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RENEWABLE ENERGY, GOVERNANCE QUALITY AND ECOLOGICAL SUSTAINABILITY: EVIDENCE FROM 15 ASIAN ECONOMIES

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Abstract

Reconciling economic development with ecological limits requires understanding how energy composition and institutional quality relate to ecological sustainability (ES). This study investigates the relationships of renewable energy consumption (REC) and governance quality (GOV) with the load capacity factor (LCF) in 15 selected Asian economies from 2002 to 2022, controlling for real GDP per capita (GDP) and trade openness (TO). GOV is constructed through principal component analysis (PCA) of six Worldwide Governance Indicators. Static common correlated effects mean group (CCEMG) estimation accommodates heterogeneous country responses and unobserved common factors, while augmented mean group (AMG) estimation provides a robustness check. The results associate REC and GOV positively with LCF, whereas GDP exhibits a negative association. TO also shows a negative association, with weaker statistical support at the 10% significance level. AMG estimates support the principal coefficient directions and significance patterns. These findings highlight the relevance of renewable energy and institutional quality to ES and suggest that economic expansion should be accompanied by measures to address ecological pressures.

1. Introduction

Economic progress is difficult to sustain when it places more demands on nature than ecosystems can meet. Economic growth has also improved living conditions but has strained the natural systems that support economic activities. Global surface temperature reached approximately 1.1°C above pre-industrial levels in 2011-2020 (IPCC, 2023), while global resource extraction has tripled over the last 50 years (United Nations Environment Program [UNEP], 2024). These pressures extend beyond climate change: Richardson et al. (2023) show that six of the nine planetary boundaries they evaluated have been crossed. These findings, when combined, underscore the importance of considering

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economic development in the context of ecological capacity to support it.

The choice of environmental indicator is central to this assessment. Ecological footprints (EFs) quantify the demand for biologically productive land and water, and CO2 emissions quantify pressure on the climate. The capacity of the ecological assets to regenerate resources and sequester some wastes is known as 'Biocapacity' (BC), according to the GFN. The measures are connected by the LCF (ratio of BC to EF). When the ecological value is below 1, there is an ecological deficit; when it is over 1, there is an ecological reserve. Pata (2021) analyzes the environmental quality (EQ) of the United States and Japan, while Shang et al. (2022) analyze its determinants in the ASEAN economies using LCF. LCF is not a measure of overall environmental quality; it indicates whether human demand is being met by the ecological resources available to meet it.

This balance is especially important in Asian economies, where development requirements, rising energy demand, and institutional contexts determine ecological outcomes. REC has a positive impact on the LCF in ASEAN economies, and GDP has a negative association, according to Shang et al. (2022). Likewise, Latif and Faridi (2023) analyses 48 Asian economies and conclude that the ecological costs of GDP are widespread, whilst GOV quality is important. These results indicate a correlation between income and ecological balance, but not a direct one. Reducing fossil-fuel dependency and the subsequent need for carbon absorption can alleviate these pressures through renewable energy, but the impact varies by country (Safdar et al., 2022). For instance, Pata (2021) found a positive relationship between renewable energy and LCF in the United States and a positive but not statistically significant one in Japan. Another possible explanation for the differences is governance, which could affect policy implementation and resource allocation through effective public administration, credible regulation, control of corruption, and the rule of law. Adams and Acheampong (2019) link renewable energy and political institutions to environmental quality, and Duran and Saqib (2024) highlight the role of environmental policy conditions and green technological development in the G20 economies. Teng et al. (2026) have more recently addressed governance as a moderating variable in the environmental innovation–sustainability nexus in the ASEAN-6 region. Income and trade openness also remain important as they can affect the intensity, structure, and quantity of production. Antweiler et al. (2001) outline these conflicting effects in terms of scale, composition, and technique, and demonstrate that the ecological impact of international integration is not predictable a priori (Safdar et al., 2024). All this evidence reinforces the need to explore REC and GOV together, while taking into account country-specific variations.

The analysis takes into account the results of previous studies but leaves an open question. The authors of the following papers address renewable energy, financial development and institutional quality, and green ICT innovation and environmental policy conditions, respectively. Renewable energy is discussed in Shang et al. (2022), financial development and institutional quality are addressed in Latif and Faridi (2023), and green ICT innovation and environmental policy conditions are addressed in Duran and Saqib (2024). For the current sample, further analyses are needed to determine whether the relationship between renewable energy use and LCF is independent of income and other common influences, and to examine the relationship between governance and LCF. This is because the study seeks to examine these linkages comprehensively across 15 Asian economies.

Using annual data for 2002 to 2022, the study aims to answer three questions. Is a higher REC share associated with higher? Does GOV retain a positive association with LCF after controlling for

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GDP and TO? Do the main findings remain consistent across estimators that evaluate heterogeneous country responses? GOV index constructed through PCA of six World Governance Indicators. In the case of Static CCEMG, the main estimates are obtained via group estimation, while the robustness of these estimates is assessed using AMG estimation. This model takes into account the distinct relationships between REC and GOV and LCF.

What makes it interesting is the use of an indicator of ecological demand relative to BC, together with a broad governance index and methods flexible enough to account for cross-country differences and unobserved common factors. This enables one to measure energy composition and institutional quality in the same sample, while accounting for GDP and TO. The results indicate a positive association between REC and GOV with LCF, while GDP and TO show a negative association with LCF. The outcomes of the current study contribute to considerate the energy and institutional dimensions that often arise as an economy grows and advances towards ES.

