



THE NEXUS BETWEEN TOURISM, ENERGY CONSUMPTION AND SDG 7: A PANEL DATA ANALYSIS OF APEC ECONOMIES.

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Abstract:

This study explores the nexus between tourism development, renewable energy consumption, environmental performance, and Sustainable Development Goal 7 (SDG 7) for 20 Asia Pacific Economic Cooperation (APEC) economies from 2015 to 2024. It uses a balanced panel data set using multiple econometric tests such as cross-sectional dependence, slope heterogeneity, unit root and panel cointegration followed by FMOLS, DOLS and PMG-ARDL model estimations. The results indicate a long-run equilibrium relation among these variables. It further reveals that GDP from tourism and foreign tourist arrivals negatively affect the performance of SDG 7 whereas tourism employment and population growth positively affect the development of sustainable energy under SDG 7. The report points to the importance of boosting sustainable tourism, expanding the use of renewable energy and improving environmental governance to enable sustainable development and clean energy transition.

Keywords:

APEC Economies, Environmental Performance; Renewable Energy Consumption; SDG7; Tourism Development.

Introduction

Tourism has improved the quality of life by creating jobs and income, increasing travel and enhancing hospitality, with international tourist numbers growing significantly in the last four decades (Uysal et al. 2012; United Nations Environment Program, 2011). The Asia-Pacific Economic Cooperation's member nations accounted for more than 30% of all foreign tourist arrivals as of 2023, highlighting their importance as important travel hubs (Thongma & Chang, 2025). APEC's tourism industry grew significantly between 1995 and 2020 in a number of metrics, including GDP (140%), visitor arrivals (136%), visitor spending (116%), private investment (220%), and public spending (446%). This contributed to 9.4% of the region's total employment (WTTC 2023). At the same time, the tourism industry, which has its roots in both economic growth and cultural interaction, frequently has the paradoxical effect of putting tremendous strain on local populations and delicate ecosystems (Azam et al., 2018; Dwyer, 2022; González-Rodríguez et al., 2023).

SDG 7, a key United Nations Sustainable Development Goal, underscores the significance of universal access to affordable, reliable, sustainable and modern energy services. Delivering SDG 7 is particularly relevant in light of rapid growth in sectors such as tourism, which can have a significant impact on energy consumption patterns and the transition to renewables (Yankson, 2021). The growth of tourism has led to a high dependence on primary energy sources, in particular, on fossil fuels which makes it difficult to achieve the goals of SDG 7 on increasing the share of renewable energy and improving energy efficiency (Becken et al., 2001). The urgency to move towards sustainable tourism models that reduce dependence on fossil fuels,

increase use of renewable energy and increase environmental efficiency is aligned with SDG 7 objectives (Hall et al., 2015; Dogru et al., 2020). Progress by APEC economies on the tourism-energy nexus is essential to achieving SDG 7 regionally and globally as they are among the world's top tourism developers and energy consumers.

Numerous studies have connected the tourism industry's explosive rise to rising carbon dioxide emissions worldwide (Zhang et al., 2018; Wang et al., 2015; Yu et al., 2012). As stated by Long et al. (2019) the tourism sector uses a lot of energy and contributes significantly to greenhouse gas emissions. According to the World Tourism Organization (2014), tourism is responsible for around 4.6% of global warming and 5% of CO₂ emissions worldwide. Energy use in APEC soared 65% since 1995 to 365.6 quadrillion BTUs in 2017, or almost 60% of the world total (Energy Information Administration, 2020). Between 1995 and 2017, CO₂ emissions rose from 13.9 to 23.3 billion tones, an average annual increase of 2.4% as the APEC economy expanded (World Bank, 2020).

The nexus of tourism development, energy use, and sustainable development has increasingly become an area of much concern among scholars, in particular in the context of achieving SDG 7. Sustainable development (SD) is a kind of development characterized by its essential foundation which will lead to economic and social change of the world. The concept of sustainable development has developed from being a narrow environment-related term to a broad multidimensional concept of global development (Shi et al., 2019). Within this context, SDG7 seeks to achieve access to affordable, reliable, sustainable, and modern energy primarily (Küfeoğlu, 2022; He et al., 2022). The SDG7 can also be achieved through properly coordinating economic development, disaster management and natural resources (Ramasubramanian & Ramakrishna, 2023). The execution of Rwanda's National LPG Master Plan will have a great impact on the health of the population, the environment, and climate change by increasing the use of LPG as a cooking fuel in households, saving lives, reducing pollution, protecting forests, and contributing to the realization of SDG 7 (Čukić et al., 2021). According to Islam et al. (2026) both the costs of energy and CO₂ emissions positively influence economic growth until a threshold. Beyond the threshold, it becomes negative or diminished. Despite its high use of energy and fast growth rate, the tourism industry has been blamed for being the primary cause of climate change (Banga et al., 2022). Tourism has a direct impact on CO₂ emissions level in Northern Cyprus, as explained by Katircioglu et al. (2020). In this sense, the higher tourism is within the country, the worse its environment becomes due to the high amount of pollution. Likewise, Ali et al. (2023) assert, tourism arrival also negatively influences the environment quality due to high GHG emissions. Nonetheless, Risso (2018) analyzes the correlation between tourism and economic growth in 179 nations within the years 1995 to 2016. The results show that there is a positive impact on per capita GDP and revenue from tourism as the level of tourist arrivals increases. Additionally, Seraj et al. (2025) investigate the impact of tourism on GDP growth in leading countries of Africa through examining the determinants of its impact and the quantitative influence on the economy. The research provides guidelines to the policymakers on how to utilize tourism as an economic development tool despite the negative consequences associated with it. As pointed out by Buhalis et al. (2023), tourism plays an important role in energy consumption, especially in regions where tourism is an essential economic activity, but also helps develop infrastructures that promote better energy services. On the other hand, the industry encourages the use of accessible and sustainable energy sources.

