_GGI\_c1_{it} \quad (6)$$

3.3 Data sources and description

This study employs an unbalanced panel dataset of 31 Asian economies spanning the period of 1996-2023. The starting year is determined by the availability of governance indicators from the Worldwide Governance Indicators (WGI) while the end year reflects the most recent data release. The time dimension ensures sufficient time variation to identify within-country dynamics and structural adjustment in Asia, thereby strengthening the identification of institutional and macro effects (Baltagi, 2008; Wooldridge, 2010).

Table 1 summarizes macroeconomic and environmental variables, obtained from the World Development Indicators (WDI), while governance measures are drawn from the Worldwide Governance Indicators (WGI), which is among the most comprehensive and internationally recognized databases (Evensen and Sovacool, 2024). Governance metrics include six dimensions: control of corruption, government effectiveness,

Table 1
Variables, Definitions, Calculations, Sources and Data description

Variable	Definitions	Calculations	Source	Obs.	Mean	Min	Max	St. Dev
re_consumption	Renewable energy consumption	% of total final energy consumption	WDIs	831	27.55	0.00	93.20	26.63
lgdp_percapita	Economic growth	Per capital GDP (logarithm)	WDIs	864	8.07	5.62	11.13	1.22
lco2_gdpppp	CO_2 emission	Per capital CO_2 emission (logarithm)	WDIs	864	-1.57	-3.83	0.65	0.75
urban_population	Urban population	% of urban residents	WDIs	896	48.42	14.57	100	21.00
z_GGI_c1	Composite index (PCA)	Standardization	WGIs	797	0.00	-2.02	2.74	1.00

Source: Authors' own work

rule of law, regulatory quality, political stability, and voice and accountability. Each dimension ranges from -2.5 (weak institutional performance) to +2.5 (strong institutional performance).

We apply PCA to the six dimensions and retain the first principal component, which captures the largest proportion of common variance across institutional indicators. The resulting index is subsequently standardized (z-score transformation) to improve comparability across countries and facilitate interpretation of interaction terms by placing the governance variable on a common scale (Aiken and West, 1991; Wooldridge, 2010). Income and CO_2 emission are logarithmically transformed, thereby reducing the skewness of their distributions, stabilizing variance and consequently enhancing the model's fit and statistical inference (Gujarati, 2004). Renewable energy consumption, urbanization are measured as percentage shares bounded between 0 and 100. Retaining percentage levels allows for direct policy interpretation in terms of share changes and avoids distortions that may arise when applying logarithmic transformation to bounded variables (Wooldridge, 2010; Gujarati, 2004).

4. Findings and Discussion

4.1 Preliminary analysis

Table 2 presents the pairwise correlation matrix. Renewable energy consumption is negatively correlated with GDP per capita (-0.63), CO_2 intensity (-0.56), and urbanization (-0.61), suggesting that higher income levels, fossil fuel intensive and more urbanized structures are associated with lower renewable energy shares in the raw data. Governance quality is positively correlated with GDP per capita (0.78) and urbanization (0.63), reflecting the association between institutional development and economic modernization. Importantly, although some correlations are moderately strong, none exceed the multicollinearity thresholds, and subsequent variance inflation factor (VIF) tests confirm that multicollinearity does not materially affect the regression analysis (see Table 3).

4.2 Empirical results

Table 4 reports the estimation results examining the moderating effects of good governance in the economic growth and renewable consumption nexus. Three models are reported: random effects (RE), fixed effects (FE), and fixed effects with country-clustered standard errors in Table 4. The Hausman test (Table 8) rejects the null hypothesis of no systematic difference between FE and RE (chi square = 14.44, p = 0.01), indicating that the fixed-effects specification is preferred. Accordingly, the FE model with clustered standard errors serves as the benchmark specification The coefficient on GDP per capita is negative and statistically significant across all specifications. This finding suggests that, within countries, economic expansion is associated with a decline in the share of renewable energy in total energy consumption. Specifically, the estimated coefficient on GDP per capita (-13.59, $p<0.01$) indicates a substantial negative within-country effect. In semi-log terms, a 1% increase in income reduces the renewable energy share by approximately 0.136 percentage points. This effect is non-trivial. Given the average renewable energy share in the sample is approximately 27.5% (Table 1), a 10% increase in GDP per capita is associated with a reduction of about 1.36 percentage points, which corresponds to approximately 4.9% of the sample mean (1.36/27.5). This indicates that negative impact of economic growth on renewable energy consumption is economically meaningful rather than merely statistically significant. The finding also has important theoretical implications. It challenges the optimistic view of automatic green growth (Bakirtas and Akpolat, 2018; Rahman and Sultana, 2022). Rather than inducing structural energy transition, economic growth in many Asian economies appears to reinforce fossil-based energy systems. Rapid industrialization, infrastructure expansion, and energy-intensive manufacturing may offset renewable gains.

Carbon intensity also exhibits a negative and significant relationship with renewable energy consumption. Economies characterized by higher carbon intensity tend to display weaker renewable penetration. This supports the structural inertia argument: production systems deeply embedded in fossil-fuel dependence are slower to diversify toward renewable sources (Eitan and Hekkert, 2023).