The rest of this paper is organized as follows. A literature review on the study is presented in Section 2. In Section 3, the data and the construction of the governance index are briefly described, along with the empirical strategy used. The findings are reported in Section 4, discussed in the same section and limitations and implications are summarized in Section 5.

2. Literature Review

2.1. REC and ES

The rise in interest in the link between REC and ES has come with the transition from emission-related indicators to ecological demand and supply indicators. This interest in the link between REC and ES has been fueled by the transition to ecological demand and supply indicators. In this literature, the conceptualization of LCF involves a relation between BC and EF, and acts as an indicator of ecological balance. Pata (2021) used the ARDL model, an augmented autoregressive distributed lag model, to analyze the relationship between REC and LCF in Japan and the United States for the period 1982-2016. The results suggest that the association of REC with LCF is positive in the United States but not in Japan. The threat to environmental degradation from economic growth exists for both countries. The conflicting results reveal that the benefits of REC do not necessarily increase linearly and that they differ across countries.

The overall relationship between REC and LCF is considered good. In this paper, Shang et al. (2022) analyzed the ASEAN economies from 1980 to 2018 using sophisticated panel techniques that allow for cross-sectional dependence, structural breaks, and slope heterogeneity. Their outcomes suggest that they think there is a link between using REC and improving LCF, and that economic growth is associated with falling ES. Likewise, Zafar, et al, (2026) and Pata et al. (2023) found that REC enhances LCF in both the short and long run for economies in Latin America and the Caribbean using a pooled mean group ARDL method for the period of 1990–2018. In general, these studies reinforce the ecological relevance of cleaner energy use. Still, variations in the samples used, in the specifications, and in the adjustment structures make it difficult to draw direct conclusions about the magnitudes of the estimated results.

The evidence does, however, show that there is a difference between increasing the REC and achieving a better ecological balance. Renewable indicators vary in the extent of their coverage of renewable technologies and in how they are calculated (as a share or an absolute volume). Furthermore, a positive correlation in REC does not automatically imply identification of the fuel being replaced or the ecological aspect that is improving. The contrast between important ASEAN achievements and the Japanese estimate's lack of importance, then, is a call for

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country-specific analysis rather than blanket acceptance of the benefits of REC.

2.2. GOV and ES

GOV provides an institutional account of variations in environmental outcomes. The effectiveness of the public sector, the credibility of regulations, the fight against corruption, and the enforcement of legal measures can affect the implementation of environmental objectives. Latif and Faridi (2023) examined financial development and LCF for 48 Asian economies from 1996 to 2020 using the system GMM estimator. In their results, they found a positive relationship between institutional quality and LCF, while financial development still creates ecological pressures in their framework. The separation implies that better institutional arrangements can go hand in hand with better ecological outcomes, but not without environmental costs of economic activity (Safdar et al., 2026).

Other studies analyzed institutions in other environmental indicators and policy pathways. Duran and Saqib (2024) and Zafar, et al. (2025) examined G20 economies from 1993 to 2021 and identified environmental policy conditions and green innovation in ICT as influencing factors in LCF. This study by Teng et al. (2026) investigated governance as a moderator of environmental technological innovation in the ASEAN-6 economies from 2002 to 2022, using carbon emissions and ecological footprint as outcomes. According to their CS-ARDL results, the favorable environmental association of innovation is strengthened by governance, and the robustness checks AMG and CCEMG reinforce this finding. These studies illustrate the relevance of institutions, but they use different policy proxies, explanatory mechanisms, and environmental outcomes than a general specification of GOV–LCF would.

Not all institutional findings are uniformly good, importantly. Dam et al. (2024) estimate carbon emissions, the ecological footprint, and the inverted LCF across OECD economies and find a negative long-run link between institutional quality and environmental degradation. Recently, Abrol and Gupta (2026) studied the institutional-quality coefficient and the green-energy–governance interaction for 25 emerging and developing economies for 2000-2021 and find a negative institutional-quality coefficient and positive green-energy–governance interaction. They conclude that the direct coefficient for the institution differs from its conditional function in an interaction model. Thus, the GOV coefficients should not be interpreted as evidence of environmental enforcement but rather as contingent on the indicator's construction and model specification.

2.3 GDP, TO and ES

GDP and TO introduce competing mechanisms into the relationship with ES. Economic growth may increase energy and material consumption, while improvements in production processes can reduce environmental pressure per unit of output. Negative income correlations are often cited in the empirical LCF literature. According to Pata (2021), environmental deterioration is related to growth in the United States and Japan; meanwhile, Shang et al. (2022) revealed that ASEAN economies have a negative GDP–LCF relationship. Similarly, in Latin American and Caribbean economies, Pata et al. (2023) and Muhammad, et al. (2025), showed an adverse long-run income association. The results are far from conclusive evidence that income has the same ecological effects across all phases of development or that a linear specification of income identifies an environmental turning point.

There is less consistent evidence related to trade openness. Antweiler et al. (2001) and Ullah, et al. (2023), identified scale, composition, and technique effects and explored how international integration can affect environmental outcomes through production volume, specialization, and production methods. In LCF research, Pata et al.

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(2023) conclude that, in the long run, increasing TO has positive effects on ES. Abrol and Gupta (2026), on the other hand, found that TO–LCF is negatively associated in emerging and developing economies. The differences imply that trade exposure is not a sufficient driver of ecological outcome, as it is linked with the economic and institutional context. GDP and TO are important controls when considering relationships between REC and GOV with LCF.