Wani et al. (2024) investigated the tourism growth and sustainability nexus in economic, environmental, and social dimensions in the Group of Seven (G7) countries over the period 2000–2021. They use PMG-ARDL Approach, Westerlund Cointegration Test and Dumitrescu-Hurlin Causality Test. The research revealed positive effects of economic growth and CO₂ emissions on tourism. In contrast, the ecological footprint, the human development index and the unemployment have a negative impact on tourism in the long term. Gyamfi et al. (2022) study the effects of different factors (aging population-AP, income, natural resources rents, globalization and energy consumption) on CO₂ emissions in the Mediterranean region. Their findings show that the Environmental Kuznets Curve theory is confirmed as income, AP and natural resources rents

are negatively related to CO₂ emissions. The others have positive nexus with CO₂ emissions and based on the findings, a multi-dimensional process is proposed to achieve SDGs 7, 8 and 13.

Pata et al. (2025) find that renewable energy and foreign direct investment (FDI) positively affect environmental performance (EP). This shows their importance in sustainable development. In addition, according to the results obtained with the help of such statistical methods as the Pesaran CD test, CIPS test, FMOLS, and DOLS on panel dataset from 30 developing countries, Ahmed and Shimada (2019) conclude that a long-term relationship and feedback effect exist between renewable energy and economic growth in Africa and Asia. However, it's found that renewable energy has a positive and significant impact on the sustainable development, and it's true in the developing countries as well as the developed countries (Sueyoshi et al., 2021; Güney, 2019). Through the analysis by CS-ARDL, the positive relationship in short and long run is also found by Işık et al. (2025). Moreover, a positive relation is found between HDI and EP by Bucher (2017), it mentions that improvement of environmental quality and environmental health are vital to sustainable development. But Eras-Almeida and Egido-Aguilera (2020) consider it is hard to ensure energy availability at an affordable price and sustainably at remote island or rural location because of isolated environment, workforce and fossil fuel dependence.

Extending from the above theoretical discussions and previous literatures, this study posits that there exists a multi-dimensional and complex interrelationship between tourism development, environmental performance and the accomplishment of SDG 7. Hence, a set of research hypotheses are formulated and tested for the purpose of examining empirically the interplay among tourism, environmental performance, and SDG 7 in APEC countries.

In order to achieve the research aims concerning the role of tourism and environment performance in sustainable development, this paper will formulate a set of hypotheses for testing. As far as the path of SDG 7 is concerned, this hypothesis intends to examine the relationship among the scale of tourism economics, number of tourists, and financial expenditures. The following hypotheses are proposed based on the preliminary analysis of the data and complexity of the energy transition process in the APEC region:

H₁: There exists a stable, long-run equilibrium relationship between tourism indicators, environmental performance, and SDG 7 achievement.

H₂: Demographic expansion and tourism employment significantly and positively contribute to the progress of SDG 7.

H₃: The overall scale of the tourism sector (TGDP) and volume of international arrivals (INTA) exert a significant downward pressure on clean energy goals.

H₄: Renewable energy consumption (REC) and environmental performance (EPI) have a non-linear or transition-dependent impact on sustainable energy achievement.

Despite the growing body of literature on the tourism–energy–environment nexus, some relevant research gaps are still under-investigated. Most of the previous studies have primarily concentrated on the nexus between tourism growth, energy consumption, and carbon emissions, but relatively little attention has been given to examining these interactions in the broader context of Sustainable Development Goal 7 and empirical evidence from the Asia-Pacific Economic Cooperation (APEC) economies, despite the region's strategic importance in global tourism and energy markets. (Katircioglu et al., 2013; J. Zhang & Zhang, 2020; Tang & Abosedra, 2014; Khanal et al., 2021; P. Wu & Shi, 2011).

This study addresses the following questions:

1. How do tourism development indicators like tourism contribution to GDP (TGDP), international tourist arrivals (INTA) and tourism-related employment influence the achievement of SDG 7 in APEC economies?

2. What is the long-run relationship between tourism development, energy consumption, and SDG 7 achievement in APEC economies?

The main objective of this study is to explore the nexus among tourism development, energy consumption, environmental performance, and SDG 7 achievement in the APEC economies using robust panel data analysis. The study particularly aims to examine the effect of tourism-related activities on sustainable energy transition, and the role of environmental performance and renewable energy adoption in achieving the clean and affordable energy target in the region. By analyzing the relationship between these factors, policymakers can better understand how to promote sustainable tourism practices that contribute to energy efficiency and environmental sustainability. This study will provide valuable insights for designing policies and strategies that support both economic growth and environmental conservation in APEC economies.

