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Exploring the Impact of Green Energy and Economic Growth on Environmental Quality in Asia: A Panel ARDL Approach

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This paper examines the impact of green energy and economic growth on environmental quality in 16 Asian countries using a panel autoregressive distributed lag model for the period 2000–2020. The findings indicate that green energy consumption positively affects environmental quality, whereas economic growth has a negative effect. Therefore, policies aimed at increasing renewable energy production and consumption should be implemented to improve environmental quality.

I. Introduction

In recent years, environmental quality has become an important issue for policymakers, environmentalists, and academics worldwide. Developing countries, including those in Asia, have focused on rapid economic growth without adequate concern for environmental quality (Ye et al., 2022). Studies have found that Asia-Pacific countries alone produce approximately 60% of greenhouse gas (GHG) emissions as a result of rapid industrialisation and urbanisation (Mahmood et al., 2020; Mohsin & Jamaani, 2023, ESCAP, n.d.). Consequently, climate change, global warming, and greenhouse gas emissions are major concerns for many countries, particularly in Asia. CO_2 Emissions is a key indicator of environmental quality and account for a greater share of total greenhouse gas emissions than other types of emissions (Hao et al., 2021; Tabash et al., 2025).

Energy use is one of the important factors influencing environmental quality (Hanafy et al., 2025). An increase in non-renewable energy use ($NREU$) drives CO_2 emissions and damages the environment, and vice versa (Chien et al., 2022). Moreover, higher $NREU$ adversely affects economic growth. In contrast, renewable energy sources, including solar and wind energy, are considered green energy sources that reduce CO_2 emissions (Bhat et al., 2022; Kahia et al., 2021; Kalyani et al., 2015; Perone, 2024). Modern industries have the potential to reduce CO_2 emissions by increasing their use of renewable energy and improving the ICT-sector trade balance (Murshed, 2020).

Economic growth is another factor that determines environmental quality. To achieve rapid economic growth, many countries have significantly increased their use of non-renewable energy and fossil fuels, thereby worsening environmental quality (Xuan, 2025). However, energy use plays a vital role in sustaining economic growth (EG) and environmental quality (Nasser et al., 2025). Although numerous studies have examined the effects of non-renewable energy consumption on environmental quality and economic growth, few have investigated the effects of renewable energy consumption (REC) and economic growth on environmental quality. A particular gap remains in the literature on Asian countries. Therefore, this paper contributes to the literature by empirically examining the effects of green energy and EG on environmental quality in Asian countries. It also makes a methodological contribution, as no identified study has examined the effects of REC and per capita GDP ($PCGDP$) on environmental quality in Asian countries using a PARDL model. Therefore, the objective of this paper is to empirically examine the effects of green energy and economic growth on environmental quality in Asian countries.

The remainder of the paper is organised as follows. Section II describes the study variables, data sources, and methods used to address the research objective. Section III discusses results and Section IV presents the conclusion.

II. Data and Methodology

To address the study objective, we use time-series data for 16 of the 48 Asian countries because complete data were available and to ensure robust results. The selected countries are: Armenia, Azerbaijan, China, Cyprus, India, Indonesia, Japan, Kazakhstan, Kyrgyz Republic, Malaysia, Mongolia, Pakistan, Philippines, Singapore, Sri Lanka, and

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Thailand. We use CO_2 emissions as the dependent variable, whereas $PCGDP$ and REC are used as independent variables. Labor force participation (LF), gross capital formation (GCF), and the ICT balance of trade ($ICTBOT$) are included as control variables. The proxy variable CO_2 emissions is used for environmental quality, GCF for industrialisation, and $PCGDP$ for economic growth. All study variables were obtained from the World Bank's World Development Indicators for the period 2000–2020.