Urbanization does not exhibit a statistically significant effect. Although descriptive statistics indicate a negative correlation between urbanization and renewable energy consumption, this relationship disappears in the within-country specification. This suggests that the observed correlation is largely driven by cross-country structural differences rather than dynamic urbanization processes within countries. Moreover, demographic concentration alone does not systematically influence renewable energy adoption, as its effect tend to be weak or context-dependent (Salim and Shafiei, 2014)

Table 2
Correlation coefficients

	re_consumption	lgdp_percapita	lco2_gdpppp	urban_population	z_GGI_c1
re_consumption	1.00				
lgdp_percapita	-0.63***	1.00			
lco2_gdpppp	-0.56***	0.20***	1.00		
urban_population	-0.61***	0.80***	0.25***	1.00	
z_GGI_c1	-0.24***	0.78***	-0.08**	0.63***	1.00

*Note: **, *** denote statistical significance at the 5%, and 1% levels, respectively.*
Source: Authors' own work

Table 3
Variance inflation factors (VIF)

Variables	VIF	1/VIF
lgdp_percapita	4.31	0.23
lco2_gdpppp	1.51	0.66
urban_population	3.40	0.29
z_GGI_c1	3.41	0.29
z_GGI_c1 * lgdp_percapita	1.77	0.56
Mean VIF	2.88	

Source: Authors' own work

Table 4
Economic growth, governance and renewable consumption

Variables	RE (1)	FE (2)	FE cluster (3)
lgdp_percapita	-13.61*** (0.67)	-13.59*** (0.67)	-13.59*** (2.54)
lco2_gdpppp	-11.79*** (0.51)	-11.77*** (0.51)	-11.77*** (1.81)
urban_population	0.01 (0.03)	0.01 (0.03)	0.01 (0.09)
z_GGI_c1	-4.05*** (0.67)	-4.36*** (0.68)	-4.36** (1.83)
z_GGI_c1 * lgdp_percapita	1.71*** (0.39)	1.74*** (0.40)	1.73** (0.88)
Constant	116.83*** (5.19)	117.03*** (4.30)	117.03*** (15.54)
Observations	713	713	713
Countries	31	31	31
R^2 (within)	0.70	0.70	0.70
Country FE	No	Yes	Yes
Sigma_ u	16.27	18.79	18.79
Sigma_e	3.62	3.62	3.62
rho	0.95	0.96	0.96

Notes: (1): Random effects (RE); (2): Fixed effects (FE); (3): FE with clustered standard errors at country level. Robust standard errors in parentheses; *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

The central contribution of this study lies in identifying governance quality as a moderating factor in the growth-renewable energy nexus. The interaction term is positive and statistically significant across fixed-effects, clustered standard errors. This result indicates that governance quality mitigates the negative effect of economic growth on renewable energy consumption. In other words, while growth alone tends to reinforce fossil dependence, strong institutions alter the developmental trajectory. Importantly, the magnitude and statistical significance of the interaction term remain stable across RE, FE, and clustered FE estimations, indicating that the moderating role of governance is not sensitive to alternative inference procedures.

Figure 1 visually presents the marginal effect of GDP per capita across different levels of governance quality. The slope is clearly upward, indicating the marginal effect becomes less negative as governance quality increases. Although the effect does not turn positive within the observed range, the magnitude of the negative impact declines substantially. This suggests that governance does not fully reverse the fossil-fuel bias of economic growth, but it significantly mitigates it. However, institutional improvements alone may not be sufficient. Complementary energy policies and technological advancements are likely required to boost the transformation of growth from a carbon-intensive expansion into a potentially renewable-supportive process (Mohamad and Ab-Rahim, 2023).

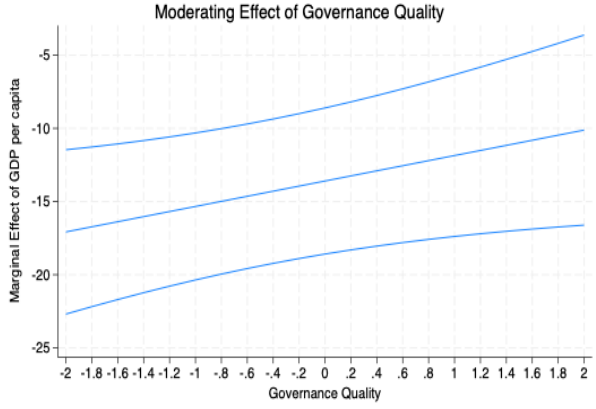

Fig 1. Moderating effect of governance quality.

These findings align with institutional transition theory, which emphasizes the role of good governance in shaping energy investment and behavioural decisions (Bertoldi, 2022; Uzar, 2020; Mahalik *et al.*, 2023). Strong governance may reduce policy uncertainty, enhance enforcement of environmental standards, and facilitate renewable energy deployment through stable regulatory frameworks. Rather than viewing economic growth and renewable energy transition as inherently conflicting, the results suggest that the relationship is conditional. Governance acts as a transmission channel that determines whether economic expansion accelerates or delays energy transition.