2. Methods

The study used a quantitative research approach with panel data analysis for APEC economies to explore the relationship between tourism development, environmental performance, renewable energy consumption and SDG 7. The study uses sophisticated panel econometric methods to address short- and long-term dynamics among variables. In order to make the results robust and reliable a number of preliminary diagnostic tests are performed before the estimation of the long run models such as multicollinearity, cross sectional dependence, unit root, slope heterogeneity, and panel cointegration tests. Moreover, the study employs FMOLS, DOLS and PMG-ARDL estimation methods to examine the equilibrium relationships and the dynamic adjustments between the variables.

2.1 Data Source and Sample Selection

The study employs a balanced panel data set of 20 APEC member economies, for the period 2015 to 2024. APEC economies are selected based on their significant role in global tourism activities, economic integration, energy consumption and sustainable development measures. Such economies also show a high degree of heterogeneity in terms of the extent of tourism development, environmental policies, renewable energy uptake and demographic makeup, which make them appropriate for panel-based comparative analysis.

International and reliable databases were used to obtain secondary data in order to ensure the validity and consistency of the data. The data for SDG 7 indicators was sourced from the United Nations Sustainable Development Database and other SDG data repositories. Tourism-related variables such as tourism contribution to GDP, international tourist arrivals, and tourism employment were obtained from the World Bank and World Tourism Organization (UNWTO) databases. Data on renewable energy use and population came from the World Development Indicators (WDI). Data for Environmental Performance Index (EPI) data was acquired from the Yale Center for Environmental Law & Policy.

Purposive sampling is used in identifying the sample economies considering the availability of data and consistency across the entire study period. The data for some countries were omitted from the data set because of missing observations for important variables, in order to preserve a balanced panel structure and to enhance the security of the econometric estimations. The final data set is thus composed of 200 observations (20 countries x 10 years).

2.2 Variable Specification

This study looks at the impact of tourism development, environmental performance, the use of renewable energy and demographic factors on achieving SDG 7. The dependent variable is SDG 7 and the explanatory variables are the tourism and environmental indicators. The operational definitions and measures of the variables are provided below.

Variable	Measurement	Description	Expected Sign
SDG7	Index Score	Sustainable Development Goal 7 index representing affordable and clean energy performance	Dependent Variable
TGDP	Percentage of GDP	Tourism contribution to Gross Domestic Product	±
INTA	Number of arrivals	International tourist arrivals	±
TE	Percentage of tourism employment	Tourism employment	+
EPI	Index Score	Environmental Performance Index	+
REC	Percentage of total energy use	Renewable energy consumption	+
POP	Total population	Total population of the country	+

Source: Authors own work

Some of the variables were log transformed if they were deemed to be heteroskedastic and/or this would enhance the efficiency of the estimation. The variables are selected based on the literature review of on-going research in the field of tourism-led development, environmental sustainability and clean energy transition. Indicators of tourism have been added to reflect the economic and mobility aspects of tourism activities, and environmental and renewable energy indicators are added to reflect the performance of tourism and the transition towards clean energy. Population is taken as a control variable, considering the pressure of population on energy demand and sustainable development.

2.3 Model Equation

The long-run relationship between the SDG 7 index and its macroeconomic and tourism-related determinants is specified by the following functional equation:

$$SDG7_{it} = \beta_0 + \beta_1 TGDP_{it} + \beta_2 INTA_{it} + \beta_3 TE_{it} + \beta_4 EPI_{it} + \beta_5 REC_{it} + \beta_6 POP_{it} + \varepsilon_{it}$$

Where:

- i represents the cross-sectional units (countries) and t denotes the time period (2015–2024).
- SDG7 is the dependent variable representing the clean energy index.
- TGDP, INTA, and TE represent the tourism sector through GDP share, international arrivals, and employment, respectively.
- EPI and REC denote environmental performance and renewable energy consumption.
- POP represents the population total.
- β_0 is the constant term, while β_1 through β_6 are the coefficients to be estimated.
- ε_{it} is the stochastic error term.

Error Correction Model (ECM)

To capture the short-run dynamics and the speed at which the system returns to the long-run equilibrium following a shock, the Pooled Mean Group (PMG) based Error Correction Model is specified as follows:

$$\Delta SDG7_{it} = \phi_i (SDG7_{it-1} - \theta'_i X_{it}) + \sum_{j=1}^{p-1} \lambda_{ij} \Delta SDG7_{it-j} + \sum_{j=0}^{q-1} \delta'_{ij} \Delta X_{it-j} + \mu_i + \varepsilon_{it}$$

In this specification:

- Δ is the first-difference operator.
- ϕ_i represents the Error Correction Term (ECT) or the speed of adjustment. For a stable long-run relationship, this coefficient must be negative and statistically significant.
- θ_i denotes the long-run equilibrium coefficients.
- λ_{ij} and δ'_{ij} represent the short-run dynamic coefficients for the dependent and independent variables, respectively.
- μ_i represents the country-specific fixed effects.