3. Methodology

The study uses a balanced annual panel of 15 selected Asian economies over the period 2002–2022 with 315 observations. Figure 3 shows the countries sampled. LCF data are obtained from the Global Footprint Network (GFN), while REC, GDP, and TO are from WDI. GOV is constructed via principal components analysis (PCA) of six Worldwide Governance Indicators (WGI), as detailed in Section 3.2. All variables are entered in natural logarithms except the standardized GOV index, which is retained in levels. Table 1 displays the variable measurements and data sources.

Table 1: Variables Description

Variable	Symbol	Measurements	Source
Ecological sustainability	lnLCF	LCF= BC/EF	GFN
Renewable energy consumption	lnREC	REC as a share of total final energy consumption (%)	WDI
Governance quality	GOV	Index	WGI
Economic development	lnGDP	Real GDP per capita, measured in constant-price US dollars	WDI
Trade openness	lnTO	Sum of exports and imports of goods and services relative to GDP (%)	WDI

3.2 Governance index construction

Governance quality is constructed using correlation-based PCA of six WGIs: GE, RQ, RL, CC, PS, and VA. PCA reduces the correlated dimensions to a parsimonious index without assigning subjective weights. Construction proceeds in three steps.

First, each indicator is standardized over the full sample of 315 countries–year observations:

$$z_{k,it} = \frac{G_{k,it} - \overline{G}_k}{s_k}, \quad k = 1, \dots, 6. \quad (1)$$

Here, G is a governance indicator, k specifies the dimension, and the mean and sample standard deviation are based on the pooled estimation sample. Standardization puts all dimensions on a like-for-like basis. The correlation matrix is then subjected to PCA, and the estimated eigenvector scoring coefficients are used to calculate PC1:

$$\begin{aligned} \mathrm{PC1}_{it} = {} & 0.4560z(\mathrm{GE}_{it}) + 0.4056z(\mathrm{RQ}_{it}) \\ & + 0.4874z(\mathrm{RL}_{it}) \\ & + 0.4527z(\mathrm{CC}_{it}) + 0.3160z(\mathrm{PS}_{it}) + \\ & 0.2919z(\mathrm{VA}_{it}). \quad (2) \end{aligned}$$

The values of these coefficients are "scoring weights," not "factor loadings." All items are scored positively, meaning that a higher score on any dimension improves the overall score. Finally, PC1 is standardized to get the governance index, which is used in regressions:

$$\mathrm{GOV}_{it} = \frac{\mathrm{PC1}_{it} - \overline{\mathrm{PC1}}}{s_{\mathrm{PC1}}}. \quad (3)$$

The result is a GOV index with a sample mean of 0 and a standard deviation of 1, where a 1-unit

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increase corresponds to a 1-SD improvement on the broad governance quality scale. The standardized levels for GOV are retained as they can be negative. All observations per country/year share the same pool-specific PCA weights, allowing for a uniform measurement across countries and time. The PCA results were compiled in Tables 2 and 3. Additional support for these results is shown in Figure 1. GOV doesn't focus specifically on environmental enforcement.

Table 2. PCA eigenvalues and explained variance

Component	Eigenvalue	Variance %	Cumulative %
PC1	**3.7902**	**63.17**	**63.17**
PC2	0.9742	16.24	79.41
PC3	0.6562	10.94	90.34
PC4	0.3528	5.88	96.22
PC5	0.1549	2.58	98.81
PC6	0.0717	1.19	100.00

Table 3. Governance scoring weights and sampling adequacy

Indicator	PC1 weight	KMO	Correlation with GOV
Government effectiveness (GE)	0.4560	0.8087	0.8878
Regulatory quality (RQ)	0.4056	0.7690	0.7897
Rule of law (RL)	0.4874	0.7003	0.9489
Control of corruption (CC)	0.4527	0.7215	0.8813
Political stability (PS)	0.3160	0.8826	0.6151
Voice and accountability (VA)	0.2919	0.5506	0.5683
Overall	-	**0.7343**	-