Overall, this study departs from much of the existing literature, which typically treats institutional quality as an independent determinant of energy outcomes (Uzar, 2020; Wang *et al.*, 2022). Instead, we model governance as a moderating factor, explicitly examining whether it mitigates the trade-off between economic growth and renewable energy consumption in Asia. This specification allows for a more direct assessment of how institutional quality conditions the effectiveness of growth in supporting the energy transition. This moderating effect can be explained through several institutional channels, including improved policy credibility, reduced investment risk, and more efficient allocation of resources toward clean energy technologies.

4.3 Extended models' results

The results from the EKC specification (model 1) in Table 5 provide strong evidence of non-linear relationship between economic growth and renewable energy consumption. The coefficient on GDP per capita is negative and statistically significant, while the squared term is positive and significant, confirming the existence of a U-shaped relationship. The findings suggest that economic growth is associated with a decline in the share of renewable energy at the early stages of development, reflecting a structural dependence on fossil fuels. However, beyond a per capita income threshold of 32,000 USD (lgdp_percapita=10.37), further economic expansion promotes the transition towards renewable energy consumption. The average income level of Asian economies remain below this

Table 5
Extended models' results

Variables	EKC specification (1)	EKC with moderating role of governance (2)
lgdp_percapita	-54.61***	-56.57***
	(10.85)	(11.24)
lgdp_percapita^2	2.63***	2.79***
	(0.68)	(0.74)
z_GGI_c1	-4.40**	-2.22
	(1.66)	(8.91)
z_GGI_c1 * lgdp_percapita		-1.20
		(5.10)
z_GGI_c1 * lgdp_percapita^2		-0.14
		(0.41)
lco2_gdpppp	-9.96***	-9.87***
	(1.57)	(1.57)
urban_population	-0.02	-0.02
	(0.11)	(0.12)
Constant	278.49***	288.21***
	(44.30)	(51.41)
Observations	713	713
Countries	31	31
R^2 (within)	0.73	0.73
Country FE	Yes	Yes
Turning point	10.37	NA

Note: standard errors clustered at the country level are reported in parentheses, *,**, and *** denote statistical significance level at the 10%, 5% and 1% respectively. Turning point is not available (NA) for EKC with moderating role of governance, given the interaction terms are not statistically significant.

threshold (mean lgdp_percapita=8.07), implying that they are still in the fossil-dependent phase. This finding provides stronger support than the linear model in Table 4, confirming the economic growth and renewable energy transition nexus is non-linear rather than purely linear.

The negative and statistically significant governance quality in model 1 (Table 5) suggests that improvements in governance are associated with a lower share of renewable energy consumption, conditional on income levels and other controls. The possible explanation is that better governance may initially enhance efficiency in existing energy systems, which are still dominated by fossil fuels in many Asian countries (Energy Institute - Statistical Review of World Energy, 2025).

When the interaction terms between governance and both the linear and quadratic income variables are introduced in model 2 (Table 5), the estimated coefficients are not statistically significant. This suggests that governance quality does not systematically alter either the slope or the curvature of the EKC relationship. The finding contrasts with the baseline linear specification in Table 4, where governance plays a significant moderating role. One possible explanation is that the inclusion of higher-order income terms introduces additional multicollinearity and reduces estimation precision, thereby weakening the statistical significance of interaction effects. Alternatively, the moderating role of governance may primarily operate in a linear growth framework rather than affecting the structural turning point of the EKC.

4.4 Robustness analysis

To evaluate the robustness of our findings, we conduct a series of additional analyses. Previous studies indicate that countries with higher institutional quality tend to exhibit a greater share of renewable energy consumption (Uzar, 2020; Wang *et al.*, 2022; Berrich *et al.*, 2024). Moreover, existing studies also commonly differentiate between developing and developed economies in their empirical analyses (Aye *et al.*, 2017; Njoh, 2021; Zeng *et al.*, 2021). Given the substantial cross-country heterogeneity in economic structure, institutional capacity, and energy systems across Asian economies, it is unlikely that a single average effect adequately captures the underlying relationships. Therefore, we extend our investigation by conducting subsample analyses based on these country group classifications. We utilize the World Bank income classification to partition our sample into lower-middle-income, upper-middle-income, and high-income country groups. Low-income countries, Afghanistan and Korea, Dem. People's Rep, are excluded from this analysis due to large missing data points which could not be effectively interpolated or extrapolated for.