2.4 Econometric Methods

The multi-step econometric framework used to examine the short- and long-term relationships between tourism, environmental performance, and SDG 7 is described in this section. The approach starts with diagnostic tests for Slope Heterogeneity and Cross-Sectional Dependency (CSD), then moves on to second-generation unit root testing to guarantee strong results throughout the multi-country panel. The Pooled Mean Group (PMG/ARDL) estimator is utilized as the main analytical tool after cointegration has been confirmed using Pedroni, Kao, and Johansen Fisher tests. FMOLS and DOLS are used for robustness verification. The figure 1 below shows the sequential econometric flow:

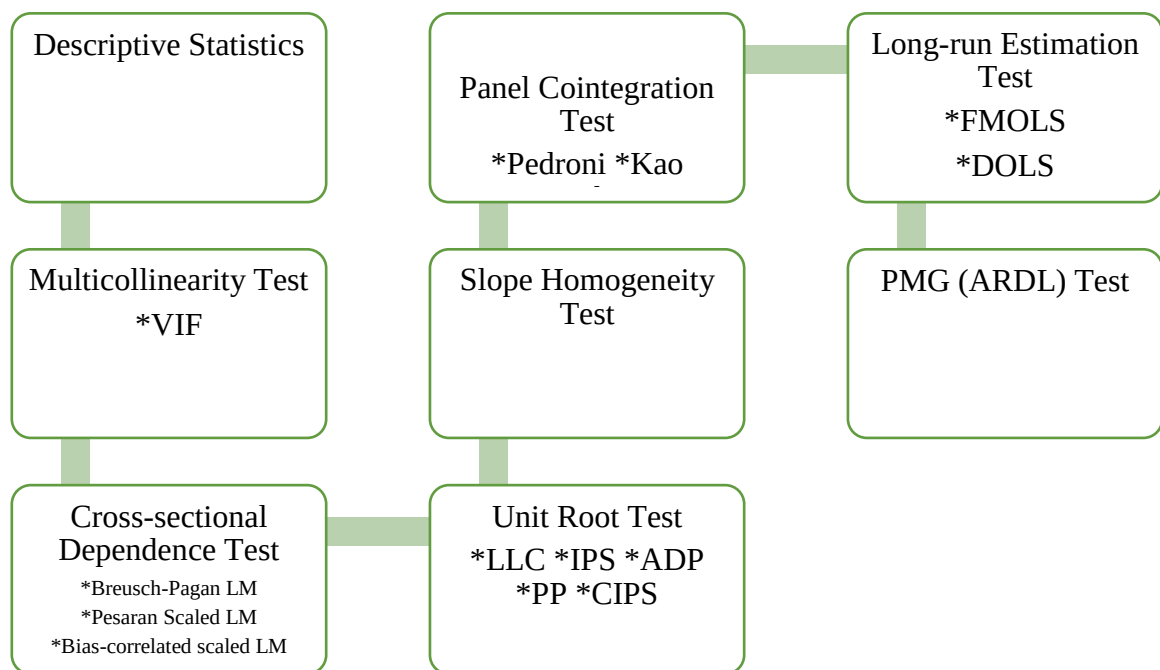


Figure 1: Econometric Model (Flow Chart)

Source: Authors own work

3. Results and Discussion

3.1 Descriptive Statistics

Table 1: Summary of Descriptive Statistics

	SDG7	TGDP	INTA	TE	EPI	REC	POP
Mean	69.47194	3.761326	16404.57	6.893910	54.19578	15.86695	1.46E+08
Median	71.00938	2.993320	9185.500	6.271500	53.90000	13.30000	46151773
Maximum	84.67700	12.85306	132000.0	19.50000	88.00000	55.30000	1.41E+09
Minimum	26.09700	0.082670	3.500000	0.600000	20.10000	0.010000	422212.0
Std. Dev.	11.35513	2.560428	20116.96	3.655165	14.68539	12.98136	3.02E+08
Skewness	-2.394411	1.062960	2.123503	0.695834	0.102159	0.958444	3.607937
Kurtosis	9.945920	3.820138	9.191589	3.064245	2.569541	3.952450	15.19739
Jarque-Bera	593.1552	43.26803	469.7736	16.17390	1.892008	38.18017	1673.709
Probability	0.000000	0.000000	0.000000	0.000308	0.388290	0.000000	0.000000
Sum	13894.39	752.2652	3280913.	1378.782	10839.16	3173.390	2.91E+10
Sum Sq. Dev.	25658.87	1304.602	8.05E+10	2658.685	42916.47	33534.63	1.82E+19
Observations	200	200	200	200	200	200	200

Source: Authors own work

Significant differences in the variables of investigation are revealed by the descriptive statistics for the 200 data from the APEC economies presented in table 1. Although the dependent variable, SDG7, has a mean value of 69.47, a non-normal distribution with negative skewness (-2.39) is indicated by a high Jarque-Bera statistic (593.15) and significant probability ($p < 0.01$). In terms of the main tourist metrics, TGDP averages 3.76%, and INTA has a high level of volatility with a standard deviation of 20,116.96, which reflects the wide range of tourism levels among the member countries.

Additionally, environmental and demographic factors show unique traits. With a mean of 54.19 and a Jarque-Bera probability of 0.388, the EPI stands out as the sole variable with a normal distribution. On the other hand, POP (Kurtosis = 15.19) and REC (0.95 and 3.60, respectively) show high leptokurtic peaks and considerable right-skewness. The adoption of robust econometric estimate techniques for the ensuing panel analysis is justified by these results, particularly the significant Jarque-Bera tests for almost all variables (except from EPI), which indicate that the data is predominantly non-normally distributed.