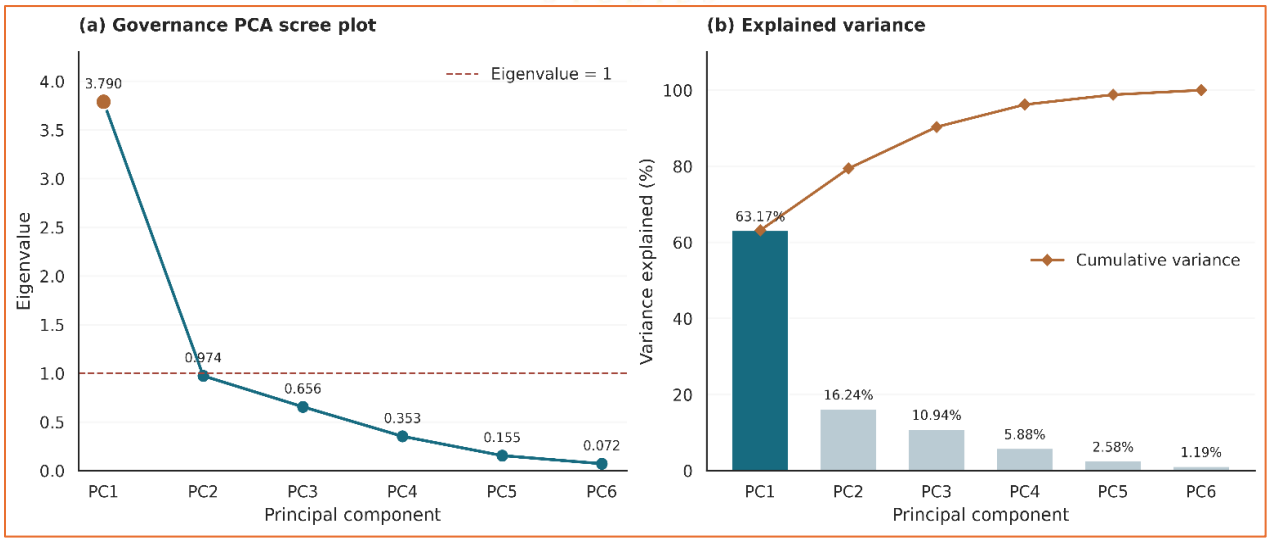


Fig 1. GOV PCA scree plot.

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3.3. Model Specification

The empirical specification relates LCF to REC and GOV, controlling for GDP and TO:

$$lnLCF_{it} = \alpha_i + \beta_{1i} lnREC_{it} + \beta_{2i} GOV_{it} + \beta_{3i} lnGDP_{it} + \beta_{4i} lnTO_{it} + \lambda_i' f_t + \varepsilon_{it}. \quad (4)$$

Here, i and t denotes country and year; α_i captures country intercepts, f_t represents unobserved common factors with country-specific loadings λ_i, and ε_{it} is the error term. Country-specific slopes allow relationships to vary across economies. Logged coefficients are elasticities, while the GOV coefficient is semi-elasticity for a one-standard-deviation increase in GOV.

3.4. Empirical Strategies

The empirical approach comprises 6 steps, as shown in **Fig. 2**. First, GOV is developed by standardization and PCA. Secondly, descriptive statistics, correlations, and VIF examine the characteristics of the sample and multicollinearity. Third, the panel diagnostics include the tests for cross-sectional dependence, slope heterogeneity, and group-wise heteroscedasticity. Fourth, the CIPS and Westerlund tests are used for stationarity and cointegration, respectively. Fifth, static CCEMG estimates the core relationships, allowing for heterogeneous slopes and unobserved common factors. Lastly, AMG assesses robustness by comparing it with the CCEMG estimates.

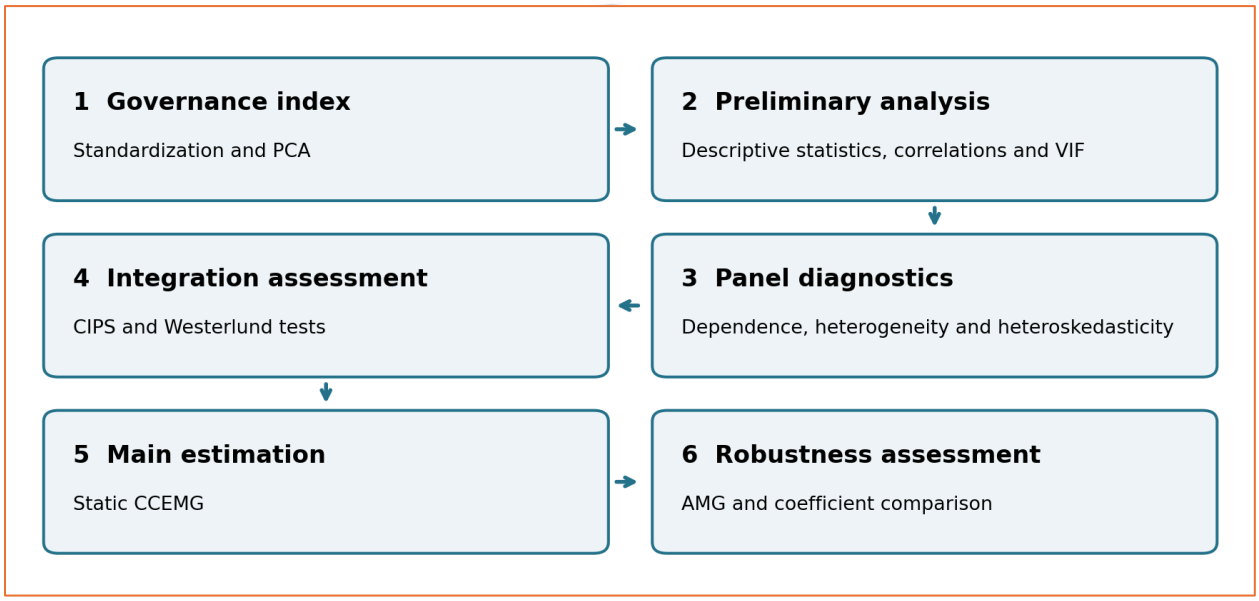


Fig 2. Sequence of empirical analysis.

4. Results and Discussions

The descriptive statistics provides essential information about the data (Gul et al., 2023; Khan et al., 2023). The descriptive statistics presented in Table 4 indicate variation in ES, REC, and economic indicators among the sampled Asian economies. The mean lnLCF is -0.5612, and the geometric mean LCF is approximately 0.57 (below the 1 ecological balance threshold). But its positive maximum value means that at some country-year observations ecological surplus can be observed. Such differences are depicted in **Fig. 3**, which shows contrasting national trajectories, with a clear long-term reduction in Mongolia and ecological deficits in many countries in the sample. GOV scores range from -2.4608 to 2.3341, reflecting differences in institutional quality.