Table 6 presents results for four groups: (1) all countries in the subsamples, (2) lower-middle-income countries, (3) upper-middle-income, and (4) high-income countries. Our findings align with the baseline results (Model 1) when we use low-middle income and upper-middle income country sample. It is observed that most coefficients for the high-income country group exhibit effects on the dependent variable that are opposite in direction compared to those observed across the full sample and other country groups. For developing countries (Models 2 and 3), the results indicate a scale effect. Increases in GDP per capita are significantly associated with a decline in the share of renewable energy in total final energy consumption. In contrast, for high-income countries (Model 4), economic growth is positively and significantly related to renewable energy

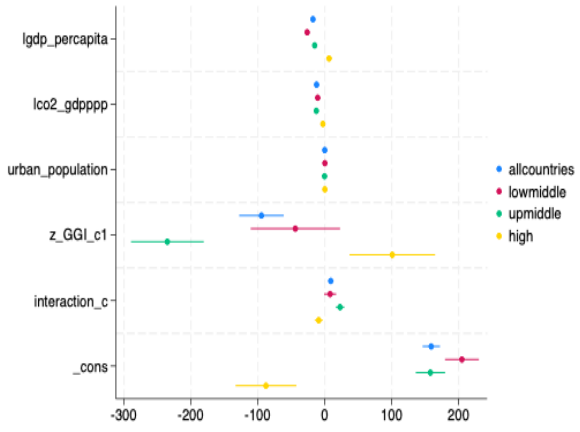

Fig 2. Coefficient estimates across income groups

Table 6.
Economic growth, governance, and renewable consumption; by level income of country

VARIABLES	(1) All countries	(2) Low middle income	(3) Upper middle income	(4) High income
lgdp_percapita	-17.690***	-26.439***	-15.077***	10.687**
	(0.909)	(1.853)	(1.422)	(4.163)
lco2_gdpppp	-12.308***	-10.643***	-12.690***	8.290***
	(0.568)	(0.771)	(0.974)	(1.348)
urban_population	0.007	0.260***	-0.293***	-0.038
	(0.038)	(0.064)	(0.036)	(0.059)
z_GGI_c1	-94.806***	-46.291	-233.968***	73.861
	(16.601)	(34.026)	(27.431)	(59.272)
z_GGI_c1 * lgdp_percapita	9.234***	8.580*	22.781***	-5.097
	(1.958)	(4.577)	(3.247)	(5.672)
Constant	159.236***	205.093***	158.077***	-109.912**
	(7.124)	(13.761)	(11.727)	(44.184)
Observations	691	322	277	92
Number of countries	30	14	12	4

** Note: Robust standard errors in parentheses; *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively*

consumption. The results align with and extend the existing empirical literature (Bamati and Raoofi, 2020), showing that the relationship between income and renewable energy varies across levels of development. In developing countries, GDP per capita appears to be a relatively weak determinant of renewable energy adoption, reflecting a growth pattern that remains more reliant on non-renewable energy sources. However, the results should be interpreted with caution due to limited sample size.

To better visualize cross-country heterogeneity, Figure 2 plots the estimated coefficients across income groups, highlighting substantial cross-country heterogeneity. The effect of GDP per capita is negative in lower and upper middle income countries, but turns positive in high-income economies. This indicates that economic growth tends to reinforce fossil fuel dependence in developing countries, while supporting renewable energy adoption in more advanced economies.

The results in Table 6 also indicate that, among the estimated interaction terms, only the interaction between GDP per capita and governance quality yields a positive and statistically significant effect on renewable energy consumption in Asian low-middle income and upper-middle income countries. This finding implies that income alone is not a sufficient driver of the energy transition; rather, its effectiveness depends critically on the institutional environment. In particular, improvements in governance quality appear to enhance the capacity of economic growth to translate into greater adoption of renewable energy, likely by reducing regulatory uncertainty, strengthening policy implementation, and improving investment conditions. These estimates further suggest that the renewable-growth relationship in developing Asian economies is inherently conditional, with governance acting as a key moderating factor. In the absence of adequate institutional quality, increases in income may continue to reinforce reliance on conventional energy sources. By contrast, stronger governance frameworks enable a more efficient allocation of resources toward cleaner energy technologies, thereby amplifying the positive impact of economic growth on renewable energy consumption.

Moreover, the estimates also reveal a contrasting relationship between CO2 emissions and renewable energy consumption across country groups. In developing economies,

Table 7
Lagged fixed effects estimation

Variables	FE cluster (lagged)
L.lgdp_percapita	-13.23***
	(2.58)
L.lco2_gdpppp	-10.86***
	(1.66)
L.urban_population	-0.01
	(0.10)
L.z_GGI_c1	-3.97**
	(1.94)
L.z_GGI_c1 * lgdp_percapita	1.65*
	(0.90)
Constant	115.68***
	(16.17)
Observations	682
Countries	31
R^2 (within)	0.65
Country FE	Yes
Sigma_ u	18.57
Sigma_e	3.81
rho	0.96

Notes: **, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.*

CO2 emissions are negatively and significantly associated with renewable energy consumption, suggesting that higher emissions are linked to a continued reliance on conventional energy sources and a slower transition toward renewables. In contrast, the relationship is reversed in developed countries, where higher emissions are positively associated with green energy consumption.