3.2 Multicollinearity (VIF) Test

Table 2: Summary of VIF Test

Variable	VIF	1/VIF
TGDP	1.59	0.630041
INTA	1.77	0.563879
TE	1.59	0.627157
EPI	1.27	0.788615
REC	1.18	0.847622
POP	1.72	0.580350
Mean VIF	1.52	

Source: Authors own work

A Variance Inflation Factor (VIF) test was used to determine whether multicollinearity existed among the independent variables in order to address potential problems with variable redundancy presented in table 2. All individual VIF values are substantially below the conservative criterion of 5.0 (or the more lenient threshold of 10.0), according to the empirical results shown in the table. In particular, the VIF values for INTA range from a maximum of 1.77 to a minimum of 1.18 for REC. Additionally, the model's mean VIF is 1.52, and all predictors' tolerance levels (1/VIF) are still much higher than 0.10. Together, these results

support the lack of severe multicollinearity, indicating that the chosen explanatory variables are independent and appropriate for producing accurate coefficient estimates in the regression analysis.

3.3 Cross-sectional Dependence Test

Table 3: Summary of Cross-sectional Dependence Test

Variables	Breusch-Pagan LM	Pesaran Scaled LM	Bias-correlated scaled LM	Pesaran CD
SDG7	837.8323***	33.23309***	32.12198***	19.94817***
TGDP	1011.478***	42.14093***	41.02982***	29.07366***
INTA	1151.711***	49.33472***	48.22361***	31.13180***
TE	538.2981***	17.86732***	16.75621***	17.05093***
EPI	1407.330***	62.44771***	61.33660***	37.08553***
REC	794.4442***	31.00733***	29.89622***	4.128375***
POP	1464.658***	65.38858***	64.27747***	25.77760***

Note: ***, **, and * indicate 99%, 95%, and 90% significance levels, respectively.

Source: Authors own work

A number of Cross-Sectional Dependence (CD) tests, such as the Breusch-Pagan LM, Pesaran Scaled LM, Bias-correlated scaled LM, and Pesaran CD tests, were carried out to take into consideration possible interdependencies among the APEC economies presented in table 3. The null hypothesis of cross-sectional independence is unequivocally rejected by the empirical findings for all variables, including SDG7, TGDP, INTA, TE, EPI, REC, and POP. There is substantial evidence of cross-sectional dependency within the panel, as shown by the test statistics, all of which are significant at the 1% level ($p < 0.01$). This suggests that shocks that happen in one APEC member nation are likely to spread to others, perhaps as a result of similar environmental policy and regional economic integration. In order to guarantee the validity and consistency of the ensuing empirical estimations, these findings require the application of second-generation econometric approaches, such as the Cross-sectionally Augmented Dickey-Fuller (CADF) or CIPS unit root tests.

3.4 Unit Root Test

Table 4: Summary of Panel Unit Root Test

Series: D(SDG7)				
Sample: 2015 2024				
Exogenous variables: Individual effects				
User-specified lags: 1				
Newey-West automatic bandwidth selection and Bartlett kernel				
Balanced observations for each test				
Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-6.59203	0.0000	20	140
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-2.16097	0.0153	20	140
ADF - Fisher Chi-square	67.6112	0.0041	20	140
PP - Fisher Chi-square	145.404	0.0000	20	160
** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.				

Source: Authors own work

Table 4 shows a series of first-generation panel unit root tests, including the Levin, Lin & Chu (LLC), Im, Pesaran and Shin (IPS), ADF-Fisher, and PP-Fisher tests, were used to ascertain the variables' integration order. These first-generation results offer a preliminary hint of stationarity given the existence of cross-sectional dependence previously observed, which is further reinforced by the consistency across both common and individual unit root process assumptions. The table displays the empirical findings for the

dependent variable, SDG7, at its first difference $I(1)$. In all four specifications, the unit root null hypothesis is rejected at a significance level of at least 5%. In particular, the IPS and ADF-Fisher tests verify stationarity with p-values of 0.015 and 0.004, respectively, while the LLC test ($t^* = -6.59$) and the PP-Fisher test ($\chi^2 = 145.40$) are significant at the 1% level ($p < 0.01$). Together, these results show that SDG7 is a non-stationary series at levels but becomes stationary following the first transition, verifying its integration at order one, $I(1)$.

CIPS Test

Table 5: Results of Second-Generation Panel Unit Root Test (CIPS)

Variables	Level CIPS (t-stat)	Level Trunc. CIPS (t-stat)	First Difference CIPS (t-stat)	First Difference Trunc. CIPS (t-stat)
SDG7	-5.67108***	-3.05083***	-7.20791***	-3.35495***
TGDP	-2.19283*	-1.95165	-5.92605***	-2.77845***
INTA	-2.21904*	-2.67489***	20.33581	-3.87345***
TE	-1.45795	-1.45795	-5.91426***	-2.68449***
EPI	-19.44680***	-3.40895***	-218182159762323.44***	-5.75000***
REC	-0.75718	-2.26809*	-0.09240	-1.22875
POP	-1.84066	-1.55363	-7.95613***	-3.46661***

Note: ***, **, and * indicate 99%, 95%, and 90% significance levels, respectively.

Source: Authors own work

To address possible cross-sectional dependence within the panel, the study makes use of the second-generation CIPS (Cross-sectionally Augmented IPS) and Truncated CIPS tests, as suggested by Pesaran (2007), presented in table 5. A mixed order of integration among the variables is shown by the empirical results, which are described in the above table. In particular, the dependent variable SDG7 and the EPI are identified as $I(0)$ because they are stationary at level and reject the null hypothesis of a unit root at the 1% significance level. TGDP, TE, INTA, and POP, on the other hand, are non-stationary at level but become extremely stationary upon initial differencing, indicating an $I(1)$ process. The overall results suggest the existence of a mixed integration framework, even while REC has minor relevance at level (10% for Truncated CIPS). This diagnostic result offers a solid foundation for the long-run estimate and cointegration analysis that follow.

