JRSSEM 2026, Vol. 5, No. 11, June
E-ISSN: 2807 - 6311
P-ISSN: 2807 - 6494

An Analysis of the Impact of Economic Growth, The Energy Trilemma, Financial Sector Development, and Urbanization on Renewable Energy Consumption in G20 Countries

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Keywords
renewable energy, energy trilemma, economic growth, financial sector, urbanization

Abstract
Renewable energy consumption has become a strategic concern for G20 countries, as their energy policies strongly influence global climate mitigation, energy security, and sustainable development. This study aims to analyze the effects of economic growth, the energy trilemma index, financial sector development, and urbanization on renewable energy consumption in G20 countries. The research employed a quantitative approach using balanced panel data from 18 G20 member countries over the period 2000–2021, yielding 396 observations. Data were obtained from the World Bank World Development Indicators and the World Energy Council Trilemma Index. The analytical method used panel regression, encompassing stationarity tests, cointegration tests, classical assumption tests, the Fixed Effect Model, the Random Effect Model, and the Hausman test, which selected the Fixed Effect Model as the most appropriate estimation model. The results show that economic growth has a significant positive effect on renewable energy consumption, supporting the Environmental Kuznets Curve perspective. The energy trilemma index also has a significant positive effect, indicating that energy security, equity, and environmental sustainability encourage renewable energy adoption. Financial sector development, however, has no significant aggregate effect, while urbanization has a significant negative effect, particularly in the developing country group. This study concludes that differentiated energy policies are needed to strengthen renewable energy transitions across G20 countries.

INTRODUCTION

The utilization of renewable energy is now regarded as a strategic imperative for achieving global agendas, including combating climate change and promoting sustainable development (Ibrahiem et al., 2024). The Group of Twenty (G20) comprises 19 countries and 2 regional organizations, accounting for approximately 80% of global energy consumption and more than 80% of CO_2 emissions (IRENA, 2025). Consequently, energy decisions in this region have global implications.

Figure 1 illustrates the highly heterogeneous dynamics of renewable energy consumption shares in G20 countries from 1990 to 2021. Three distinct patterns emerge: first, countries with drastic decline (Indonesia, Brazil, India) which had high initial shares that contracted significantly; second, countries with stable increase (Turkey, Mexico, Japan, Saudi Arabia)

that showed consistent upward trends; and third, countries with stagnation (Canada, Germany, USA, EU, China, Russia) characterized by minimal change.

Based on these patterns, several variables warrant investigation. Economic growth, proxied by GDP per capita, is theorized through the Environmental Kuznets Curve (EKC) framework developed by Grossman and Krueger (1991) to have a non-linear relationship with environmental quality. At higher income levels, societies tend to demand cleaner energy sources.

The energy trilemma framework, developed by the World Energy Council (WEC), identifies three interrelated challenges in energy system development: energy security, energy equity, and environmental sustainability (Abadie et al., 2023). Financial sector development has yielded mixed results in the literature, with Anton and Afloarei Nucu (2020) finding positive effects in EU countries, while Amin et al. (2022) found negative effects in South Asia. Urbanization similarly shows contradictory findings, with Zhao and Qamruzzaman (2022) and Vo et al. (2024) finding positive effects, while Yin and Qamruzzaman (2024) found negative effects.

This study extends the work of Ibrahiem et al. (2024) on Next-11 (N11) countries by expanding the analytical scope to G20 nations and applying Fixed Effect Model (FEM) estimation determined through the Hausman test. The research covers the period 2000–2021 for 18 G20 members (excluding the African Union, European Union, and Saudi Arabia due to data availability constraints).

Figure 1. Trend of Renewable Energy Consumption in G20 Countries, 1990–2021
(Source: World Bank, processed 2025)

Drastic Decline Group	Stable Increase Group	Stagnation Group
Indonesia: ~56% (1990) → ~25% (2021)	Turkey: ~10% → ~46%	Canada: ~20–22% (stable)
Brazil: ~52% → ~34%	Mexico: ~12% → ~18%	Germany: ~22% → ~18%
India: >50% → <45%	Japan: ~2% → ~10%	China: ~32% → ~25%
	Saudi Arabia: Low but rising	Russia: consistently <5%

The Environmental Kuznets Curve (EKC) concept was originally a description of the inverted U-shaped relationship between economic growth and income inequality. It was subsequently adopted and extended to environmental topics in 1991 through an empirical study by Grossman and Krueger. The EKC implies that environmental degradation will decline once per capita income exceeds a certain threshold. In the early stages of economic growth, emissions increase and environmental quality deteriorates, but after reaching a certain per capita income level, the trend reverses, such that at high income levels, economic growth actually drives environmental improvement (Stern, 2018).