A balanced panel autoregressive distributed lag (PARDL) model is used to address the study objective. Before estimating the PARDL model, cross-sectional dependence was tested to determine its suitability (Barbieri, 2009). Accordingly, cross-sectional dependence was estimated as follows:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{p}_{ij}\right) \quad (1)$$

where T denotes the time period, N denotes the cross-sectional units (1, 2, ..., n), and $\widehat{p}_{ij}$is the pairwise correlation between the cross-sectional errors, estimated as follows:

$$\widehat{p}_{ij} = \frac{\sum_{t=1}^{T}\widehat{\mu}_{it}\widehat{\mu}_{jt}}{\left(\sum_{t=1}^{T}\widehat{\mu}_{it}^{2}\right)^{\frac{1}{2}}\left(\sum_{t=1}^{T}\widehat{\mu}_{it}^{2}\right)^{\frac{1}{2}}} \quad (2)$$

here $\widehat{\mu}_{jt}$ denotes the estimated error for time period *t* and cross-sectional unit *i*. If cross-sectional dependence is detected, the stationarity of the variables is examined using Pesaran's (2006) second-generation panel unit root test. A necessary condition for applying the PARDL model is that all study variables must be stationary at either I (0) or I (1). If any variable is stationary beyond I (1), the PARDL model cannot be used, and an alternative model must be selected. The basic specification of the PARDL model is as follows:

$$CO_2 = f(REC,\ PCGDP,\ GCF,\ LF,\ ICTBOT) \quad (3)$$

The long-run PARDL model takes the following form:

$$\begin{aligned} CO_{2it} = {} & \alpha_0 + \varphi_1 REC_{it} + \varphi_2 PCGDP_{it} \\ & + \varphi_3 GCF_{it} + \varphi_4 LF_{it} + \varphi_5 ICTGTOP_{it} \\ & + \varepsilon_{it} \end{aligned} \quad (4)$$

In Equation (4), α_0 is the intercept, φ_1,...,φ_5 are slope coefficients, i denotes the cross-sectional unit $(1, 2 \ldots n)$, t is the time period, and ε_{it} is the error term. It is assumed that in REC Asian countries, including solar and wind energy consumption, reduces CO_2 emissions; therefore, the φ_1 value is expected to be negative. Increased economic activity in Asian countries may increase energy consumption and CO_2 emissions. Therefore, φ_2 is expected to be positive. The short-run effects of the study variables on CO_2 emissions are estimated using the ECM model as follows.

$$\begin{aligned} \Delta CO_{2,it} = {} & \alpha_0 + \sum_{k=1}^{n}\beta_{1k}\Delta CO_{2,it-k} + \sum_{k=0}^{n}\beta_{2k}\Delta REC_{it-k} \\ & + \sum_{k=0}^{n}\beta_{3k}\Delta PCGDP_{it-k} + \sum_{k=0}^{n}\beta_{4k}\Delta GCF_{it-k} \\ & + \sum_{k=0}^{n}\beta_{5k}\Delta LF_{it-k} + \sum_{k=0}^{n}\beta_{6k}\Delta ICTGTOP_{it-k} \\ & + \alpha_1 CO_{2,it-1} + \alpha_2 REC_{it-1} \\ & + \alpha_3 PCGDP_{it-1} + \alpha_4 GCF_{it-1} \\ & + \alpha_5 LF_{it-1} + \alpha_6 ICTGTOP_{it-1} + \varepsilon_{it} \end{aligned} \quad (5)$$

The model's robustness is assessed using the fully modified ordinary least squares (FMOLS) technique. In addition to estimating the PARDL model, we calculate descriptive statistics and pairwise correlations to analyse the dispersion and interrelationships among the study variables. Cointegration among the variables is also examined using the Pedroni test.