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In light of the above, the relationships between the variables are initially assessed in Table 5 and **Fig. 4**. The correlations of lnLCF with GOV (0.2350) and lnTO (0.3983) are positive. In contrast, its correlations with lnREC and lnGDP are weakly negative (-0.0499) and (-0.1084), respectively. These unconditional relationships will give preliminary evidence but not estimates of the relationship after controlling for other factors. The highest absolute correlation among the explanatory variables is between GOV and lnGDP (0.5815), implying that good GOV is associated with higher income. All pairwise correlations of regressors are less than 0.80. Consistently, Table 6 reports VIF values ranging from 1.30 to 2.54, with an average of 1.91, signifying that multicollinearity is unlikely to be severe in the pooled regressor set. Taken together, these initial results inspire the following analysis of conditional relationships that accounts for cross-country dependence and heterogeneity.

Table 4. Descriptive statistics

Variable	N	Mean	SD	Minimum	Maximum
lnLCF	315	-0.5612	0.5665	-1.5063	1.5140
lnREC	315	3.1339	1.2362	-0.2231	4.5218
GOV	315	0.0000	1.0000	-2.4608	2.3341
lnGDP	315	7.7867	0.7104	6.3216	9.3784
lnTO	315	4.2193	0.5591	3.1411	5.3489

Table 5. Pairwise correlations

Variable	lnLCF	lnREC	GOV	lnGDP	lnTO
lnLCF	1.0000	-	-	-	-
lnREC	-0.0499	1.0000	-	-	-
GOV	0.2350	-0.0017	1.0000	-	-
lnGDP	-0.1084	-0.5181	0.5815	1.0000	-
lnTO	0.3983	-0.2181	0.4272	0.3783	1.0000

Table 6. VIF test

Variable	VIF	1/VIF
lnREC	1.73	0.579110
GOV	2.06	0.484585
lnGDP	2.54	0.394094
lnTO	1.30	0.769481
Mean VIF	**1.91**	-

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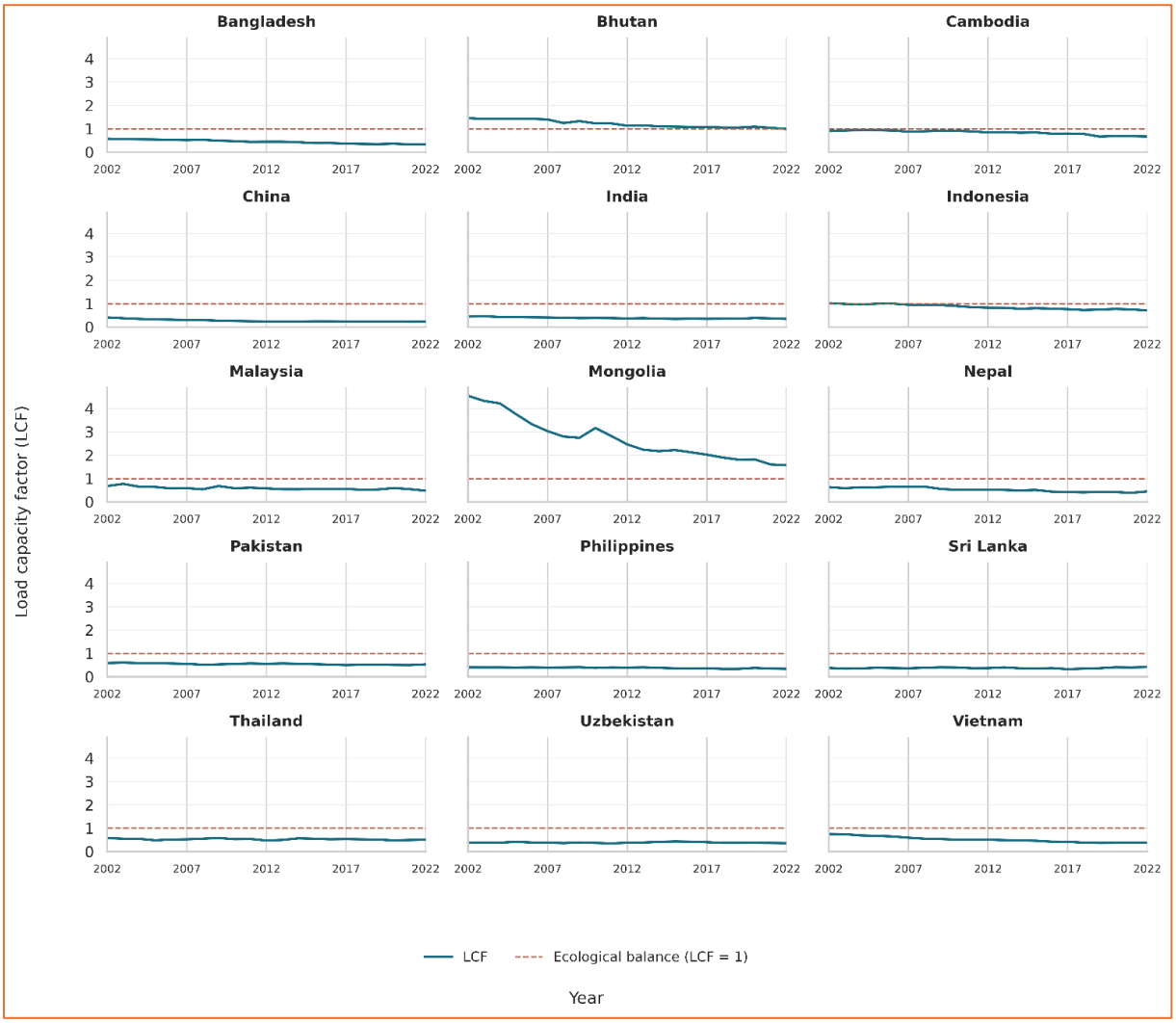