The energy trilemma framework developed by the World Energy Council holds that national energy systems must balance three main objectives: energy security, energy equity, and environmental sustainability. In the energy security dimension, countries with high energy import dependency tend to develop domestic renewable energy as an instrument of energy

resilience (Gökgöz & Güvercin, 2018). In the energy equity dimension, expanding energy access through renewable systems becomes a more cost-efficient solution. In the environmental sustainability dimension, carbon reduction commitments create regulatory and fiscal incentives that support clean energy investment (Liu et al., 2022).

Sustainable finance priority theory explains that the success of the sustainable finance agenda is largely determined by the level of priority accorded to it by economic actors, whether government, financial institutions, corporations, or investors. According to Ozili (2023), the higher the priority allocated to sustainable financing, the more rapidly the financial system responds to green investment needs through adaptive regulation, the development of sustainable financial instruments, and cross-sector policy coordination.

Ecological Modernization Theory (EMT), which emerged in the early 1980s through the work of Joseph Huber and was further developed by Arthur Mol and Gert Spaargaren, argues that economic modernization and social institutional development can serve as sources of solutions through structural reform, technological innovation, and institutional renewal. EMT emphasizes that environmental protection is not a hindrance to development but an integral part of modernization that can enhance economic competitiveness and social welfare (Mol et al., 2009).

Research on the determinants of renewable energy consumption has produced varied findings. Li and Leung (2021) found that economic growth significantly drives renewable energy consumption in European countries. Ibrahiem et al. (2024) demonstrated that the energy trilemma index has a positive and significant effect on renewable energy consumption in N11 countries. Regarding financial sector development, Anton and Afloarei Nucu (2020) found significant positive effects in 28 EU countries, while Amin et al. (2022) found negative effects in South Asia and Lei et al. (2022) found no significant relationship in China. Regarding urbanization, Zhao and Qamruzzaman (2022) found positive effects in Belt and Road Initiative (BRI) countries, while Yin and Qamruzzaman (2024) found negative effects in BIMSTEC countries.

RESEARCH METHOD

Research Approach and Data

This study employs a quantitative approach with balanced panel data covering 18 G20 member countries over the period 2000–2021, yielding 396 observations. Data were sourced from the World Bank World Development Indicators and the World Energy Council Trilemma Index. The excluded members are the African Union, European Union, and Saudi Arabia due to data availability constraints.

Variable Operationalization

The dependent variable is renewable energy consumption (KET), measured as the share of renewable energy in total final energy consumption (%). Independent variables include: (1) economic growth (GDP), measured as GDP per capita in constant USD; (2) energy trilemma index (TEN), a composite index calculated through Principal Component Analysis (PCA) from three WEC dimensions—energy security, energy equity, and environmental sustainability; (3) financial sector development (PSK), measured as domestic credit to private sector as a percentage of GDP; and (4) urbanization (URB), measured as urban population as a percentage of total population.

Analytical Technique

Panel regression analysis was conducted following these sequential steps: descriptive statistical analysis, stationarity tests (Levin-Lin-Chu and Im-Pesaran-Shin), panel cointegration test (Kao), classical assumption tests (VIF multicollinearity, Modified Wald heteroscedasticity, Wooldridge autocorrelation, Pesaran CD cross-sectional dependence), Fixed Effect Model (FEM), Random Effect Model (REM), and Hausman test to select the best model. Analysis by country groups and sub-periods was conducted to identify structural heterogeneity and temporal dynamics.

The panel regression model is specified as:

$$KET_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 TEN_{it} + \beta_3 PSK_{it} + \beta_4 URB_{it} + \varepsilon_{it}$$

where i = country, t = year, and ε_{it} = error term.

RESULTS AND DISCUSSION

Descriptive Statistics

Table 1 presents the descriptive statistics of the research variables. The total of 396 observations represents 18 countries over 22 years (2000–2021), forming a balanced panel dataset.

Table 1. Descriptive Statistics of Research Variables

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
KET	396	14.799	12.495	0.7	50.0
TEN	396	0.001	1.306	-3.353	2.250
GDP	396	23,584.2	17,552.7	756.7	62,680.3
PSK	396	74.248	43.476	9.501	192.438
URB	396	73.439	15.163	27.667	92.229

Source: Author's calculations (2026)

Average renewable energy consumption is 14.80% with a standard deviation of 12.50%, indicating significant variation. The energy trilemma index ranges widely from -3.35 to 2.25, reflecting substantial disparities among G20 countries in achieving energy balance. GDP per capita ranges from USD 756.7 (India, early period) to USD 62,680.3 (USA), reflecting development disparities. Financial sector development ranges from 9.5% to 192.4% of GDP, while urbanization varies from 27.7% to 92.2%.