III. Main Findings

Table 1 reports descriptive statistics and correlations, indicating that the mean and standard deviation of REC are higher than those of the other variables. Per capita GDP has the lowest mean value, whereas environmental quality (CO_2) has the lowest standard deviation. The skewness and kurtosis values indicate that the study variables are positively skewed, except for LF. The Jarque–Bera statistics are significant at the 1% significance level, indicating that the study variables are normally distributed. The correlation results indicate that environmental quality (CO_2) is negatively correlated with REC and economic growth ($PCGDP$but positively correlated with the control variables GCF, $ICTBOT$, and LF.

Table 2 reports the unit root and cointegration tests and indicates that economic growth ($PCGDP$) is stationary at level, whereas the other variables are non-stationary at level. However, all variables become stationary at $I(1)$, which indicates that the study variables are a mixture of $I(0)$ and $I(1)$, confirming the appropriateness of using the PARDL model to estimate the impact.

Cointegration is estimated using the Pedroni test. The null hypothesis for both cointegration tests is that the variables are not cointegrated, whereas the alternative hypothesis is that they are cointegrated. The Pedroni cointegration test provides 11 test statistics, of which the majority (six) are significant at the 1% significance level.

The cross-sectional dependence test indicates no cross-sectional dependence among the variables; therefore, the PARDL model can be used. The AIC suggests an optimal lag length of 2 for model estimation. Table 3 presents the long-run equations of the PARDL and FMOLS models and shows that the REC coefficient is negative and significant at the 1% significance level. This means that an increase in RE consumption reduces CO_2 emissions, and improves environmental quality. Similarly, the $PCGDP$ coefficient value (0.04) is positive and significant, which means that CO_2 emissions increase, or environmental quality deteriorates, as $PCGDP$ increases. Likewise, among the control variables, the coefficients of $ICTBOT$ and LF are positive and significant, indicating that CO_2 emissions increase, or environmental quality deteriorates. The GCF coefficient value indicates a negative relationship with CO_2 emissions.

The short-run equation shows that the EC coefficient (COINTEQ01) is negative and statistically significant, indicating that short-run adjustment is required to reach the long-run equilibrium. Among the study variables, REC and $PCGDP$ have short-run effects on CO_2 emissions, whereas PCGDP affects CO_2 emissions with a one-year lag.

The robustness of the model is assessed using the FMOLS technique. The results reveal that an increase in REC significantly improves the environmental quality in Asian countries.

Table 1. Descriptive statistics and correlation results

Panel A: Descriptive statistics						
	CO2	**REC**	**PCGDP**	**GCF**	**ICTBOT**	**LF**
Mean	4.35	19.20	3.81	27.49	-0.50	68.13
Std.Dev.	3.50	17.81	4.75	8.45	5.84	8.00
Skewness	0.81	0.75	0.92	0.89	1.52	-0.46
Kurtosis	2.78	2.36	9.53	3.79	6.69	2.11
Jarque-Bera	37.24	36.81	645.14	52.74	320.23	22.63
Probability	0.00	0.00	0.00	0.00	0.00	0.00
Panel B: Correlation						
$CO2$	1					
REC	-0.74	1				
$PCGDP$	-0.06	-0.06	1			
GCF	0.03	-0.08	0.32	1		
$ICTBOT$	0.19	-0.19	-0.04	-0.05	1	
LF	0.58	-0.63	0.04	0.11	0.23	1

Note: This table reports selected descriptive statistics, namely the mean, standard deviation, skewness, kurtosis, Jarque–Bera probability, and correlations among the study variables.

Table 2. Unit root and cointegration test

Panel A: Pesaran- CIPS unit root test						
	$CO2$	REC	$PCGDP$	GCF	$ICTBOT$	LF
Level (t-stat)	-1.79	-1.07	-2.38**	-1.89	-1.69	-1.7
First difference(t-test)	-3.42***	-2.60***	-3.92***	-3.34***	-3.274***	-3.17***
Panel B: Pedroni residual cointegration test						
Alternative hypothesis: common AR coefs. (inside -Dimension)						
PanelTest Statistics	Statistics	Prob.	Weight Statistics		Prob.	
v-statistic	-2.44	0.99	-2.49		0.99	
rho-statistic	2.23	0.98	2.88		0.99	
Phillips P-statistic	-3.98***	0.00	-2.24**		0.01	
ADF-statistic	-5.76***	0.00	-2.6***		0.00	
Alternative hypothesis: individual AR coefs. (inter-Dimension)						
Group statistics rho-statistic	4.31	1				
PP-statistic	-3.78***	0.00				
ADF-statistic	-4.06***	0.00				