3.5 Slope Homogeneity Test

Table 6: Results of Slope Homogeneity Test

Testing for slope heterogeneity (Pesaran, Yamagata. 2008. Journal of Econometrics)		
H0: slope coefficients are homogenous		
	Delta	p-value
	1.810	0.070
adj.	4.046	0.000
Variables partialled out: constant		

Source: Authors own work

The study uses the test created by Pesaran and Yamagata (2008) to assess the assumption of slope homogeneity, presented in table 6, after cross-sectional dependence has been identified. Determining if the relationship between the independent factors and SDG 7 is consistent across all economies in the panel is crucial. The empirical findings show a Delta (Δ) statistic of 1.810 ($p = 0.070$) and a Delta adjusted (Δ_{adj}) statistic of 4.046 ($p = 0.000$). The adjusted Delta statistic strongly rejects the null hypothesis of slope homogeneity at the 1% level, whereas the standard Delta is just marginally significant. These results support the panel's slope heterogeneity, indicating that macroeconomic drivers of sustainable development are strongly influenced by national features. In order to prevent biased results, this justifies the use of heterogeneous panel estimators.

3.6 Panel Cointegration Test

Table 7: Summary of Panel Cointegration Test

Test Type	Statistic	Individual Intercept	
		Weighted Statistic	p-value
Pedroni (Within-Dimension)			
	Panel v-Statistic	-3.936371	1.0000
	Panel rho-Statistic	5.661195	1.0000
	Panel PP-Statistic	-11.58825	0.0000
Pedroni (Between-Dimension)	Panel ADF-Statistic	-4.374296	0.0000
	Group rho-Statistic	7.287831	1.0000
	Group PP-Statistic	-17.56364	0.0000
	Group ADF-Statistic	-8.679732	0.0000

Source: Authors own work

Table 7 represents the Pedroni (1999, 2004) panel cointegration test to examine whether there is a long-run equilibrium relationship between the variables. Seven functional statistics are offered by this framework, which are divided into between-dimension (group-specific) and within-dimension (panel-specific) tests. Four of the seven statistics—the Panel PP, Panel ADF, Group PP, and Group ADF—strongly reject the null hypothesis of no cointegration at the 1% significance level ($p < 0.01$), as seen in the above table. Pedroni's technique states that strong evidence of a consistent long-term link is provided by the significance of most of these statistics, especially the ADF-type tests, which have higher power in tiny panels. Thus, these findings support the following estimation of long-run coefficients using FMOLS and DOLS by confirming that SDG 7 and its macroeconomic causes move together in the long run.

Table 8: Kao Residual Cointegration Test

Series: SDG7 TGDP INTA TE EPI REC POP		
Sample: 2015 2024		
Included observations: 200		
Null Hypothesis: No cointegration		
Trend assumption: No deterministic trend		
Automatic lag length selection based on SIC with a max lag of 1		
Newey-West automatic bandwidth selection and Bartlett kernel		
	t-Statistic	Prob.
ADF	-3.800981	0.0001
Residual variance	0.591880	
HAC variance	0.651013	

Source: Authors own work

Table 8 presents the residual-based cointegration test developed by Kao (1999) to further validate the long-run equilibrium relationship. The Kao test forces homogenous pooling on the cointegrating vectors, in contrast to the Pedroni test. The empirical data demonstrate that the ADF t-statistic of -3.800981, with a p-value of 0.0001, is extremely significant. At the 1% significance level, this outcome permits the null hypothesis of "no cointegration" to be rejected. The validity of the ensuing FMOLS and DOLS estimations is supported by the convergence of both Pedroni and Kao test results, which offer strong evidence of a stable long-run correlation between SDG 7 and its macroeconomic drivers.

Table 9: Johansen Fisher Panel Cointegration Test

Series: SDG7 TGDP INTA TE EPI REC POP				
Sample: 2015 2024				
Included observations: 200				
Trend assumption: Case 3 (Johansen-Hendry-Juselius): Cointegrating relationship includes a constant. Short-run dynamics include a constant.				
Lags interval (in first differences): 1 to 1				
Unrestricted Cointegration Rank Test (Trace and Maximum Eigenvalue)				
Hypothesized	Fisher Stat.*		Fisher Stat.*	
No. of CE(s)	(from trace test)	Prob.	(from max-eigen test)	Prob.
None	0.000	1.0000	0.000	1.0000
At most 1	0.000	1.0000	0.000	1.0000
At most 2	214.1	0.0000	166.9	0.0000
At most 3	737.2	0.0000	916.2	0.0000
At most 4	728.9	0.0000	651.4	0.0000
At most 5	704.3	0.0000	775.7	0.0000
At most 6	57.73	0.0344	57.73	0.0344
* Probabilities are computed using asymptotic Chi-square distribution.				