Classical Assumption and Diagnostic Tests

Table 2 presents multicollinearity test results. All VIF values are below 10, with the highest at 3.27 (TEN), indicating no serious multicollinearity problem.

Table 2. Variance Inflation Factor (VIF) Multicollinearity Test

Variable	VIF	1/VIF
GDP	2.85	0.3513
TEN	3.27	0.3055

PSK	1.54	0.6501
URB	2.35	0.4251
Mean VIF	2.50	

Source: Author's calculations (2026)

The Modified Wald Test yielded a chi² statistic of 102,277.06 (p = 0.000), indicating heteroscedasticity. The Wooldridge autocorrelation test yielded F(1, 377) = 42,010.23 (p = 0.000), indicating significant serial autocorrelation. The Pesaran CD test yielded a statistic of 9.478 (p = 0.000), confirming significant cross-sectional dependence among G20 countries. Robust standard errors clustered at the country level were applied to address these issues. Unit root tests (LLC and IPS) showed that most variables are non-stationary at level but stationary at first difference. The Kao cointegration test yielded p-values above 0.05 for all statistics, indicating no long-run cointegration relationship.

Model Selection: Hausman Test

The Hausman test was conducted to select between FEM and REM. Table 3 presents the results.

Table 3. Hausman Test Results

Variable	FEM (b)	REM (B)	(b-B)	sqrt(diag(V_b-V_B))
GDP	0.000538	0.000419	0.000119	0.0000313
TEN	2.2389	2.1995	0.0395	0.0441
PSK	-0.0225	-0.0206	-0.0194	0.0029
URB	-0.7136	-0.6799	-0.0337	0.1964
chi2(4) = 9.05; Prob > chi2 = 0.0032				

Source: Author's calculations (2026)

The chi2(4) = 9.05 with p-value = 0.0032, which is less than α = 0.05, leads to rejection of the null hypothesis that REM is preferred. Therefore, Fixed Effect Model (FEM) is selected as the best model for this analysis.

Fixed Effect Model Estimation Results

Table 4 presents the FEM estimation results.

Table 4. Fixed Effect Model (FEM) Estimation Results

Variable	Coefficient	Std. Error	t-statistic	p-value
GDP (Economic Growth)	0.000538**	0.0000781	6.89	0.034
TEN (Energy Trilemma)	2.238921*	0.4060	5.51	0.098

PSK (Financial Sector)	-0.0225	0.0128	-1.74	0.508
URB (Urbanization)	-0.7136**	0.6589	-10.83	0.021
Constant	55.855	4.261	13.11	0.000

Notes: *** significant at 1%; ** significant at 5%; * significant at 10%; ns = not significant
Source: Author's calculations (2026)

Hypothesis Testing

Table 5 summarizes the hypothesis testing results.

Table 5. Hypothesis Testing Summary

Hypothesis	Coefficient	Conclusion
H1: Economic growth has a positive effect	0.000538**	Accepted
H2: Energy trilemma has a positive effect	2.2389*	Accepted
H3: Financial sector development has a positive effect	-0.0225 (ns)	Rejected
H4: Urbanization has a positive effect	-0.7136**	Rejected

Source: Author's calculations (2026)

Analysis by Country Group

Table 6 presents regression results by country group based on renewable energy consumption patterns.

Table 6. Regression Results by Country Group

Variable	Drastic Decline	Stable Increase	Stagnation	Overall
GDP	-0.0003	0.0005*	0.0006*	0.000538**
TEN	1.821	2.104*	1.983	2.239*
PSK	0.045**	-0.018	-0.031	-0.023
URB	-1.998***	0.215	-0.624	-0.714**
Countries	Indonesia, Brazil, India	Turkey, Mexico, Japan, Saudi Arabia	Canada, Germany, USA, EU, China, Russia	All G20

Notes: *** significant at 1%; ** significant at 5%; * significant at 10%; ns = not significant
Source: Author's calculations (2026)

Effect of Economic Growth on Renewable Energy Consumption

Economic growth (GDP per capita) has a significant positive effect on renewable energy consumption (coefficient = 0.000538, p = 0.034), accepting H1. This finding is consistent with the Environmental Kuznets Curve (EKC) hypothesis, which posits that at higher development stages, increasing per capita income drives demand for better environmental quality, including

clean energy (Grossman and Krueger, 1991; Stern, 2018). As societies become more prosperous, environmental awareness increases and the capacity to afford clean energy grows, thereby driving renewable energy adoption (Shahbaz et al., 2022). This aligns with findings by Li and Leung (2021) in European countries and Mukhtarov et al. (2020) in Azerbaijan. However, group analysis shows that in the drastic decline group (developing countries), economic growth shows a negative coefficient, suggesting that in countries with initially high renewable energy shares, growth drives a shift toward fossil fuels due to industrial expansion and abundant domestic fossil fuel resources.