Regarding urbanization, the results are consistent with prior evidence that its effect on renewable energy consumption is heterogeneous and contingent on the stage of development (Wang *et al.*, 2022; Salahuddin, 2019). In developing and emerging economies, urban population growth may constrain renewable energy consumption when expansion is energy-intensive and fossil fuel-dependent, but can support renewable adoption once certain thresholds are reached and policy frameworks are in place. In developed economies, urbanization mainly increases overall energy demand, while renewable energy consumption expansion is driven more by policy,

Table 8
Diagnostic tests

Test	Statistic	p-value
Hausman test	14.44	0.01
Persaran CD test	1.21	0.22
Average absolute correlation	0.51	

technology, and demographic scale than by the urbanization rate itself.

Overall, the baseline results remain robust across alternative country classifications. The evidence indicates that lower-and upper-middle-income countries are most responsive to improvements in governance quality, which help offset the adverse effects of economic growth on the transition away from fossil fuel dependence toward renewable energy. To further address potential endogeneity concerns, particularly reverse causality and dynamic adjustment effects, we re-estimate the baseline model (Table 4) using lagged explanatory variables. Table 7 reports the estimation results of the lagged fixed-effects model within country-clustered standard errors.

The estimation results remain largely consistent with the baseline findings. The coefficient on lagged GDP per capita is negative and statistically significant (β=-13.23, p<0.01), confirming the economic growth continues to exert a negative impact on the share of renewable energy consumption even when accounting for temporal dynamics. Similarly, lagged CO_2 intensity remains negative and highly significant (β=-10.86, p<0.01), indicating the carbon-intensive production structure persistently hinder the transition toward renewable energy. The governance quality retains a negative and statistically significant coefficent (β=-3.97, p<0.05), while the interaction term remains positive, its strength weakens slightly compared to the baseline specification (β = 1.65, p<0.10). Although the interaction term becomes marginally significant at the 10% level in the lagged specification, its sign and magnitude remain consistent with the baseline results, supporting the robustness of the moderating effect. Urbanization, however, sustains statistically insignificant, suggesting that within-country changes in urban population do not systematically affect renewable energy consumption overtime.

Table 8 reports diagnostic tests supporting the econometric specification. The Hausman test confirms the consistency of the fixed-effects estimator. Furthermore, the intra-class correlation coefficient (rho= 0.96) reported in Table 4 indicates that approximately 96% of the variation in renewable energy consumption arises from cross-country differences rather than within-country fluctuations. This substantial unobserved heterogeneity justifies controlling for country-specific fixed effects. Pesaran's CD test does not reject the null hypothesis of cross-sectional independence (p = 0.22). Although Asian economies are economically interconnected in practice, the absence of statistically significant residual cross-sectional dependence suggests that common shocks are largely captured by the included regressors and country effects. Standard errors clustered at the country level further account for potential heteroskedasticity and serial correlation within panels.

4.5 Sensitivity analysis

We replace the composite governance index with its six individual components to further assess the sensitivity of our findings (Table 9). The results reveal substantial heterogeneity across institutional dimensions. Among the six indicators, government effectiveness emerges as the most robust moderating factor. The interaction term between GDP per capita and government effectiveness is positive and statistically significant at the 1% level, indicating stronger administrative capacity enhances the ability of economic growth to support renewable energy transition. Regulatory quality also exhibits a positive moderating effect, although at a weaker level of statistical significance. The stable regulatory frameworks can facilitate renewable energy investment by reducing policy

Table 9.
Sensitivity analysis: governance dimensions and renewable energy consumption

Variables	Control of corruption (1)	Government effectiveness (2)	Political stability (3)	Regulatory quality (4)	Rule of law (5)	Voice & accountability (6)
lgdp_percapita	-15.19***	-13.78***	-15.01***	-13.77***	-15.21***	-16.31***
	(2.36)	(2.42)	(2.46)	(2.43)	(2.83)	(2.52)
Governance	-12.11	-19.08***	-9.05 (5.86)	-17.72* (9.28)	-8.92	6.43
	(7.81)	(6.24)			(7.33)	(8.01)
lgdp_percapita*Governance	1.26	1.94***	0.90	1.74*	0.96 (0.79)	-0.89
	(0.91)	(0.70)	(0.70)	(1.04)		(1.03)
lco2_gdpppp	-12.14***	-12.28***	-11.87***	-11.66***	-11.94***	-12.11***
	(1.71)	(1.91)	(1.83)	(1.97)	(1.82)	(1.66)
urban_population	0.06	0.02	0.07	0.01	0.06	0.09
	(0.09)	(0.09)	(0.10)	(0.10)	(0.11)	(0.10)
Constant	126.98***	116.76***	125.95***	118.80***	127.97***	136.22***
	(14.62)	(15.24)	(15.05)	(15.02)	(17.41)	(16.57)
Observation	713	713	713	713	713	713
Countries	31	31	31	31	31	31
R^2 (within)	0.683	0.699	0.695	0.702	0.680	0.679

Notes: clustered standard errors in parentheses. *, **, *** denote 10%, 5% and 1% respectivelly

uncertainty and improving the business environment (Uzar, 2020).