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

IV. Conclusion

This study examines the influence of green energy and economic growth on environmental quality in 16 Asian countries using the PARDL model. The study found that an increase in green energy consumption significantly reduces CO_2 emissions, which improves environmental quality. Similarly, an increase in economic growth ($PCGDP$) leads to higher CO_2 emissions and worsens environmental quality. Our findings are consistent with those of Sikder et al. (2022) and Lojanica et al. (2025), who found that in Asian developing countries, economic growth (GDP) positively affects the CO_2 emissions. Therefore, appropriate policies should be implemented to reduce the ${CO}_{2}\ $emissions to improve environmental quality in these countries. Government policy should focus on increasing both the production and consumption of green energy by providing subsidies. Further, the policies should focus on strengthening the green energy infrastructure by increasing investment in research and development.

This study is limited to 16 of the 48 Asian countries and a 21-year period because of data unavailability. Future research could include additional Asian and non-Asian countries to enable comparative analysis.

Table 3. Panel ARDL test and FMOLS test results

Panel A: PARDL model long-run equation				
Variables	**Coefficients**	**Std. Error**	**t-Statistic**	**Prob.**
REC	-0.07***	0.01	-11.00	0.00
$PCGDP$	0.04***	0.01	4.13	0.00
GCF	-0.03***	0.00	-6.21	0.00
$ICTBOT$	0.03***	0.01	3.39	0.00
LF	0.06**	0.03	2.16	0.03
Short Run Equation				
$COINTEQ01$	-0.10**	0.05	-2.11	0.03
$D(REC)$	-0.45**	0.24	-1.86	0.05
$D(REC(-1))$	0.13	0.17	0.77	0.44
$D(PCGDP)$	0.03	0.02	1.32	0.18
$D(PCGDP(-1))$	0.01***	0.01	2.80	0.00
$D(GCF)$	0.01	0.03	0.21	0.82
$D(GCF(-1)$	0.02	0.02	0.96	0.33
$D(ICTBOT)$	0.00	0.02	-0.17	0.86
$D(ICTBOT(-1))$	0.11	0.10	1.06	0.28
$D(LF)$	0.07	0.08	0.89	0.37
$D(LF(-1))$	-0.11	0.18	-0.64	0.52
C	0.38	0.21	1.77	0.07
Panel B: Panel FMOLS				
REC	-0.08***		-4.36	0.00
$PCGDP$	-0.03		-1.77	0.08
GCF	0.00		-0.07	0.95
$ICTBOT$	0.02		1.10	0.27
LF	-0.02		-0.61	0.54

Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

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References

Barbieri, L. (2009). Panel unit root tests under cross-sectional dependence: An overview. *Journal of Statistics: Advances in Theory and Applications*, *1*(2), 117–158.

Bhat, M. Y., Sofi, A. A., & Sajith, S. (2022). Domino-effect of energy consumption and economic growth on environmental quality: role of green energy in G20 countries. *Management of Environmental Quality: An International Journal*, *33*(3), 756–775. https://doi.org/10.1108/MEQ-08-2021-0194

Chien, F., Hsu, C. C., Ozturk, I., Sharif, A., & Sadiq, M. (2022). The role of renewable energy and urbanization towards greenhouse gas emission in top Asian countries: Evidence from advance panel estimations. *Renewable Energy*, *186*, 207–216. https://doi.org/10.1016/j.renene.2021.12.118