Fig 3. Country-specific LCF trajectories from 2002 to 2022

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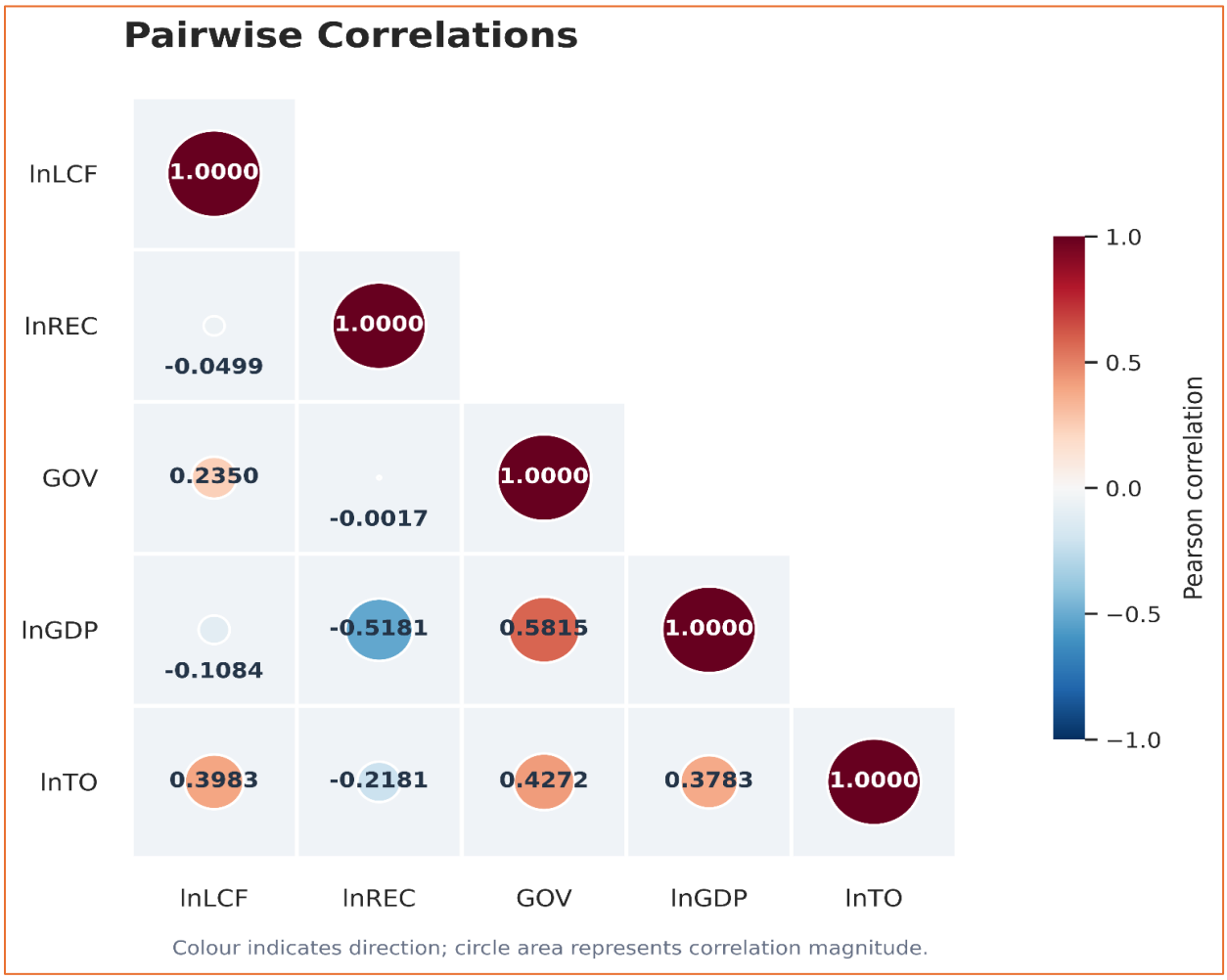


Fig 4. Pairwise correlations

Table 7 reports the significant CD statistics for all variables ($p < 0.000$), which indicate that CD are interdependent across countries and therefore justify the use of estimation techniques that allow for unobserved common factors. The homogeneity of the slopes statistics indicates that the null hypothesis of homogeneous coefficients is rejected (Table 8), as does the modified Wald test of equal error variances across countries. These results confirm the benefits of using heterogeneous estimators such as CCEMG and AMG. Table 9 presents the second-generation CIPS results, given evidence of CSD. All the series tested show no sign of rejecting the unit-root null in levels but reject it at the 1% level for all first differences, indicating that the series are integrated of order one. The Westerlund tests then provide an answer to the question of whether the variables have an equilibrium relationship or not (Table 10). G_t and P_t reject the null of no cointegration at the 1% ($p = 0.003$) and 5% ($p = 0.017$) significance levels, respectively, whereas G_a and P_a do not reject the null of no cointegration. The results support the cointegration hypothesis to some degree but do not show consistent evidence across statistics.

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The following CCEMG and AMG estimates are thus treated as conditional associations in levels, and the long-run interpretation should be considered with caution until the specification of cointegration and dependence-robust inference is confirmed.