In contrast, the remaining 4 governance dimensions, including control of corruption, political stability, rule of law, and voice and accountability, do not show statistically significant interaction effects, suggesting that their roles are less directly linked to the energy transition process in the Asian context. The findings imply that only specific institutional channels directly influence the growth-renewable energy nexus. In general, these results reinforce the importance of governance quality in the baseline model while highlighting the heterogeneity across institutional dimensions. This also mitigates concerns regarding aggregation bias in composite governance indices.

5. Conclusion

The study investigates whether governance quality moderates the relationship between economic growth and renewable energy consumption in 31 Asian economies over the period 1996-2023. Using panel fixed-effects estimation, the analysis yields three principal findings. First, economic growth is negatively associated with the share of renewable energy consumption. This suggests that growth-led development in many Asian economies remains structurally energy-intensive and fossil-dependent. Renewable transition does not occur automatically as income rises. Second, governance quality plays a decisive moderating role. The positive and significant interaction term indicates that stronger institutional frameworks mitigate the negative impact of economic growth on renewable energy consumption. Institutional capacity transforms the developmental trajectory by shaping regulatory credibility, investment incentives, and enforcement mechanisms. In high-governance environments, economic expansion becomes more compatible with renewable energy transition. Third, diagnostic tests confirm the appropriateness of the fixed-effects specification and indicate no significant residual cross-sectional dependence. The results are robust to clustered standard errors and alternative estimators, reinforcing the credibility of the moderating effect.

The findings contribute to the green growth literature by demonstrating that the growth-renewable nexus is conditional on institutional quality. Rather than asking whether growth promotes renewable energy, the more relevant question is under what governance conditions growth can support sustainable energy transition. This conditional perspective helps reconcile divergent empirical findings in previous studies. From a policy standpoint, the results suggest that economic expansion alone is insufficient to ensure renewable transition. Institutional reforms should prioritize strengthening government effectiveness and regulatory quality as these dimensions are shown to play the most critical role in enabling economic growth to support renewable energy transition. Policy efforts should be targeted rather than uniformly distributed across all aspects of governance.

Despite its contributions, this study has several limitations. First, the analysis focuses on static panel estimation; dynamic approaches may provide additional insights into adjustment mechanisms and persistence effects in renewable transition. Second, potential spatial spill overs and regional heterogeneity within Asia could be explored using spatial econometric techniques. Finally, incorporating sectoral-level data may allow for a more granular understanding of how governance influences renewable deployment across industries. Future studies addressing these issues would further advance our understanding of the institutional foundations of sustainable energy transition.

Acknowledgement

This research is funded (supported) by Vietnamese Ministry of Education and Training under the project **B2025-KSA-01**

Reference

Acemoglu, D., Johnson, S., & Robinson, J. A. (2001). The colonial origins of comparative development: An empirical investigation. *American Economic Review*, *91*(5), 1369-1401. https://doi.org/10.1257/aer.91.5.1369

Aiken, L. S., West, S. G., & Reno, R. R. (1991). Multiple Regression: Testing and Interpreting Interactions. London: Sage Publications Ltd..

Asongu, S., & Odhiambo, N. M. (2022). Governance and renewable energy consumption in Sub-Saharan Africa. *International Journal of Energy Sector Management*, *16*(2), 209-223. https://doi.org/10.1108/IJESM-10-2020-0009

Aye, G. C., & Edoja, P. E. (2017). Effect of economic growth on CO2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance*, *5*(1), 1379239. https://doi.org/10.1080/23322039.2017.1379239

Bakirtas, T., & Akpolat, A. G. (2018). The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. Energy, 147, 110-121. https://doi.org/10.1016/j.energy.2018.01.011

Bamati, N., & Raoofi, A. (2020). Development level and the impact of technological factor on renewable energy production. *Renewable Energy*, *151*, 946-955. https://doi.org/10.1016/j.renene.2019.11.098

Baltagi, B. H. (2008). *Econometric analysis of panel data* (Vol. 4, pp. 135-145). Chichester: John Wiley & Sons.

Berrich, O., Mafakheri, F., & Dabbou, H. (2024). Renewable energy transition and the Paris agreement: how governance quality makes a difference? *Energies*, *17*(17), 4238 https://doi.org/10.3390/en17174238

Bertoldi, P. (2022). Policies for energy conservation and sufficiency: Review of existing policies and recommendations for new and effective policies in OECD countries. *Energy and Buildings*, *264*, 112075. https://doi.org/10.1016/j.enbuild.2022.112075

Blazquez, J., Fuentes, R., & Manzano, B. (2020). On some economic principles of the energy transition. *Energy Policy*, *147*, 111807. https://doi.org/10.1016/j.enpol.2020.111807

Brambor, T., Clark, W. R., & Golder, M. (2006). Understanding interaction models: Improving empirical analyses. *Political Analysis*, *14*(1), 63-82. https://doi.org/10.1093/pan/mpi014

Doğan, B., Balsalobre-Lorente, D., & Nasir, M. A. (2020). European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. *Journal of Environmental Management*, *273*, 111146. https://doi.org/10.1016/j.jenvman.2020.111146