Source: Authors own work

The Johansen Fisher Panel Cointegration test, as suggested by Maddala and Wu (1999), presented in table 9 to supplement the Pedroni and Kao tests. To ascertain the cointegration rank in a panel environment, this test averages the p-values of each Johansen maximum eigenvalue and trace statistics. The null hypothesis of at most one cointegrating equation is strongly rejected by both the Fisher trace and maximum eigenvalue statistics, as shown in above table, with significance emerging from "At most 2" through "At most 6" at the 1% and 5% levels. SDG 7 and the chosen explanatory variables are in a stable, long-term equilibrium, as demonstrated by this multi-vector cointegration, which supports the previous conclusions. The econometric reliability of the ensuing FMOLS and DOLS estimations is guaranteed by this multi-test validation.

3.7 Long-run Estimation (FMOLS and DOLS) Test

Table 10: Panel Fully Modified Least Squares (FMOLS) Test

Dependent Variable: SDG7				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
TGDP	-0.171408	0.094322	-1.817259	0.0711
INTA	1.37E-05	8.95E-06	1.535550	0.1267
TE	-0.129860	0.110216	-1.178225	0.2405
EPI	-0.025850	0.011882	-2.175625	0.0311
REC	-0.085170	0.044311	-1.922082	0.0564
POP	2.68E-07	4.44E-08	6.036109	0.0000
R-squared	0.992937	Mean dependent var		69.66088
Adjusted R-squared	0.991790	S.D. dependent var		11.36046
S.E. of regression	1.029340	Sum squared resid		163.1692
Long-run variance	1.449280			

Source: Authors own work

The Panel Fully Modified Least Squares (FMOLS) method was used to estimate the long-run coefficients in order to take serial correlation and endogeneity into consideration, presented in table 10. The findings, which are summed up in the table above, offer a complex picture of the factors influencing SDG 7 in the panel under study. With an Adjusted R-squared of 0.991, the model demonstrates remarkable explanatory power. Population (POP) is the most powerful driver of the clean energy index, according to the empirical results, with a positive coefficient (2.68E-07) that is significant at the 1% level ($p < 0.01$). This implies that the development of energy infrastructure and greater access to energy are inextricably related to population growth in these economies.

On the other hand, the negative coefficients for EPI and REC are -0.025 ($p = 0.031$) and -0.085 ($p = 0.056$), respectively. These negative indicators probably indicate a structural transition phase, despite the fact that they could seem paradoxical. Before long-term efficiencies are achieved, improvements in environmental standards (EPI) and the transition to renewable energy sources (REC) frequently necessitate large initial capital reallocation and grid changes, which can cause a brief "trade-off" effect in the total energy achievement index. This implies that rather from being finished, the energy transition in these countries is still in a transformative stage. In terms of the tourism industry, INTA and Tourism Employment (TE) continue to be statistically insignificant, but Tourism GDP (TGDP) shows a marginal negative impact significant at the 10% level ($p = 0.071$). This suggests that although the tourist industry's total economic scale has some long-term impact on energy objectives, visitor volume and spending have not yet reached a crucial level to significantly alter the trajectory of SDG 7 in this particular panel.

Table 11: Panel Dynamic Least Squares (DOLS) Test

Dependent Variable: SDG7				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
TGDP	-0.679408	0.149607	-4.541294	0.0001
INTA	3.50E-05	1.82E-05	1.919112	0.0634
TE	0.082107	0.170488	0.481602	0.6332
EPI	0.009242	0.019446	0.475256	0.6376
REC	0.270904	0.121405	2.231409	0.0324
POP	4.62E-07	1.34E-07	3.442552	0.0015
R-squared	0.999120	Mean dependent var		69.66088
Adjusted R-squared	0.995366	S.D. dependent var		11.36046
S.E. of regression	0.773346	Sum squared resid		20.33420
Long-run variance	0.089559			

Source: Authors own work

Table 11 shows the Panel Dynamic Least Squares (DOLS) estimator to confirm the long-run coefficients' robustness. The identified equilibrium correlations are reinforced by the DOLS results, which are shown in the above table and broadly support the conclusions from the FMOLS estimation. In particular, Population (POP) continues to be a highly significant positive factor (4.62E-07, $p = 0.0015$), demonstrating that SDG 7 progress is continuously driven by demographic expansion across several estimators. Notably, REC exhibits a larger positive significance in the DOLS model (0.270, $p = 0.0324$), indicating that the switch to renewable energy considerably advances sustainable energy goals when leads and lags of the explanatory variables are taken into consideration.

Additionally, the negative effect of tourist GDP (TGDP) is more noticeable and statistically significant in the DOLS framework (-0.679, $p = 0.0001$), supporting the claim that the tourist sector's overall size eventually pushes the clean energy index downward. In this formulation, INTA is slightly significant at the 10% level (3.50E-05, $p = 0.0634$), while EPI and TE are still statistically insignificant. The DOLS model's high Adjusted R-squared (0.995) establishes the overall consistency of the macroeconomic and tourism-related drivers of SDG 7 throughout the APEC region and confirms an outstanding match.