Table 7. Cross-sectional dependence tests

Variable	CD statistic	p value	Decision at 5%
lnLCF	26.02	0.000	Reject H0
lnREC	16.04	0.000	Reject H0
GOV	14.14	0.000	Reject H0
lnGDP	46.05	0.000	Reject H0
lnTO	10.12	0.000	Reject H0

Notes: H_0 is cross-sectional independence. Values displayed as 0.000 in the source are reported as p 0.000.

Table 8. Slope heterogeneity and GroupWise heteroscedasticity

Test	Statistic	p value	Null decision
Δ	11.237	0.000	Reject
Adjusted Δ	13.296	0.000	Reject
Modified Wald	$\chi^2(15) = 2419.21$	0.000	Reject

Table 9. CIPS panel unit root tests

Variable	Level constant and trend	First difference constant
lnLCF	-2.240	-4.301***
lnREC	-2.124	-3.883***
GOV	-2.483	-3.999***
lnGDP	-1.477	-2.795***
lnTO	-2.172	-3.790***

Notes: *** denotes significance at 1%, as reported in the source.

Table 10. Westerlund cointegration test

Statistic	Value	p-value	Decision
G_t	-1.753	0.003***	Reject H_0
G_a	-5.317	0.994	Do not reject H_0
P_t	-3.911	0.017**	Reject H_0
P_a	-5.398	0.862	Do not reject H_0

Table 11 shows the results of the main static CCEMG estimates: positive relationships are found between lnREC and GOV with lnLCF, while negative relationships are found between lnGDP, lnTO, and lnLCF. The coefficient of renewable energy consumption is positive (0.4492, p=0.000), meaning that for a 1% increase in lnREC in total final energy consumption, the LCF would increase by about 0.449%, with other variables held constant. The results are similar to those reported by Pata et al. (2023) and Karimi Alavijeh et al. (2024) for the Latin American and Caribbean economies and BRI countries, respectively. One possible reason is that a cleaner energy mix would reduce reliance on fossil fuels and the ecological need for carbon

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absorption. Furthermore, there is a positive relationship between GOV and the dependent variable at the 1% level (0.3456, p = 0.006). CF is transformed by a log function, with a mean coefficient estimated at 0.3456 and a standard deviation of 1.0 for every 1.0-unit increase in GOV. The finding is consistent with the findings of Latif and Faridi (2023), based on an Asian sample, who found that LCF is positively related to GOV. Although not directly tested in the present model, stronger institutions can support the implementation of environmental policies, reduce regulatory evasion, and enhance resource allocation.

Additionally, lnGDP has a negative coefficient of -0.4389 (p = 0.012), indicating that for every 1% rise in income, LCF is likely to decrease by 0.439%. The observed pattern is similar to the increase in ecological demand outpacing the increase in ecological supply or efficiency due to economic growth, which aligns with the negative income relationships reported by Pata et al. (2023) and Latif and Faridi (2023). For the coefficient of TO, the sign is negative (p = 0.081), and the estimated coefficient is -0.0778, indicating that openness reduces LCF by around 0.078% per unit increase in lnTO. It is not significant at the 5% level, but is significant at the 10% level, suggesting that the evidence of its significance is weaker than for the other explanatory variables. Greater trade exposure could be linked to resource-intensive production and consumption, but this is not distinguished in the model. The finding is at odds with the positive association with TO reported by Pata et al. (2023). It seems to reflect the different ways in which openness interacts with the production structure, energy composition, and institutional conditions. The residual CD is -1.77 (p = 0.0761), indicating that cross-sectional independence is not rejected at 5% but may be rejected at 10%. In general, the estimates link cleaner energy use and better governance to a more positive ecological balance, and point to the environmental risks of rising incomes and (albeit less conclusively) of lnTO. Finally, AMG robustness estimates reported in Table 12 corroborate the main findings of the CCEMG. The association of lnREC and GOV with lnLCF, there remains a positive and significant association, whereas lnGDP remains negatively and significantly associated. Finally, lnTO is still negatively associated with lnLCF, though this is not quite significant at the 10% level. The magnitudes of the coefficients vary, but the directions and patterns of significance are robust to alternative treatments of common shocks and country-specific heterogeneity, supporting the robustness of the principal findings. Fig.5 compares the coefficient estimates across both estimators.

Table 11. Static CCEMG estimates

Variable	Coefficient	Standard error	p value
GOV	0.3456***	0.1258	0.006
lnGDP	-0.4389**	0.1753	0.012
lnREC	0.4492***	0.1119	0.000
lnTO	-0.0778*	0.0446	0.081
Observations	315	-	-
Countries	15	-	-
Residual CD	-1.77	-	0.0761
Residual df per country	11	-	-
Root MSE	0.04	-	-

Notes: ***, ** and * denote 1%, 5% and 10% significance.

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Table 12. AMG robustness estimates in levels

Variable	Coefficient	Standard error	p value
GOV	0.5465***	0.1586	0.000
lnGDP	-0.4593***	0.1051	0.000
lnREC	0.3577***	0.0974	0.000
lnTO	-0.0855*	0.0488	0.080
Common dynamic process	0.6238	0.3958	0.115
Constant	2.2107	1.3862	0.111
Observations	315	–	–
Countries	15	–	–
Wald $\chi^2(4)$	93.47	–	0.000
Root MSE	0.0341	–	–

Notes: ***, ** and * denote 1%, 5% and 10% significance.