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, *80*(4), 549-560. https://doi.org/10.1162/003465398557825

Eitan, A., & Hekkert, M. P. (2023). Locked in transition? Towards a conceptualization of path-dependence lock-ins in the renewable energy landscape. *Energy Research & Social Science*, *106*, 103316. https://doi.org/10.1016/j.erss.2023.103316

Energy Institute - Statistical Review of World Energy (2025). *Population based on various sources (2024)*. https://ourworldindata.org/grapher/fossil-fuels-per-capita?tab=line&time=earliest..2024&country=OWID_EUR~USA~AUS~OWID_ASI

Evensen, D., & Sovacool, B. K. (2024). Political economy of low-carbon electricity: Governance effects across 198 countries. Renewable and Sustainable Energy Reviews, 189, 114016. https://doi.org/10.1016/j.rser.2023.114016

Eyuboglu, K., & Uzar, U. (2025). The social, economic, and environmental drivers of renewable energy: Is income inequality a threat to renewable energy transition? *Journal of Cleaner Production*, *490*, 144780. https://doi.org/10.1016/j.jclepro.2025.144780

Gershon, O., Asafo, J. K., Sowah, J. N., & Tanko, F. (2025). Persistence of emissions in selected African countries: energy consumption and population growth dynamics. *Energy Strategy Reviews*, *57*, 101628. https://doi.org/10.1016/j.esr.2024.101628

Goyal, N., Taeihagh, A., & Howlett, M. (2022). Mapping the use of public policy theories in energy transitions research: a bibliometric review and computational text analysis. *Routledge Handbook of Energy Transitions*, 332-349. https://doi.org/10.4324/9781003183020

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353-377. https://doi.org/10.2307/2118443

Gujarati, D. N. (2004). Basic econometrics- 4th Edition, McGraw-Hill Companies.

Haldar, A., & Sethi, N. (2021). Effect of institutional quality and renewable energy consumption on CO2 emissions− an empirical investigation for developing countries. *Environmental Science and Pollution Research*, *28*(12), 15485-15503. https://doi.org/10.1007/s11356-020-11532-2

Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalán, C. (2006). Climate change and human health: impacts, vulnerability and public health. *Public Health*, *120*(7), 585-596. https://doi.org/10.1016/j.puhe.2006.01.002

Hair Jr, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate data analysis. *7th Edition, Pearson, New York.*.

Hausman, J. A. (1978). Specification tests in econometrics. *Econometrica: Journal of the Econometric Society*, 1251-1271. https://doi.org/10.2307/1913827

Heshmati, A., & Rashidghalam, M. (2020). Measurement and analysis of urban infrastructure and its effects on urbanization in China. *Journal of Infrastructure Systems*, *26*(1), 04019030. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000513

IMF (2025). Annual GDP growth,1980-2030. https://ourworldindata.org/grapher/real-gdp growth?country=OWID_WRL~Middle+East+and+Central+Asia +%28IMF%29~ASEAN-5+%28IMF%29

IPCC. (2022). Emissions Trends and Drivers. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.004

Javaid, M., Haleem, A., Rab, S., Singh, R. P., & Suman, R. (2021). Sensors for daily life: A review. Sensors International, 2, 100121. https://doi.org/10.1016/j.sintl.2021.100121

Kabeyi, M. J. B., & Olanrewaju, O. A. (2022). Sustainable energy transition for renewable and low carbon grid electricity generation and supply. Frontiers in Energy research, 9, 743114. https://doi.org/10.3389/fenrg.2021.743114

Keynes, J. M. (1936). *The general theory of employment, interest and money (1936)* (p. 149). Whitefish: Kessinger Publishing.

Li, R., Yang, Z., & Wang, Q. (2025). Does renewable energy reduce energy intensity? A matter of income inequality. *Humanities and Social Sciences Communications*, *12*(1), 138. https://doi.org/10.1057/s41599-025-04439-1

Liu, Y. (2009). Exploring the relationship between urbanization and energy consumption in China using ARDL (autoregressive distributed lag) and FDM (factor decomposition model). *Energy*, *34*(11), 1846-1854. https://doi.org/10.1016/j.energy.2009.07.029

Mahalik, M. K., Patel, G., Sahoo, B. K., & Rahman, M. M. (2023). Impact of income inequality on renewable energy demand in south Asian economies. *Energy Policy*, *180*, 113628. https://doi.org/10.1016/j.enpol.2023.113628

Marques, A. C., Fuinhas, J. A., & Manso, J. P. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy*, *38*(11), 6877-6885. https://doi.org/10.1016/j.enpol.2010.07.003

Menegaki, A. N., & Ozturk, I. (2013). Growth and energy nexus in Europe revisited: Evidence from a fixed effects political economy model. *Energy Policy*, *61*, 881-887. https://doi.org/10.1016/j.enpol.2013.06.076

Mentel, G., Lewandowska, A., Berniak-Woźny, J., & Tarczyński, W. (2023). Green and renewable energy innovations: a comprehensive bibliometric analysis. Energies, 16(3), 1428. https://doi.org/10.3390/en16031428