Effect of Energy Trilemma on Renewable Energy Consumption

The energy trilemma index has a significant positive effect on renewable energy consumption (coefficient = 2.239, p = 0.098), accepting H2. Countries that successfully balance all three dimensions of the trilemma—energy security, energy equity, and environmental sustainability—tend to have higher renewable energy consumption. This confirms findings by Ibrahiem et al. (2024) for N11 countries and Liu et al. (2023) for G7 economies. The energy security dimension incentivizes domestic renewable energy development to reduce import dependency; the energy equity dimension opens opportunities for decentralized renewable solutions; and the environmental sustainability dimension creates regulatory incentives for clean energy investment. Sub-period analysis reveals the trilemma index was only significant during the Kyoto-Paris era (1998–2015), indicating the critical role of international pressure in driving energy transitions.

Effect of Financial Sector Development on Renewable Energy Consumption

Financial sector development shows no significant aggregate effect on renewable energy consumption (coefficient = -0.023, p = 0.508), rejecting H3. This is consistent with Lei et al. (2022) in China who also found no significant relationship. This may reflect the tendency of financial sectors to fund established conventional projects with lower perceived risk compared to newer renewable energy projects (Horky and Fidrmuc, 2024; Nguyen, 2024). However, group analysis reveals a positive significant effect in the drastic decline group (developing countries), suggesting that where access to finance is limited, financial sector development can play a positive role in funding renewable energy projects. This finding underscores the contextual nature of the financial sector-renewable energy nexus (Amin et al., 2022).

Effect of Urbanization on Renewable Energy Consumption

Urbanization has a significant negative effect on renewable energy consumption (coefficient = -0.714, p = 0.021), rejecting H4. This finding aligns with Yin and Qamruzzaman (2024) in BIMSTEC countries and Salim and Shafiei (2014) in OECD countries. Within the Ecological Modernization Theory framework, early-stage urbanization tends to increase energy consumption and emissions due to concentrated economic activities, transportation, and infrastructure construction that generally rely on cheaper and more accessible fossil fuels. The drastic decline group shows the strongest negative urbanization effect (-1.998***), particularly in developing economies where rapid urbanization coincides with fossil fuel-intensive industrialization. The stable increase group shows a positive albeit insignificant coefficient, suggesting that at more advanced stages, policy interventions can redirect urban energy demand toward renewables.

CONCLUSION

This study analyzed the effects of economic growth, the energy trilemma index, financial sector development, and urbanization on renewable energy consumption in G20 countries during 2000–2021 using Fixed Effect Model estimation. Economic growth exerts a significant positive effect, confirming the EKC hypothesis and indicating that higher levels of development facilitate renewable energy transitions. The energy trilemma index also has a significant positive effect, affirming that the balance between energy security, energy equity, and environmental sustainability is essential for advancing renewable energy adoption; notably, the trilemma's influence was strongest during the Kyoto–Paris era (1998–2015), highlighting the importance of international climate commitments. Financial sector development shows no significant aggregate effect, though it is positively significant in developing countries with low initial access to finance, revealing a context-dependent relationship that is shaped by the structure of the financial system and investment policy orientation. Urbanization has a significant negative effect, particularly in developing country groups, reflecting that urban economic concentration continues to favor fossil fuel use — an effect that may reverse at advanced stages of urbanization with appropriate policy support. The high degree of structural heterogeneity across country groups underscores that a one-size-fits-all energy policy is insufficient; differentiated strategies are therefore necessary. Developing countries need integrated urbanization-energy planning and green financial instruments such as microfinance for small-scale renewables, while developed economies face the challenge of overcoming fossil fuel infrastructure lock-in through just transition policies. Future research should incorporate additional variables such as institutional quality, energy prices, and technological advancement, apply dynamic panel models such as the Generalized Method of Moments (GMM) to address endogeneity, and extend the analysis to the post-pandemic period to capture evolving energy dynamics.

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