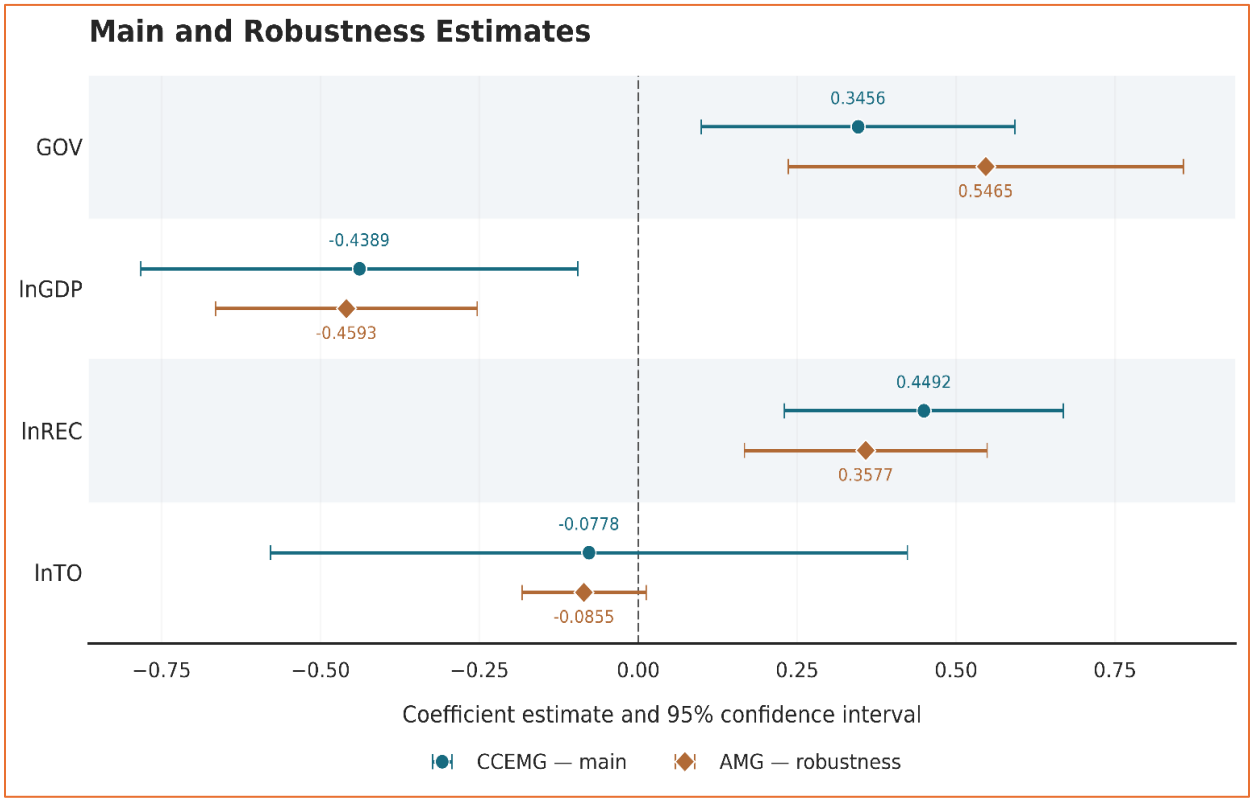


Fig 5. Comparison of CCEMG and AMG coefficient estimates.

5. Conclusion and Policy Recommendations

This study examined the associations of REC and GOV with ES, measured by LCF, in 15 selected Asian economies during 2002–2022, controlling for GDP and TO. Static CCEMG estimation accommodated heterogeneous country responses and unobserved common factors, while AMG estimation assessed robustness. The CCEMG findings reveal positive and statistically significant associations of REC and GOV with LCF. Specifically, a 1% relative increase in REC is associated with approximately 0.449% higher

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LCF, while a one-standard-deviation increase in GOV is associated with 0.3456 log points higher LCF. These findings suggest that a greater renewable share in the energy mix and stronger institutional quality accompany a more favorable ecological balance. In contrast, a 1% increase in GDP is associated with approximately 0.439% lower LCF, indicating that higher income does not necessarily coincide with improved ES in the sampled economies. TO also exhibits a negative association with LCF, although significance only at the 10% level warrants a more cautious interpretation. AMG estimates preserve the principal coefficient directions and significance patterns, supporting the consistency of the findings across alternative treatments of common influences and country heterogeneity. Taken together, the results highlight the importance of considering energy composition and institutional conditions alongside economic expansion. Two policy priorities follow. First, governments should support sustainably sourced renewable energy through reliable grid infrastructure, transparent investment incentives and measures that facilitate fossil-fuel displacement. Such efforts should consider land use, biodiversity and resource requirements alongside emissions, because renewable energy expansion alone does not ensure improvement across every ecological dimension. Second, governments should strengthen institutional implementation capacity through transparent regulation, accountable public investment and consistent environmental enforcement. Incorporating ecological assessments into development planning and trade decisions could help address the pressures associated with expanding production and consumption. These priorities reflect the observed relationships; the model does not establish the causal effects of specific policies or directly identify the mechanisms linking REC and GOV to LCF. The selected sample, aggregate REC indicator and broad GOV index also limit generalization and conceal differences across renewable technologies and institutional dimensions. Moreover, mixed cointegration evidence calls for caution in interpreting the estimates as established long-run relationships. Future research could examine technology-specific renewable energy sources, individual governance dimensions and country-level institutional mechanisms, while using research designs that more directly address endogeneity and causal identification.

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