3.8 PMG (ARDL) Test

Table 12: Results of PMG (ARDL) Test

Dependent Variable: D(SDG7)	
Method: ARDL	
Sample: 2016 2024	
Included observations: 180	
Number of cross-sections: 20	
Max. dependent lags: 1 (Fixed)	
Fixed-lag linear regressors: TGDP INTA TE EPI REC POP	
Deterministics: Unrestricted constant and unrestricted trend (Case 5)	
Selected model: PMG(1,0,0,0,0,0)	

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Long-run (Pooled) Coefficients				
TGDP	-0.097903	0.012175	-8.041057	0.0000
INTA	-9.74E-06	5.22E-07	-18.67240	0.0000
TE	0.088607	0.008652	10.24151	0.0000
EPI	-0.004552	0.000738	-6.172092	0.0000
REC	-0.035421	0.007460	-4.747999	0.0000
POP	9.38E-08	1.40E-08	6.702393	0.0000
Short-run (Mean-Group) Coefficients				
COINTEQ	-0.829625	0.100099	-8.288072	0.0000
C	48.87209	7.140382	6.844465	0.0000
@TREND	0.122077	0.058505	2.086597	0.0384
Log-Likelihood:	2.358042			

Source: Authors own work

Table 12 presents the Pooled Mean Group (PMG) estimator within a panel ARDL framework to capture both long-run and short-run dynamics in light of the diverse integration levels found in the CIPS unit root testing. All explanatory variables have a highly significant long-term impact on SDG 7 at the 1% level, according to the empirical results shown in the above table. In particular, Population (POP) and Tourism Employment (TE) show positive long-run correlations of 9.38E-08 and 0.088, respectively, indicating that tourism-related spending and population expansion are important drivers of sustainable energy advancement. On the other hand, negative long-run coefficients are produced by TGDP, INTA, EPI and REC. This suggests that the current level of tourism and the ongoing energy transition phase may put structural pressure on the clean energy index in the APEC region.

A stable long-run equilibrium is confirmed in the short run by the Error Correction Term (COINTEQ), which is negative and extremely significant (-0.829, $p = 0.0000$). With about 82.9% of the departure from the long-run equilibrium being rectified in a single period, the coefficient magnitude indicates an exceptionally high rate of adjustment. Additionally, independent of the model's particular regressors, the significant positive coefficient for the @TREND (0.122, $p = 0.0384$) shows an independent increasing trajectory in SDG 7 performance over time.

4. Conclusion

This research aims to examine the tourism development–environmental performance–renewable energy use relationship in the context of APEC economies from 2015 to 2024, under SDG 7 (SDG 7: Ensure access to affordable, reliable, sustainable and modern energy). The advanced panel econometric modeling techniques used such as FMOLS, DOLS, and PMG-ARDL estimators captures the short-run and long-run dynamics among the variables selected for the study.

The empirical results are consistent with the existence of a long-run equilibrium relationship between the indicators of tourism, environmental factors and the sustainable development of energy. The findings indicate that tourism has mixed impacts for SDG 7 achievement. In detail, tourism employment and population increase both positively affect sustainable energy development, while tourism GDP and international tourist arrivals have negative in the long run effects on clean energy performance. In addition, the results also show that there are important linkages between renewable energy use and environmental performance and that the transition to sustainable energy systems is structurally complicated in APEC economies, especially SDG 7.

Moreover, the PMG-ARDL estimation shows that the economy's speed of adjustment to the long run following the hitting of a short run shock is high. The study adds to the literature on the tourism-energy-sustainability nexus and offers in-depth evidence from the APEC economies, underscoring the need for a well-balanced tourism development and sustainable energy policies to fulfill SDG 7 targets.

This study offers some policy implications for governments, policymakers and APEC regional organizations. First, policy development should encourage environmentally-friendly tourism activities to help reduce the negative environmental impacts of tourism growth. The construction of green tourism infrastructure, eco-friendly transportation, and sustainable accommodation facilities will help alleviate the environmental impact of tourism activities.

Second, governments should step up investments in renewable energy technologies and boost the policies on clean energy transition. The involvement of public and private sector through partnerships is key to increase the availability of renewable energy in tourism and other sectors and increase energy efficiency in SDG 7.

Third, the tourism spending illustrates the positive effect of tourism on sustainable energy development, suggesting the need to effectively leverage tourism income to invest in green energy and environmental protection programs. Therefore, it is necessary to create an incentive system for the financial sector, subsidies and/or sustainable financing methods for investments in energy efficient tourism.

Furthermore, the regional cooperation between APEC economies is a key point to be promoted to enable technology transfer, environmental governance, and sustainable management of tourism. Regional economic and environmental shocks could have strong impacts on the SDG 7 performance across the region, given that there is cross-sectional dependence among the countries. Incorporated policy co-ordination and integrated approaches to sustainability can then improve the sustainable development results in the longer-term.

Lastly, country-specific strategies for sustainable development should be based on the policies implemented as the results of the slope heterogeneity show that the effect of tourism and environment variables varies among economies. Embracing tailored policy interventions by adapting to the national economic structures, the intensity of the tourism sector and the capacity for energy transition would yield better results in achieving sustainable energy targets.

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The authors utilized ChatGPT just for language editing, grammatical check, and increasing the clarity and readability of the manuscript during the creation of this publication. The AI tool was not utilized to produce research data, perform statistical analysis, analyze empirical findings, or make scientific judgements. The authors take full responsibility for the content, accuracy, originality and integrity of the work and have evaluated and confirmed all AI-assisted content.

Author Contributions

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Md. Sazedur Rahman: Validation, Investigation, Writing – Review & Editing.

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All authors contributed to the interpretation of the findings, critically reviewed the manuscript, approved the final version, and agreed to be accountable for the work.

Declaration of conflicting interest

The authors state that there are no known conflicting financial or non-financial interests that could have influenced the work reported in this study.

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