Hanafy, M. A., Ali, R. M., Elgharbawy, A. S., Osman, A. I., Farrag, M. A., & Al-Anazi, A. H. (2025). Life Cycle Assessment of Facile Applicable Biodiesel Production. *South African Journal of Chemical Engineering*. https://doi.org/10.1016/j.sajce.2025.08.011

Hao, Y., Zhang, Z. Y., Yang, C., & Wu, H. (2021). Does structural labour change affect CO2 emissions? Theoretical and empirical evidence from China. *Technological Forecasting and Social Change*, *171*, 120936. https://doi.org/10.1016/j.techfore.2021.120936

Kahia, M., Omri, A., & Jarraya, B. (2021). Green energy, economic growth and environmental quality nexus in Saudi Arabia. *Sustainability*, *13*(3), 1264. https://doi.org/10.3390/su13031264

Kalyani, V. L., Dudy, M. K., & Pareek, S. (2015). Green energy: The need of the world. *Journal of Management Engineering and Information Technology*, *2*(5), 18–26.

Lojanica, N., Pantović, D., Dimitrijević, M., Obradović, S., & Nancu, D. (2025). The Effects of Renewable Energy, Economic Growth, and Trade on CO2 Emissions in the EU-15. *Energies*, *18*(16), 4363. https://doi.org/10.3390/en18164363

Mahmood, H., Alkhateeb, T. T. Y., & Furqan, M. (2020). Industrialization, urbanization and CO2 emissions in Saudi Arabia: Asymmetry analysis. *Energy Reports*, *6*, 1553–1560. https://doi.org/10.1016/j.egyr.2020.06.004

Mohsin, M., & Jamaani, F. (2023). Unfolding impact of natural resources, economic growth, and energy nexus on the sustainable environment: Guidelines for green finance goals in 10 Asian countries. *Resources Policy*, *86*, 104238. https://doi.org/10.1016/j.resourpol.2023.104238

Murshed, M. (2020). An empirical analysis of the non-linear impacts of ICT-trade openness on renewable energy transition, energy efficiency, clean cooking fuel access and environmental sustainability in South Asia. *Environmental Science and Pollution Research*, *27*(29), 36254–36281. https://doi.org/10.1007/s11356-020-09497-3

Nasser, B., Tawalbeh, M., Al-Othman, A., & Yusuf, M. (2025). Contributions of Green Energy Materials to Sustainable. *Renewable and Sustainable Energy Technology*, *4*(1), 1–28. https://doi.org/10.53941/rset.2025.100004

Ngoc Xuan, V. (2025). Energy factors affecting environmental pollution for sustainable development goals: The case of India. *Energy Exploration & Exploitation*, *43*(1), 410–450. https://doi.org/10.1177/01445987241282349

Perone, G. (2024). The relationship between renewable energy production and CO2 emissions in 27 OECD countries: A panel cointegration and Granger non-causality approach. *Journal of Cleaner Production*, *434*, 139655. https://doi.org/10.1016/j.jclepro.2023.139655

Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., Kwame Yeboah, F., & Dou, X. (2022). The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the panel ARDL approach. *Science of the Total Environment*, *837*, 155795. https://doi.org/10.1016/j.scitotenv.2022.155795

Tabash, M. I., Farooq, U., Hassen, M., & El Refae, G. A. (2025). Do technological innovation and financial development determine environmental quality? Empirical evidence from Arab countries. *Review of Accounting and Finance*, *24*(2), 177–192. https://doi.org/10.1108/RAF-02-2024-0050

Ye, F., He, Y., Yi, Y., Quan, Y., & Deng, Y. (2022). Promotion of environmental regulation on the decoupling of marine economic growth from marine environmental pollution based on interprovincial data in China. *Journal of Environmental Planning and Management*, *65*(8), 1456–1482. https://doi.org/10.1080/09640568.2021.1932771

(N.d.). https://www.unescap.org/kp/2024/survey2024