Mohamad, A. H. H., & Ab-Rahim, R. (2025). Mapping the research landscape of energy market and renewable energy: A bibliometric analysis. *International Journal of Renewable Energy Development*, *14*(4), 703-716. https://doi.org/10.61435/ijred.2025.61058

Nepal, R., & Paija, N. (2019). Energy security, electricity, population and economic growth: The case of a developing South Asian resource-rich economy. *Energy Policy*, *132*, 771-781. https://doi.org/10.1016/j.enpol.2019.05.054

Nguyen, Q. L. H. T. T., & Pham, A. T. Q. (2025). Moderating Role of Governance in the Nexus of Economic Growth and Renewable Energy Consumption: The Case of Southeast Asian Countries. In *Green Economic Development and Transition to Low-Carbon Economy in the East and Southeast Asia* (pp. 165-188). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-0628-3_10

Njoh, A. J. (2021). Renewable energy as a determinant of inter-country differentials in CO2 emissions in Africa. *Renewable Energy*, *172*, 1225-1232. https://doi.org/10.1016/j.renene.2021.03.096

North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge University Press, Cambridge.

Overland, I., Juraev, J., & Vakulchuk, R. (2022). Are renewable energy sources more evenly distributed than fossil fuels? Renewable Energy, 200, 379-386. https://doi.org/10.1016/j.renene.2022.09.046

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews*, *34*(6-10), 1089-1117. https://doi.org/10.1080/07474938.2014.956623

Radtke, J. (2025). Understanding the complexity of governing energy transitions: introducing an integrated approach of policy and transition perspectives. *Environmental Policy and Governance*, *35*(4), 595-614. https://doi.org/10.1002/eet.2158

Rahman, M. M., & Sultana, N. (2022). Impacts of institutional quality, economic growth, and exports on renewable energy: Emerging countries perspective. Renewable Energy, 189, 938-951. https://doi.org/10.1016/j.renene.2022.03.034

Salahuddin, M., Ali, M. I., Vink, N., & Gow, J. (2019). The effects of urbanization and globalization on CO2 emissions: evidence from the Sub-Saharan Africa (SSA) countries. *Environmental Science and Pollution Research*, *26*(3), 2699-2709. https://doi.org/10.1007/s11356-018-3790-4

Salim, R. A., & Shafiei, S. (2014). Urbanization and renewable and non-renewable energy consumption in OECD countries: An empirical analysis. *Economic Modelling*, *38*, 581-591. https://doi.org/10.1016/j.econmod.2014.02.008

Sarkodie, S. A., Adams, S., & Leirvik, T. (2020). Foreign direct investment and renewable energy in climate change mitigation: does governance matter? *Journal of Cleaner Production*, *263*, 121262. https://doi.org/10.1016/j.jclepro.2020.121262

Shahbaz, M., Wang, J., Dong, K., & Zhao, J. (2022). The impact of digital economy on energy transition across the globe: The mediating role of government governance. *Renewable and Sustainable Energy Reviews,* 166, 112620. https://doi.org/10.1016/j.rser.2022.112620

Shao, H., Wang, Y., Lee, C. C., & Wen, H. (2024). How does political stability affect renewable energy finance? International evidence. *Energy*, *313*, 133829. https://doi.org/10.1016/j.energy.2024.133829

Shukla, A. K., Sudhakar, K., & Baredar, P. (2017). Renewable energy resources in South Asian countries: Challenges, policy and recommendations. *Resource-Efficient Technologies*, *3*(3), 342-346. https://doi.org/10.1016/j.reffit.2016.12.003

Solow, R. M. (1956). A contribution to the theory of economic growth. *The Quarterly Journal of Economics*, *70*(1), 65-94. https://doi.org/10.2307/1884513

Uzar, U. (2020). Political economy of renewable energy: does institutional quality make a difference in renewable energy consumption? *Renewable Energy*, *155*, 591-603. https://doi.org/10.1016/j.renene.2020.03.172

Wang, E., Gozgor, G., Mahalik, M. K., Patel, G., & Hu, G. (2022). Effects of institutional quality and political risk on the renewable energy

consumption in the OECD countries. *Resources Policy*, *79*, 103041. https://doi.org/10.1016/j.resourpol.2022.103041

Wise, J. (2021). COP26: fifty countries commit to climate resilient and low carbon health systems. https://doi.org/10.1136/bmj.n2734 .

Wooldridge, J. M. (2010). *Econometric Analysis of Cross section and Panel Data*. MIT press.

Yıldırım, B., Kasman, S., & Kasman, A. (2025). Spatial convergence of renewable energy consumption in the EU: Assessing the role of environmental policies and regional dynamics. *Environment, Development and Sustainability*, 1-27. https://doi.org/10.1007/s10668-025-06967-x

Zeng, C., Stringer, L. C., & Lv, T. (2021). The spatial spillover effect of fossil fuel energy trade on CO2 emissions. *Energy*, *223*, 120038. https://doi.org/10.1016/j.energy.2021.120038